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[Eleventh Annual Report.]

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To the Director of the
United States Geological Survey,
Washington, D. C.

Washington, D. C., *October*, 1891.

ELEVENTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1889-'90

BY

J. W. POWELL
DIRECTOR

PART I—GEOLOGY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1891

ELEVENTH ANNUAL REPORT

OF THE

DIRECTOR

OF THE

UNITED STATES GEOLOGICAL SURVEY.

Part I—GEOLOGY.

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., September 1, 1890.

Sir: I have the honor to transmit herewith a report of the operations of the Geological Survey for the year ending June 30, 1890.

I am, sir, with great respect, your obedient servant,

J. W. Powell,
Director.

Hon. John W. Noble,
Secretary of the Interior.

ELEVENTH ANNUAL REPORT OF THE UNITED STATES GEOLOGICAL SURVEY.

By J. W. Powell, Director.

CHANGES IN ORGANIZATION.

By a law enacted March 20, 1888, the functions of the Geological Survey were enlarged. It was given general charge of the investigation of the great problem of Western agriculture by irrigation—the utilization of the water of streams for the irrigation of growing crops; and it was specifically required to determine throughout the arid region of the United States the sites which should be reserved for the construction of reservoirs to store water, the lines to be followed by canals to convey water, and the areas of arable land on which the scant water of the region should be used for the fertilization of crops. On the 2d of October, in the same year, the sum of $100,000 was appropriated for this work, and on the 3d of March, 1889, the further sum of $250,000 was appropriated. No great investigation of this character had previously been undertaken on the American continent, and its magnitude, novelty, and urgency conspired to render the responsibility of its organization a heavy one.

Perceiving that if this subject received at his hands all the attention it deserved it would be possible to devote but little time to the conduct of the Geological Survey proper, the Director determined to delegate a portion of his administrative supervision. Questions arising in connection with the work in geology, paleontology, topography, etc., were from time to time referred for consideration and determination to chiefs of divisions and other officers of the Survey, and especially to Mr.

G. K. Gilbert, geologist in charge of the Appalachian Division and of the Division of Geologic Correlation. In order to give Mr. Gilbert more time for such duties he was relieved from charge of the Appalachian Division, and it was finally determined, with the concurrence of the Secretary of the Interior, that it would be best so to modify the internal organization of the Survey as to place under his charge all of the divisions constituted for purposes of geologic research. At the beginning of the fiscal year the Geologic Branch was constituted of the existing geologic divisions, twelve in number, and Mr. Gilbert was given general charge.

Another change in organization resulted from a modification of the legal provision for the engraving of the sheets of the topographic and geologic atlas of the United States prepared by the Survey. In previous years the appropriations for this purpose had been placed under the control of the Public Printer, but the act appropriating money for this year placed the work in charge of the Geological Survey. A large portion of the engraving can be advantageously done under the contract system, but the work of revising sheets in order to bring them up to date, and certain experimental work designed for the development of more economic methods, can not advantageously be made the subject of contract, and for their execution a Division of Engraving was organized within the Survey.

PROGRESS OF TOPOGRAPHIC WORK FOR GEOLOGIC PURPOSES.

During the year the operations of the Topographic Branch of the Survey have been carried on in twenty of the States, and an area of 46,807 square miles has been surveyed and mapped. Of this area 11,637 square miles were surveyed with a view to publication upon the scale of 1:62,500, with contour intervals of 5, 10, or 20 feet; and the remainder, 35,170 square miles, upon the scale of 1:125,000, with contour intervals of 20, 50, or 100 feet. No work was executed upon the scale of 1:250,000, and probably none will be done in the future. The distribution of the surveyed area is shown graphically upon Pl. I, in the pocket at the end of this volume, and the details of the work are set forth in the accompanying administrative report by Mr. Gannett. The present condition of the topographic survey is exhibited in the accompanying table:

Table showing the present condition of topographic surveys and the areas surveyed in 1889–'90, *by States and Territories.*

States.	Total area.	Area surveyed to date.	Area surveyed in 1889–'90.	Scale	Contour interval.
	Sq. miles.	*Sq. miles.*	*Sq. miles.*		*Feet.*
Alabama	52,250	14,870	3,250	1:125000	50 and 100
Arizona	113,020	41,000	....	1:250000	200 and 250
Arkansas	53,850	10,500	3,000	1:125000	50
California	158,360	25,200	....	1:125000 1:250000	100 and 200
Colorado	103,925	2,500	....	1: 62500 1:125000	50 and 100
Connecticut	4,990	3,177	2,477	1: 62500	20
District of Columbia	70	70	....	1: 62500	20
Florida	58,680	250	250	1: 62500	10
Georgia	59,475	13,875	3,345	1:125000	50 and 100
Illinois	56,650	600	600	1: 62500	5 and 10
Iowa	56,025	4,475	2,025	1: 62500	20
Kansas	82,080	44,200	12,000	1:125000	20 and 50
Kentucky	40,400	9,770	2,700	1:125000	100
Louisiana	48,720	2,000	2,000	1: 62500	5
Maine	33,040	1,332	1,012	1: 62500	20
Maryland	12,210	3,480	....	1: 62500 1:125000	20, 50, 100
Massachusetts	8,315	8,315	....	1: 62500	20
Michigan	58,915	63	63	1: 62500	20
Missouri	69,415	26,000	....	1: 62500 1:125000	20 and 50
Montana	146,080	10,400	....	1:250000	200
Nevada	110,700	14,000	....	1:250000	200 and 250
New Hampshire	9,305	675	....	1: 62500	20
New Jersey	7,815	7,815	....	1: 62500	10 and 20
New Mexico	122,580	17,500	....	1:250000	200
New York	49,170	645	....	1: 62500	20
North Carolina	52,250	10,400	500	1:125000	100
Oregon	96,030	11,000	....	1:250000	200
Pennsylvania	42,215	2,927	2,085	1: 62500	20
Rhode Island	1,250	1,250	....	1: 62500	20

Table showing the present condition of topographic surveys and the areas surveyed in 1889-'90, *etc.*—Continued.

States.	Total area.	Area surveyed to date.	Area surveyed in 1889-'90.	Scale.	Contour interval.
	Sq. miles.	*Sq. miles.*	*Sq. miles.*		*Feet.*
South Carolina	30,570	2,300	....	1:125000	100
Tennessee	42,050	12,615	....	1:125000	100
Texas	265,780	32,250	6,000	1:125000	20 and 50
Utah	84,970	6,000	....	1:250000	250
Vermont	9,565	550	450	1: 62500	20
Virginia	42,450	29,550	1,775	1:125000	20, 50, 100
West Virginia	24,780	18,350	2,600	1:125000	100
Wisconsin	56,040	2,265	675	1: 62500	20
Wyoming, including Yellowstone National Park	97,890	4,000	....	1:125000	100

The work of the past year completes 82 atlas sheets, of which 48 are upon the scale of 1:62,500 and 34 upon the scale 1:125,000. The entire number of atlas sheets completed up to the present date by survey and by compilation is 488. Of this number 186 are upon the scale of 1:62,500, 241 upon the scale of 1:125,000, and 61 upon the scale of 1:250,000.

The organization of the topographic branch has remained substantially the same as in the previous year.

In the spring of 1889 an appropriation of $25,000 was made by the State of Connecticut for the purpose of cooperating with this organization in a topographic survey of that State. For that purpose articles of agreement were drawn up and signed. Under them work was prosecuted actively throughout the season, and the western half of the State, comprising twelve atlas sheets, was surveyed.

In compliance with an urgent request from the director of the Second Geological Survey of Pennsylvania and other State officers, work was instituted in the anthracite region of that State, and prosecuted actively throughout the season. Nine map districts were surveyed.

Work was carried on also in the southwestern part of Maine, where six map districts were surveyed, and in southern Vermont, where two were surveyed. In the southern Appalachian region work has been actively prosecuted by five topographic parties and one triangulation party. The surveyed areas lie in the Piedmont region of Virginia, in the central part of West Virginia, and in eastern Kentucky, northeastern Georgia, and central Alabama, completing altogether twelve sheets of the map. All of this region is of great importance by reason of the large deposits of coal and iron found therein.

A survey of the iron region of the upper peninsula of Michigan was begun. In southern Wisconsin three atlas-sheet districts were surveyed, lying mainly in the region of the moraine of the great continental glacier.

Work was commenced in Illinois, having the city of Chicago for its initial point. An urgent demand for work in this region was experienced on account of the great engineering plans under consideration for connecting the waters of the Great Lakes with those of the Mississippi by ship canal. The consideration of questions relating to drainage and water supply was also demanded by the citizens of Chicago

The survey of Iowa, commenced two years ago, was actively prosecuted and nine atlas sheets were produced.

In southern Kansas work was prosecuted by several parties, and twelve sheets, comprising 12,000 square miles, were made. The special theater of operation in this region was selected as one of great interest to agricultural industries. It is in the sub-humid region, and the climate is such that agriculture without irrigation is not possible from year to year. In some years it is successful, in others it is not, and the people are now turning their attention to local irrigation. To subserve these purposes a topographic map is of prime value, as irrigation must depend chiefly upon the storage of storm waters. The region is not embraced in that included in the Irrigation Survey which, under the terms of the law, included only those regions where agriculture depends upon the utilization of perennial streams. The work already accomplished will be of much value in showing how the storm waters of that country can be stored. It is also necessary for the Geological Survey.

Work was continued in the Ozark Hills of Arkansas, and three sheets, comprising about 3,000 square miles, were completed.

Topographic surveys were prosecuted also in Texas, where six sheets were finished.

During the winter a survey of the alluvial region of the lower Mississippi was commenced and eight sheets upon a scale of 1:62,500 in contour intervals of 5 feet were completed in the southern portion of Louisiana.

During the winter also a small area was surveyed in Florida, comprising one atlas sheet district upon the scale of 1:62,500. The purpose of the work in this region is a geological examination of the peninsula, especially in reference to the deposits of phosphate rocks which are found there in great abundance.

An account of the topographic work of the Irrigation Survey will be found in connection with the report on that subject. (See Part II.)

ENGRAVING.

The engraving of maps has gone forward during the year with a satisfactory degree of rapidity. At the date of my last report 249 sheets had been engraved; during the year 95 sheets have been engraved; making the total number engraved up to the present date, 344. In addition to the regular atlas sheets there has been engraved a map of the State of Massachusetts upon a scale of 1:250,000 in 100-foot contours, which has been compiled in this form from the large scale sheets, and a map of the United States upon a scale of 1:2,500,000. At the date of my last report there were pending three contracts made through the Public Printer for engraving, one with Messrs. Sinclair & Sons of Philadelphia, for 100 sheets; one with Mr. H. C. Evans, of this city, for 30 sheets; and one with Messrs. George S. Harris & Sons of Philadelphia, for 21 sheets. The last of these contracts has been completed; the other two have not yet been finished, although work upon them is well advanced.

During the year contracts have been made with Messrs. Julius Bien & Co., New York City, as follows: One for 20 sheets of the general topographic and geologic atlas of the

United States; a second for the reduced map of Massachusetts, as above described; a third for the map of the United States upon a scale of 1:2,500,000, and a fourth for 48 sheets of the general atlas. A contract has also been made with Mr. H. C. Evans for 30 sheets of the general atlas.

Detailed information regarding the progress of the engraving will be found in Mr. Gannett's report.

The following table shows in summary form the number and distribution of the atlas sheets thus far engraved.

Table showing number, distribution, etc., of the atlas sheets engraved to June 30, 1890.

State.	Wholly within State.	Partly within State.	Scale.	Contour interval.	Approximate area.
				Feet.	*Sq. miles.*
Alabama	11	3	1:125000	50 and 100	12,200
Arizona	14	2	1:250000	200 and 250	58,000
Arkansas	5		1:125000	50	5,000
California	11	1	1:125000 1:250000	100 and 200	28,000
Colorado	3		1: 62500 1:125000	50 and 100	1,450
Connecticut		9	1: 62500	20	700
District of Columbia		2	1: 62500	20	70
Georgia	6	4	1:125000	50 and 100	8,800
Illinois		1	1: 62500	20	200
Iowa	8		1: 62500	20	1,800
Kansas	27	6	1:125000	50	31,000
Kentucky	1	7	1:125000	100	5,000
Maryland	1	7	1:125000 1: 62500	20, 50, 100	2,000
Massachusetts	29	22	1: 62500	20	8,300
Missouri	25	9	1;125000 1: 62500	20 and 50	26,300
Montana	8		1:250000	200	28,000
Nevada	4	3	1:250000	200 and 250	23,500
New Hampshire		8	1: 62500	20	675
New Jersey	22		1: 62500	10 and 20	5,000
New Mexico	7		1:125000 1:250000	100 and 200	19,000
New York		4	1: 62500	20	250
North Carolina	2	13	1:125000	100	6,000

Table showing number, distribution, etc., of the atlas sheets engraved to June 30, 1890—Continued.

State.	Wholly within State.	Partly within State.	Scale.	Contour interval.	Approximate area.
				Feet.	*Sq. miles.*
Oregon	1		1:250000	200	3,500
Pennsylvania	3		1: 62500	20	675
Rhode Island	7	6	1: 62500	20	1,250
South Carolina	1	3	1:125000	100	1,500
Tennessee	6	14	1:125000	100	12,000
Texas	21		1:125000	50	21,000
Utah	17	1	1:250000	250	65,000
Virginia	9	24	1: 62500 1:125000	20, 50, 100	20,000
West Virginia	4	13	1:125000	100	11,000
Wisconsin	1		1: 62500	20	225
Wyoming	4		1:125000	100	3,600

PROGRESS IN GEOLOGIC WORK.

The primary work of the Geological Survey, to which all other work may be regarded as accessory, consists of two principal parts: the determination and publication of the local distribution of rocks, and the determination and publication of the general facts of the geology of the country. The topographic work, as explained in previous reports, has been organized and prosecuted for the purpose of furnishing suitable base maps on which to exhibit the facts of local distribution, and this local or areal work can be advantageously conducted only in regions previously covered by topographic surveys. Before the results of topographic work were available, the geologic corps was necessarily occupied with the determination of the general facts of American geology. As the topographic maps are engraved for one district after another, the areal work in geology is gradually increased. During the year it has been continued in Massachusetts, Maryland, Virginia, Tennessee, Alabama, Georgia, North Carolina, Michigan, Montana, Wyoming, and California, and has been begun in Connecticut.

The areal work in Massachusetts has been of two kinds: the delineation of the indurated formations of the "under geology" and the delineation of the unconsolidated formations of the "surface geology." These works have been carried on by two corps, and the corps engaged on the under geology has carried preliminary studies of geologic structure into the State of Vermont. In Maryland and Virginia the areal work has been combined with an analytical study of the level formations of the whole coastal plan, and with local studies of the crystalline rocks against which they rest. In Tennessee, Alabama, Georgia, and North Carolina, the areal work is united with a thorough study of the complicated structure of the formations bearing the iron and coal of those States. In Michigan it is associated with structural studies of the iron-bearing and copper-bearing rocks, and these studies are inseparable from those carried on in Wisconsin and Minnesota. In Montana and Wyoming the areal work is united with important studies in mountain structure, especially the structure of mountains of extravasation. In California the principal field is the district known as the "Gold Belt," and the formations mapped include not only the auriferous gravels but the indurated formations from which they were derived and in which the deep mines are found.

The general investigation of the glacial formations of the Northern States, the studies of the gold and silver mines and the study of the coal beds in Colorado, and the geologic explorations in Alaska have been continued. The geologic reconnaissance on the Yukon, undertaken with aid of the U. S. Coast and Geodetic Survey, was eminently successful, and opened the way to an expedition on new ground under the joint auspices of the Survey and the National Geographic Society. A special investigation of the Narragansett coal basin has been renewed, and also the investigation of the phosphate-bearing formations of Florida. In cooperation with the State Geological Survey of Texas, work was resumed on the stratigraphy of the Cretaceous formations in that State. Under special instruction from the Secretary of the Interior, an investigation of the zinc deposits of Missouri was instituted, and this was carried forward in cooperation with the State survey.

local stratigraphic study was also instituted in conjunction with the State work. A special study was made of the structure of the Crazy Mountains of Montana, and another of the Wells Creek basin in western Tennessee.

Great progress has been made in the work of summarizing existing knowledge as to the relation of American formations to the geologic time scale recognized by the geologists of the world. The work of digesting the literature and the field work necessary to its coordination have been practically completed, and much progress has been made in the preparation of the essays which are to present and discuss the material.

The various researches thus briefly indicated are described at length in the accompanying report of the chief geologist, Mr. G. K. Gilbert, and in the reports of the chiefs of geologic divisions.

PROGRESS IN PALEONTOLOGIC WORK.

Fossils are the labels by means of which the geologic age of strata is ascertained. In each geologic province the order of sequence of formations is determined by their superposition and by the same means the chronologic order of the contained groups of organic remains becomes known. By comparing the sequences of life groups of different geologic provinces one with another the general system of life sequences for the globe is ascertained. This general system is not simple but highly complex, and every important collection of fossils from a new locality enlarges our knowledge of it. At the same time the recognition of the relation of the newly collected fossils to the life system determines the geologic age of the formation in which they were entombed. There is thus a continual interaction between the geologic and the paleontologic work. The stratigraphic work of the geologist and the collection of fossils enlarge our knowledge of the history of life on the globe, and the general facts of that history enable the paleontologist to group together local formations in a consistent chronologic system.

From this interdependence of geology and paleontology arises the twofold function of the paleontologic corps of the

Survey. It gathers fossils from formations whose stratigraphic relations are known and by their study amplifies, corrects, and perfects the body of generalizations as to the distribution in space and time of animals and plants. It gathers fossils from formations of unknown age, or receives those gathered by geologists, and through their comparative study determines their geologic date.

The paleontologic field is so broad that an individual student can acquire the familiarity of an expert in but a narrow portion thereof, and the work of the paleontologists of the Survey is therefore highly specialized. Not only is the corps organized into divisions, each one of which takes cognizance of the fossils of a particular biologic class or of a particular geologic age, but each individual research undertaken is narrowly limited, either in its biologic or in its chronologic range.

The general organization of the work, as previously set forth, classifies it primarily on a biologic basis, and secondarily on a chronologic basis. One division studies vertebrate fossils; another division fossil insects; a group of divisions study invertebrate fossils (excepting insects), and a single division fossil plants. The remains of aquatic invertebrates are by far the most abundant in the rocks, and are of the greatest utility for the correlation of formations, and for these reasons work upon them is apportioned among several divisions, and is divided upon the basis of geologic chronology. One division studies forms from Paleozoic strata, another from Jura-Trias, a third from Cretaceous, and a fourth from Cenozoic.

Mr. C. D. Walcott, who has charge of the work on invertebrate fossils from Paleozoic formations, has for his principal assistant Prof. Henry S. Williams. Between these gentlemen the field is still further divided, Mr. Walcott studying chiefly the Cambrian and Silurian fossils, and Prof. Williams devoting himself to those from Devonian and Carboniferous formations. Mr. Walcott has for several years given special attention to Cambrian fossils, gathering them from many parts of the United States, grouping them into faunas with a definite sequence, and at the same time studying and classifying the formations which contain them. His results have been published from time to time in a series of papers, and a general summary now in preparation will constitute one of the set of essays on the correlation of formations. This year he has also begun a similar systematic investigation of the faunas of the Silurian.

Prof. Williams has been occupied for some years with refined and important studies of the Devonian faunas and their relations to lithologic texture and other stratigraphic details. This year he has undertaken also a general study of the faunas of the Carboniferous, and in the preparation of the correlation essay undertaken by him he will discuss the classification of both Devonian and Carboniferous rocks.

In the summer of 1888 Prof. Alpheus Hyatt visited the most important of the western localities from which Jura-Trias fossils have been obtained. The local stratigraphy was studied, and collections of invertebrate fossils were made which rank in extent and variety with the most important of those previously contained in the museums of the country. Last summer he increased his collections by a visit to New Mexico, and he has since been engaged in their systematic study. From this work it is believed that data will eventually be gathered for the satisfactory classification of the formations of this period.

Dr. C. A. White, who has charge of the work on Cretaceous fossils, has made a special study of the fauna and stratigraphy of the highest Cretaceous formation, the Laramie, and preliminary results of his work have been published from time to time, but the subject is not yet ready for monographic treatment. The prosecution of this research has been temporarily discontinued, that he might prepare a general review of the geology and paleontology of the Cretaceous formations of America to constitute an essay of the correlation series. The year has been largely devoted to this work.

Dr. W. H. Dall, who has charge of the work on Cenozoic invertebrates, has given his chief attention to those gathered from the formations of the Atlantic and Gulf Coastal Plains. The National Museum contains large collections of these fossils, the accumulation of many years, and an extensive literature has been based upon them, but through inadequate stratigraphic knowledge, and through imperfect correlation of the work of different students great confusion has arisen. Dr. Dall has undertaken to reduce to order this paleontologic material and thus render it instructive and useful to the geologist instead of misleading. The fossils themselves have been classified and carefully compared, group by group, supplementary material has been gathered in the field so as to connect them with the rapidly growing body of stratigraphic data, and the modern shells contained in the Museum have been arranged and labeled so as to render them available for purposes of comparative study. In connection with this general work, he is also preparing an essay on the correlation of the newer Cenozoic or Neocene.

Comparison of the geologic history of vertebrates with that of invertebrates shows that the evolution of vertebrates is relatively rapid, and that vertebrate species are relatively evanescent. The occurrence in a local formation of a vertebrate species whose age has been previously ascertained, has therefore peculiar value for the purposes of correlation. In the work of collection, Prof. O. C. Marsh, in charge of vertebrate paleontology, endeavors, as far as possible, to secure entire skeletons instead of individual bones or fragments, so that the data for comparison may be as full as possible, and in this endeavor he has been peculiarly successful. The collections in his hands are now so large that the work of laboratory preparation, comparative study, drawing, description, and publication will require many years, and his field force has accordingly been diminished in order that the resources of his division may be concentrated in the laboratory and study. In the preparation of the material for publication a biologic order is followed, each monograph describing the species of an order or other biologic group. The volumes now in preparation relate to the Brontotheridæ, Stegosauria, Sauropoda, and Ceratopsia.

Several years ago a few vertebrate fossils from the newer formations of Florida were figured and described by Prof. Joseph Leidy, of Philadelphia. More recently the assistants of the Survey have made large collections from the same formations, and these have been placed in the hands of Prof. Leidy, who has kindly consented to prepare a report thereon, and has the work well in hand.

The evolution of plants has been comparatively slow. A species has, in general, a long life, and during that life it acquires wide distribution over the surface of the earth. Fossil plants are thus less serviceable than vertebrates for the determination of precise correlations between the formations of contiguous geologic provinces, but they are peculiarly valuable for the chronologic comparison of the formations of widely separated continents. For this reason a comprehensive knowledge of the fossil floras of the world is of great importance to the students of American geology, and as the literature of the subject is widely scattered through the scientific journals the Division of Paleobotany, under Mr. L. F. Ward, has undertaken to assemble it, and to extract and systematically arrange those data on which the work of American correlation must be based. Bibliographic work has been carried on for several years, including the preparation of a systematic and alphabetic index of all described species of fossil plants. While this work is not yet ready for publication, its period of usefulness has already begun, and Prof. Ward has based upon it a number of studies of problems in geologic correlation. During the year he has investigated the floral data available for the correlation of the Triassic formations of America with one another and with corresponding European formations.

In the department of paleobotany two collaborators aid the work of the Survey. A volume on the fossil plants of the Triassic rocks of New Jersey and the Connecticut Valley has been completed and published by Dr. John S. Newberry, of Columbia College, New York, and he has in preparation monographs on the Laramie flora and on the flora of the Amboy clays of New Jersey. Prof. W. M. Fontaine, of the University of Virginia, has been engaged during the summer on field studies and field collections, preparatory to the discussion of the fossil plants of the lower Carboniferous formations of Virginia.

Hitherto our knowledge of the ancient history of insect life has been too meager to be of service in the geologic work of correlation, but through the labors of Dr. S. H. Scudder it is rapidly growing. He is engaged upon a monograph of the insects of Florissant, Colorado, and during the year has made numerous collections from other localities.

Details of the work of the various paleontologic divisions, including the progress of the various special researches, the journeys and collections made in the field, the special reports on local collections made to field geologists, and the distribution of work among assistants, are set forth at length in the administrative reports of the chiefs of paleontologic divisions.

PROGRESS IN ACCESSORY WORK.

CHEMISTRY AND PHYSICS.

General charge of the work of the chemical and physical laboratory has remained with Prof. F. W. Clarke, and the physical work has been conducted, as heretofore, under the immediate direction of Dr. Carl Barus. Routine work, comprising chiefly the analysis of rocks, a knowledge of whose chemical constitution is desired by geologists in connection with their studies, has consumed the greater share of the time of the chemists. The remainder has been bestowed on original research in mineralogy, so directed as to contribute toward the solution of general problems of chemical geology. As an aid to the study of rock metamorphism, the laboratory has undertaken an investigation into the molecular constitution of the silicates, and much time has been given this year to the study of magnesian silicates, to which has been applied a novel method of research.

Among the great problems of terrestrial physics is the question of the condition of the earth's interior. It is known that the temperature of the crust increases rapidly with depth from the surface, and that all solids tend toward melting with the rise of temperature. It is known that the pressure to which the materials of the earth are subjected increases with depth below the surface, and that in the case of most solids at the surface of the earth pressure tends to prevent liquefaction. Deeply buried rocks seem thus to be subjected to conflicting tendencies, and in order to determine inferentially whether they are solid or molten, it is necessary to apply the laws of liquefaction and solidification far beyond the range of pressures and temperatures with which we are familiar. As an aid to inference in this difficult field, Dr. Barus has conducted a series of experiments in which he has measured the volumes of various liquids when subjected simultaneously to great pressure and high temperature, the pressures ranging up to 2,000 atmospheres and the associated temperatures to 200° Centigrade.

MATHEMATICS.

Routine duty in connection with the topographic divisions has largely occupied the time of the Mathematical Division. Field expeditions were made for the determination of the latitudes and longitudes of Speareville, Kansas, Boisé City, Idaho, and Cisco, Texas, and to determine the position of the one hundred and fifth meridian in El Paso County, Texas. In aid of the Division of Chemistry, least-square adjustment, involving the solution of thirty simultaneous equations, was applied to the ratios of the atomic weights of the chemical elements.

The division has remained in charge of Mr. R. S. Woodward, but at the close of the year he resigned to accept a position on the U. S. Coast and Geodetic Survey. His resignation was accepted with regret, as this Survey can ill afford to lose his rare ability for mathematical research. Since his first association with the Survey in 1884, he has not only supervised the computations made in connection with the triangulation and astronomic determinations, conducted the computation of a series of tables for the use of the Topographic Branch, and given aid to geologists having occasion to treat their data by mathematical methods, but he has made important additions to geologic science by discussing and advancing, on several lines, the theories of terrestrial physics. His discussion of the form and position of the sea level of the earth as dependent on superficial distribution of matter yielded formulæ and numerical results of importance in the discussion of the physical results of the filling and emptying of the Bonneville Basin, of the formation and dissolution of the northern ice-sheet, and of all other phenomena involving the influence of superficial masses on the geoid. His discussion of the problem of a heated sphere presented by the earth, and of the contraction resulting from its slow cooling, is especially valuable for its indication of the additional work needed for the determination of the constants involved and for its illustration of the dependence of the mathematical results upon important postulates, the possibility of whose future demonstration is not apparent. He has also studied and discussed the distribution of density and pressure within the earth, and made a preliminary study of the stresses and strains involved in the deformation of the earth's crust within the limits of elasticity.

STATISTICS OF MINERAL PRODUCTS.

The present being the year in which the eleventh general census of the United States is being taken, it was believed to be advantageous to combine the annual work under the Geological Survey with the cognate Division of Mining Statistics under the Census Bureau, and on the recommendation of the Superintendent of the Census and the Director of the Survey this step was taken by order of the Secretary of the Interior. As a joint labor of the two bureaus the work has been much enlarged so as to include not only the collection of statistics relating to the product of the mines, but also the general facts relating to mining industries. Under this plan the work has proceeded with satisfaction.

The following is a tabulated statement of the mineral products of the United States for the calendar year 1889:

Metallic products of the United States in 1889.

	Quantity.	Value.
Pig iron, spot value....................long tons..	7,603,642	$110,000,000
Silver, coining value.................troy ounces..	50,000,000	64,646,464
Copper, value at New York City..........pounds..	250,000,000	36,000,000
Gold, coining value..................troy ounces..	1,587,000	32,800,000
Lead, value at New York City.........short tons..	185,000	17,000,000
Zinc, value at New York City.............do....	59,000	6,000,000
Quicksilver, value at San Francisco........flasks..	26,464	1,190,500
Nickel, value at Philadelphia.............pounds..	150,000	100,000
Aluminum, value at Philadelphia...........do....	25,000	100,000
Antimony, value at San Francisco.....short tons..	50	10,000
Platinum, value (crude) at New York..troy ounces..	100	500
Total..	....	267,847,464

Non-metallic mineral products of the United States in 1889 (*spot values*).

	Quantity.	Value.
Bituminous coal....long tons..	100,000,000	$130,000,000
Pennsylvania anthracite....do....	45,000,000	100,000,000
Building stone....	....	30,000,000
Lime....barrels..	50,000,000	25,000,000
Natural gas....	....	25,000,000
Petroleum....barrels..	25,000,000	20,000,000
Cement....do....	6,500,000	5,000,000
Salt....do....	10,000,000	5,000,000
Limestone for iron flux....long tons..	6,000,000	3,000,000
South Carolina phosphate rock....do....	450,000	2,500,000
Mineral waters....gallons sold..	20,000,000	3,000,000
Zinc, white....short tons..	20,000,000	1,600,000
Gypsum....do....	170,000	600,000
Borax....pounds..	8,000,000	500,000
Mineral paints....long tons..	30,000	500,000
Asphaltum....short tons..	60,000	300,000
Manganese ore....long tons..	30,000	300,000
Flint....do....	25,000	150,000
Pyrites....do....	60,000	175,000
New Jersey marls....short tons..	125,000	75,000
Crude barytes....long tons..	25,000	100,000
Bromine....pounds..	300,000	90,000
Corundum....short tons..	600	90,000
Gold quartz, souvenirs, jewelry, etc....	....	60,000
Mica....pounds..	10,000	15,000
Precious stones....	....	100,000
Feldspar....long tons..	10,000	50,000
Graphite....pounds..	500,000	35,000
Fluorspar....short tons..	6,000	30,000
Slate ground as pigment....long tons..	2,000	20,000
Chrome iron ore....do....	2,000	25,000
Novaculite....pounds..	1,500,000	18,000
Cobalt oxide....do....	5,000	10,000
Rutile....do....	1,000	3,000
Asbestus....short tons..	1	46
Total....	....	353,346,046

Résumé of the values of the metallic and non-metallic mineral substances produced in the United States in 1889.

Metals	$267,847,464
Mineral substances named in the foregoing table	353,346,046
Estimated value of mineral products unspecified	10,000,000
Grand total	631,293,510

PUBLICATIONS.

The Editorial Division of the Survey is in charge of the executive officer, Dr. W. A. Croffut. The division gives final revision to manuscript reports accepted for publication, and cooperates with authors in the reading of proof. During the year the following volumes have been published:

The Eighth Annual Report, covering the operations of the fiscal year 1886-'87.
Monograph XV. The Potomac or Younger Mesozoic Flora, by W. M. Fontaine.
Monograph XVI. The Paleozoic Fishes of North America, by J. S. Newberry.
Bulletin 53. The Geology of Nantucket, by N. S. Shaler.
Bulletin 54. On the Thermo-electric Measurement of High Temperatures, by Carl Barus.
Bulletin 55. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1886-'87, by F. W. Clarke.
Bulletin 56. Fossil Wood and Lignite of the Potomac Formation, by F. H. Knowlton.
Bulletin 57. A Geological Reconnaissance in Southwestern Kansas, by Robert Hay.
Bulletin 58. The Glacial Boundary in Western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, by G. F. Wright.
Bulletin 59. The Gabbros and Associated Rocks in Delaware, by F. D. Chester.
Bulletin 60. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1887-'88, by F. W. Clarke.
Bulletin 61. Contributions to the Mineralogy of the Pacific Coast, by W. H. Melville and W. Lindgren.
Bulletin 63. A Bibliography of Paleozoic Crustacea from 1698 to 1889, by A. W. Vogdes.
Mineral Resources of the United States, calendar year 1888, by David T. Day.

ILLUSTRATIONS.

At the close of the preceding fiscal year Mr. W. H. Holmes resigned from the Geological Survey to accept an important position in the Bureau of Ethnology, and the Division of Illustrations was placed in charge of Mr. De Lancey W. Gill, who had previously been Mr. Holmes's chief assistant in the draughting room. Mr. J. K. Hillers has remained, as heretofore, in charge of the photographic laboratory. The work of the division includes the preparation of views, diagrams, and maps for the illustration of reports and papers, and is chiefly performed in the draughting room and the photographic laboratory. The ease with which the modern field camera can be manipulated has caused it largely to supplant the pencil as a means of procuring views of geologic subjects. The geologist carries with him a camera and a supply of dry plates and performs the outdoor portion of the manipulation. Negatives are developed and proofs are printed in the photographic laboratory, and these are made the basis either of pen drawings or of reproductions by automatic half-tone processes. The photographic laboratory is likewise charged with the reduction and enlargement of topographic maps for the purposes of collation and combination, and with the reproduction of topographic sheets for field use by the geologist before they have been engraved.. During the year there have been made 1,803 negatives, 9,140 prints, and 34 transparencies; and 960 drawings were produced by the draughting room.

The work of the division is described in detail in Mr. Gill's administrative report.

ORGANIZATION OF THE ENGRAVING DIVISION.

The general plan for the publication of the geologic atlas of the United States includes the preparation of more than 7,000 atlas sheets, each representing the geologic and topographic features of a rectangular area bounded by meridians and parallels. For the delineation of topographic features each sheet receives three impressions, each with a different color. For the delineation of the geology, each sheet will receive from two to twenty additional impressions. The preparation of the plates from which these impressions are made is so great an undertaking that much attention and, if necessary, a considerable outlay may be advantageously bestowed on preliminary experimentation to ascertain or develop the most economic methods. It is believed that the problem has been practically solved for the engraving of the topographic features, and that work has been carried forward for several years. A series of contracts have been let and the plates for many topographic sheets have been engraved The problem of engraving the geologic features is more difficult, and its solution requires careful experimentation. Such experimentation, demanding the constant interaction of trial and suggestion and the fullest possible information concerning cost, can not be conducted under the contract system.

As the topographic sheets are engraved, proof copies are placed in the hands of geologists, to use in connection with their work, and they are also given to engineers and other persons whose work demands local topographic data. Through this preliminary use errors are sometimes discovered, and such errors must be corrected upon the engraved plates before they are approved for publication. Moreover, the cultural elements of topography—such as names, towns, roads, and railroads—undergo changes, and so far as these changes supervene between the engraving of maps and their publication the engraved plates should be revised so as to conform thereto. The modification of engraved plates by way of correction and revision is a work which can not advantageously be performed under the contract system.

For these reasons an engraving division has been organized within the Survey. Mr. S. J. Kübel, appointed Chief Engraver in February, was placed in charge; the necessary assistants were employed, and the necessary plant was purchased. Its first work was the revision and correction of engraved topographic plates, and it has also begun the experimental work indicated above. The details of its organization appear in the report of the Chief Engraver, herewith.

THE LIBRARY.

The library has continued in charge of Mr. C. C. Darwin, whose report contains a full account of its work. The Library Division conducts the exchanges of the Survey, sending out its publications and receiving those of its correspondents. It likewise purchases, receives, catalogues, and otherwise cares for books and pamphlets. The acquisitions during the year by purchase and exchange number 3,212 books and 3,857 pamphlets. Through its exchange system the Survey has sent out 15,019 volumes, 2,931 have been sold, and 28,897 have been distributed gratuitously.

DISBURSEMENTS.

The accounts of the Survey are in the hands of Mr. Jno. D. McChesney, chief disbursing clerk, who, during the entire existence of the Bureau under its present direction has been responsible for this important service, and who has discharged with unvarying care and fidelity the trusts confided to him.

FINANCIAL STATEMENT.

Amounts appropriated for and expended by the United States Geological Survey for the fiscal year ending June 30, 1890.

	Geological Survey.	Salaries, office of Geological Survey.	Geological maps of the United States.	Total appropriation.
Appropriation fiscal year ending June 30, 1890, act approved March 2, 1889	$470,700.00	$35,540.00	$45,000.00	$551,240.00
Amounts expended, classified as follows, viz:				
A.—Services	333,400.01	35,047.27	2,824.65	
B.—Traveling expenses	26,850.55		44.20	
C.—Transportation of property	2,131.53			
D.—Field subsistence	20,367.23			
E.—Field supplies and expenses	28,172.37			
F.—Field material	7,708.79			
G.—Instruments	3,627.85		287.40	
H.—Laboratory material	3,091.88			
I.—Photographic material	2,207.69			
K.—Books and maps	6,251.33		9,730.00	
L.—Stationery and drawing material	2,021.52		409.22	
M.—Illustrations for reports	19.00			
N.—Office rents	850.00			
O.—Office furniture	3,625.40		385.62	
P.—Office supplies and repairs	2,046.32		2,033.63	
Q.—Storage	417.10			

Amounts appropriated for and expended by the United States Geological Survey for the fiscal year ending June 30, 1890—Continued.

	Geological Survey.	Salaries, office of Geological Survey.	Geological maps of the United States.	Total appropriation.
Amounts expended, etc.—Continued.				
R.—Correspondence	$153.86	....	....	
S.—Bonded railroad accounts:				
Freight $124.92				
Transportation of assistants... 827.81	952.73	....	....	
Total expenditures	443,895.16	$35,047.27	$15,714.72	$494,657.15
Balance unexpended June 30, 1890	26,804.84	492.73	29,285.28	56,582.85
Probable amount required to meet outstanding liabilities, including contracts for engraving Geological maps	26,804.84	....	29,285.28	56,090.12

In Mr. McChesney's administrative report will be found a statement of the details of disbursements of which the above is a concise summation.

ACCOMPANYING PAPERS.

Appended to this report are the administrative reports of the chiefs of branches and divisions, and two scientific papers, the first by Mr. W. J. McGee, on the Geology of Northeastern Iowa, the second by Mr. A. J. Phinney, on Natural Gas Districts in Indiana.

The administrative reports of previous years have had for their chief function the statement of the scope and quantity of work done and the exhibition of its relation to the general plan. In some instances brief statements of the results of investigations have been added. In the preparation of the reports contained in this volume the communication of results of investigation has been avoided, and the reports will be found to be purely administrative in scope. The change has been made in the interest of the scientific reader, who will look more naturally to the bulletins and other scientific publications of the Survey than to its administrative reports for the material he desires. Announcements of discoveries and other results, when intermingled with accounts of operations and other irrelevant matter, are difficult of access and to a large extent concealed.

Before becoming a member of the Survey Mr. McGee began an investigation of the superficial geology of northeastern Iowa and gave much time to it. He carried the work so far as to achieve important generalizations, but was not satisfied to present his results as final without additional field study. As the Survey had undertaken, through its Glacial Division, the general study of the glacial formations of a large district, including the area studied by Mr. McGee, and as it was undesirable to duplicate his work, it was arranged that he should perform the field work necessary to complete his original undertaking and present the matter for publication, so that his data and results would be available for use in the more general work. The field work was completed in 1888, and the results are embodied in the accompanying essay. From a body of phenomena, varied, significant, and typical of a larger area than the one examined, he deduces a series of local pictures of the advancing and retreating ice sheet, and thus contributes a chapter to the complicated history of the geographic and climatic revolutions of the Pleistocene.

Three or four years ago attention was attracted to gas escaping from springs and other natural openings in Ohio and Indiana, and test bores were put down in great number in these and other States. At that time little was known of the laws governing the origin and distribution of rock gas. With the view of developing these laws and at the same time utilizing the opportunity of ascertaining the rock structure of the region afforded by the many borings, researches were at once undertaken by the Survey. The first move resulted in the acquisition of exceedingly valuable data collected by Prof. Edward Orton, State geologist of Ohio, and an arrangement was effected under which Prof. Orton assembled and discussed his data in the form of a systematic treatise, which was published in the ninth annual report. Meantime Dr. A. J. Phinney, an amateur geologist of Muncie, Ind., undertook to keep a record of the successful and unsuccessful prospect bores of Indiana; and learning of the industry and success with which the doctor had carried forward his work it was deemed wiser to enter into relations with him than to institute a new investigation traversing the same field. It was accordingly arranged that Dr. Phinney should extend his studies and prepare the results for publication under the direction and auspices of the Geological Survey. The work was carried on under the immediate supervision of Mr. W. J. McGee. As indicated in earlier reports, the first study was completed and a treatise prepared for publication nearly two years ago; and, as indicated in the last report, this treatise was sent to press as a bulletin of the survey. But new information continued to pour in, and since it was thought desirable to incorporate the latest discoveries, publication was still further delayed. The treatise has now been brought up to date; and in view of the importance of the subject with which it deals, it has been deemed best to incorporate it in the present report as one of the accompanying papers. It contains records of a large number of borings, both successful and unsuccessful, put down in search of rock gas and petroleum in Indiana; a résumé of the geologic structure of the State not only as ascertained from surface exploration but as revealed by the drill; a statement (illustrated by maps and profiles) of the character and extent of the great Indiana gas field, the largest of the known world; and certain practical information relating to the gas wells and the use of the new fuel. The paper includes an introductory chapter by Mr. McGee, in which the geographic and geologic distribution and the origin and laws of accumulation of the lighter bitumens are discussed. From this introductory chapter and from the memoir prepared by Prof. Orton, published in the eighth annual report, it will be seen that the laws governing the distribution of rock gas, petroleum, and related substances are now so well known that the geologist is able to indicate with considerable accuracy the productive territory, actual and possible, within the United States, and to reliably prognosticate the results of borings in any part of the country. Economic geology has never made a more rapid advance than within the period covered by these publications on rock gas.

OFFICES AND LABORATORIES.

The main office of the Survey at Washington has continued in the Hooe Building, where it was established in 1884. While this building is large and well suited for the purpose to which it is applied, it affords only a fraction of the space required for all the office and laboratory work.

Through the courtesy of the Secretary of the Smithsonian Institution, the chemical and physical laboratories and the principal offices and laboratories of paleontology continue to occupy rooms in the National Museum, and quarters are furnished to the division of Cenozoic Invertebrate Paleontology in the building of the Smithsonian Institution. This arrangement is highly advantageous to the Survey. It is provided by law that the collections of rocks, minerals, ores, and fossils made by the Survey shall finally be deposited in the National Museum, and the existing adjustment of relations relieves the Survey from the necessity of furnishing cases and other museum appliances and reduces the final transfer of the specimens to little more than a clerical formality. Moreover, the Museum and the Institution contain a very large body of cognate material which is constantly used by the paleontologic students for the purpose of comparison, and which this arrangement renders conveniently accessible. Still further to promote the work of the Survey a number of its officers have been appointed honorary curators of the Museum, and are thereby given direct control of all the museum material cognate to their work.

Through the courtesy of the officers of the Peabody Museum of Yale College, the students of vertebrate paleontology have the use of spacious laboratories and enjoy valuable museum facilities. The Museum likewise contains large collections of vertebrate fossils which are under the control of the paleontologist of the Survey, and are of great service in connection with his work. On account of the bulk of the collection of vertebrate fossils, the facilities afforded by the Peabody Museum are comparable in importance with those enjoyed in the National Museum, and the arrangement is in every way similar except that the vertebrate fossils belonging to the Government are eventually transferred from the laboratories at New Haven to the Museum in Washington.

The Atlantic Coast Division of Geology and the Division of Jura-Trias Paleontology have their headquarters at Cambridge, Mass., where they receive important favors, including office and laboratory space and the use of museum material from the Museum of Comparative Zoology of Harvard College. The work on Devonian and Carboniferous fossils is carried on at Ithaca, New York, museum space and laboratory facilities being furnished by Cornell University. The headquarters of the Glacial Division of Geology and the headquarters, during summer and autumn, of the Lake Superior Division of Geology, are at Madison, Wisconsin, where museum space and laboratory facilities are afforded by the University of Wisconsin. During the summer the geologist in charge of the Division of Zinc made a series of preliminary chemical examinations in St. Louis, where he received laboratory facilities through the courtesy of the Washington University.

The Archean Division of Geology has its headquarters at Newport, Rhode Island, maintaining the only office outside of Washington for which rent is paid. During the year the office of the California Division has been transferred from San Francisco to Washington.

ACKNOWLEDGMENTS.

The Survey is indebted to the Secretary of the Interior for advice, assistance, and support in all its work.

The Superintendent of the U. S. Coast and Geodetic Survey has not only furnished the Geological Survey with a large amount of unpublished cartographic and astronomic material, but has afforded every facility for the examination and use of the archives of that Bureau.

The Chief Signal Officer of the Army has furnished for the use of the Survey a large body of unpublished data, and has otherwise facilitated its work in all possible ways.

For the free use of offices, laboratories, museum space and museum material, the Survey is greatly indebted to the officers of the Smithsonian Institution, the Peabody Museum, the Museum of Comparative Zoology, Cornell University, the University of Wisconsin, and Washington University. Without their friendly aid its operations would be greatly hampered and many important researches would necessarily be stopped.

It is the pleasant duty of the Director to call the attention of the Secretary and of the Congress to the thorough manner in which the officers of the Survey have performed their duties. This is true alike of the administrative officers and of the scientific assistants. Their labors have been constant, vigorous, and efficient, and they cordially cooperate for the common purpose of discovering and publishing to the world the geologic structure of the United States and the mineral resources contained in its rock formations. I have been especially indebted to Mr. Gilbert for the thorough and vigorous manner in which he has executed the administrative duties assigned him during the last year.

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, 1890.

ADMINISTRATIVE REPORTS.

REPORT OF MR. HENRY GANNETT.

U. S. GEOLOGICAL SURVEY,
TOPOGRAPHIC BRANCH,
Washington, D. C., July 1, 1890.

SIR: I have the honor to submit the following report upon the operations of the Topographic Branch of the Survey during the last fiscal year. It has been my practice heretofore to make the report upon these operations conform strictly in time to the period between July 1 and June 30. Concerning that portion of the report which relates to field operations this practice involves cutting the field season into two unequal parts, thereby destroying the unity of presentation of the results of field work. It seems to me advisable to preserve that unity, and therefore, in this report I shall present the results of the field operations for the season of 1889, leaving for a future report the results of the field work executed during the months of May and June of the fiscal year just closed. This course involves a repetition of the results of work executed during May and June of the year 1889, which were detailed in my last report.

During the year the work of this branch has been carried on in twenty States, viz: Maine, Vermont, Connecticut, New York, Pennsylvania, Virginia, West Virginia, North Carolina, Georgia, Kentucky, Alabama, Florida, Louisiana, Texas, Arkansas, Kansas, Iowa, Illinois, Wisconsin, and Michigan.

The entire area surveyed was 46,807 square miles. Of this, 11,637 square miles were surveyed upon the scale of 1:62,500 in contour intervals of 5, 10, or 20 feet, and 35,170 square miles upon the scale of 1:125,000 in contour intervals of 20, 50, or 100 feet. No work was executed upon the scale of 1:250,000. The number of atlas sheets completed by the season's work was eighty-two, forty-eight of them being upon the scale of 1:62,500 and thirty-four of them upon the scale of 1:125,000. The area surveyed by the Geographic Branch is distributed as shown in the following table and in the map which constitutes Plate I:

State.	Scale of field work.	Scale of publication.	Contour interval.	Area surveyed.
				Sq. miles.
Maine	1 : 45000	1 : 62500	20	1,012
Vermont	1 : 45000	1 : 62500	20	450
Connecticut	1 : 45000	1 : 62500	20	2,477
Pennsylvania	1 : 45000	1 : 62500	20	2,085
Virginia	1 : 126720	1 : 125000	50	1,775
West Virginia	1 : 126720	1 : 125000	100	2,600
Kentucky	1 : 126720	1 : 125000	100	2,700
North Carolina	1 : 126720	1 : 125000	100	500
Georgia	1 : 126720	1 : 125000	100	3,345
Alabama	1 : 126720	1 : 125000	100	3,250
Florida	1 : 63360	1 : 62500	10	250
Michigan	1 : 31680	1 : 62500	20	63
Wisconsin	1 : 31680	1 : 62500	20	675
Illinois	1 : 31680	1 : 62500	5 and 10	600
Iowa	1 : 31680	1 : 62500	20	2,025
Kansas	1 : 63360	1 : 125000	20	12,000
Arkansas	1 : 63360	1 : 125000	50	3,000
Texas	1 : 63360	1 : 125000	20	6,000
Louisiana	1 : 63360	1 : 62500	5	2,000

ORGANIZATION.

The organization of the Branch has remained substantially the same as at the date of closing my last report. The Geographic Branch comprises the four divisions named, respectively, Northeastern, Southeastern, Northern Central, and Southern Central. The Northeastern Division comprehends all work done in the States north of Mason and Dixon's Line and east of Ohio. The Southeastern Division comprehends all work executed south of Mason and Dixon's Line and the Ohio River, and east of the Mississippi River, and the east boundary of Louisiana. The Northern Central Division comprises all work done in the States of the Mississippi Valley north of the southern boundary of Kansas and east of the one hundredth meridian; and the Southern Central Division comprises all work done in the States of Arkansas, Texas, and Louisiana.

NORTHEASTERN DIVISION.

This division has remained under charge of Mr. Marcus Baker. It has surveyed an area of 6,024 square miles, completing twenty-nine atlas sheets, all on the scale of 1:62,500, and with a contour interval of 20 feet. The field of work was in southwestern Maine, southern Vermont, western Connecticut, southeastern New York, and the anthracite coal region of Pennsylvania. The parties of this division took the field early in the season.

The work in Maine was resumed early in May by Mr. W. H. Lovell, with two assistants, and later with three. It was actively prosecuted throughout the season, and upon closing work in November, Mr. Lovell reported an area of 1,012 square miles, completing six atlas sheets.

Early in August Mr. G. E. Hyde was detailed from Mr. Lovell's party for the purpose of surveying two atlas sheets in southern Vermont, near the Massachusetts boundary. Although this region is extremely rugged, Mr. Hyde succeeded in completing the task assigned him, leaving the field at the close of November.

It was stated in my last report that the legislature of Connecticut had made an appropriation for a survey of the State in cooperation with this organization. The Commissioners on the part of the State were Prof. William H. Brewer, Dr. J. H. Chapin, and Mr. John W. Bacon. These gentlemen, acting for the State, entered into agreement with the U. S. Geological Survey, and under that agreement work was prosecuted during the entire season. An area of 2,477 square miles, comprising the western half of the State, and including twelve atlas sheets, was surveyed.

Upon examining the condition of the primary control for topographic work in the State, it was found that upon many of the sheets the positions determined by the U. S. Coast and Geodetic Survey were sufficient in number for the purpose. Upon many other sheets, however, it was apparent that the existing control was insufficient and that additional triangulation was necessary. For this purpose Mr. S. S. Gannett was detailed to this division, and his time from the middle of July to the end of September was devoted to this work. During this time Mr. Gannett completed the triangulation necessary for the map of the entire State.

It was also found necessary to make provision throughout for the control of the vertical element of the maps. For the purpose of supplying this Mr. W. R. Atkinson was detailed at the beginning of the season to run lines of level over the sheets projected for the season's work. During the months of May and June, he ran 145 miles of such lines in the western part of the State, most of the way on railroads, determining the elevation above mean tide of all road crossings and other points desired as datum points.

For the survey of topographic details, three parties were placed in the field during May, the first in charge of Mr. J. H. Jennings, the second in charge of Mr. E. W. F. Natter, and the third under Mr. E. B. Clark, each with one or more assistants. Early in July, Mr. Atkinson, having completed the leveling work, was placed in charge of a topographic party, with one assistant, and an additional party was added to the force under the charge of Mr. M. B. Lambert. With this force, work was prosecuted until the end of November, and the parties were not entirely withdrawn from the field until the latter part of December. As stated above, the area surveyed in the State during the season was 2,477 square miles, comprising the western half of the State and completing, with some revision yet to be performed, twelve atlas sheets.

In my last report it was stated that the sheets including Staten Island, Harlem, and Brooklyn, New York, were completed. It was discovered, however, that certain small areas required further examination and revision, and it was decided also to revise thoroughly the northwestern of the four sheets comprising the metropolitan district, which had been surveyed by the State of New Jersey for the purpose of bringing the cultural features up to date, and especially of adding the houses throughout the sheet, a feature which has been omitted in the New Jersey map. For this purpose Mr. Frank Sutton, who had been associated with Mr. S. H. Bodfish upon the survey of these New York sheets, was detailed, with one assistant, and the greater part of the season was occupied in an examination and revision of this area.

In response to an urgent request from the director of the Second Geological Survey of Pennsylvania, Prof. J. P. Leslie, work upon a somewhat extensive scale was commenced in the anthracite coal region of that State. The extension of the triangulation in this region in order to adapt the work of the U. S. Coast and Geodetic Survey to the needs of the map was commenced at the opening of the season by Mr. S. S. Gannett, carried forward by him until the middle of July, and subsequently resumed in the latter part of the season.

Three topographic parties were detailed to this area, respectively under Messrs. R. D. Cummin, F. P. Gulliver and William Kramer, each with one assistant. Work was prosecuted throughout the season rapidly and effectively, and nine sheets were completed, comprising 2,085 square miles, including about one-half of the anthracite coal region.

SOUTHEASTERN DIVISION.

This division has remained in charge of Mr. Gilbert Thompson. An area of 14,420 square miles has been surveyed during the season and twelve atlas sheets have been completed. Work has been prosecuted in Virginia, West Virginia, Kentucky, North Carolina, Alabama, Georgia, and Florida.

The Virginia party was in charge of Mr. A. E. Murlin, with three assistants. The territory assigned him lay southwest of Richmond. This party commenced work on July 1 and prosecuted it continuously until November 22, completing the survey of 1,775 square miles. This area completes the Palmyra sheet, and includes the whole of the Farmville sheet and about a quarter of the Appomattox sheet. The country is entirely of a rolling character and is mainly covered with forests, rendering triangulation impossible, and therefore the work was executed entirely by traverse methods.

The West Virginia party was in charge of Mr. L. C. Fletcher, who had five assistants. The party left for the field early in May, and by the middle of the month was at work. The work was prosecuted continuously until the middle of November. The output of the party amounts to 2,600 square miles, completing three atlas sheets. The territory surveyed by this party presented great difficulties, lying entirely within the Cumberland or Alleghany plateau. Much of the secondary triangulation was necessarily done from the tops of high trees, which involved a large amount of climbing and heavy chopping.

The Kentucky party was in charge of Mr. E. C. Barnard. The party was large, comprising, besides Mr. Barnard, five assistants. The party took the field early in May, and prosecuted work continuously until the middle of November. They surveyed an area of 2,700 square miles, completing two sheets and a portion of a third. The work comprised not only topographic details. but the extension of primary triangulation over much of the territory. The area surveyed comprises a part of the lower slopes of the Cumberland plateau, a very rugged region covered with dense forests, and the natural difficulties of surveying were greatly increased by the hostility of the inhabitants.

The work in Georgia was directed towards mapping the drainage basin of the Savannah River, with the view of obtaining information which might be of use in preventing disasters from floods. The party was placed in charge of Mr. Merrill Hackett, who, with four assistants, took the field about the middle of June and commenced work about the 1st of July. The party left the field early in December, having surveyed an area of 3,345 square miles, completing two atlas sheets and portions of a third. Besides surveying the topographic details of this area, Mr. Hackett's party ran more than 200 miles of traverse for its primary control.

The party working in Alabama, as in previous years, was in charge of Mr. Louis Nell, who left for the field with three assistants about the middle of June, and was fairly at work on the 1st of July. Work was prosecuted until near the end of November, when the party left the field, having mapped 3,250 square miles, completing two atlas sheets, and portions of several contiguous sheets. This area lies in central Alabama, north and northwest of Montgomery. Besides surveying this area Mr. Nell's party occupied six stations for primary triangulation and ran 302 miles of line for primary control.

In addition to the primary triangulation and control lines executed by the parties as above detailed, a special party for this work was put in the field in charge of Mr. C. M. Yeates for the purpose of extending triangulation in southern Virginia, from the Blue Ridge to the vicinity of Danville. Mr. Yeates commenced work early in July and finished on November 30, having constructed and occupied during that time eight primary triangulation stations and having run 121 miles of control line.

For the completion of the Wilkesboro sheet, North Carolina, a portion of which was surveyed in 1888 by Mr. J. W. Hays, Mr. R. L. Longstreet was detailed. He commenced work upon this sheet on the 1st of September and, with one or two interruptions, continued work until December, finishing the sheet and surveying an area estimated at 500 square miles.

On the 1st of February Mr. Hersey Munroe, with an assistant, was detailed for the purpose of commencing work in Florida. The area selected for the inception of work was in the neighborhood of Gainesville, Alachua County. The scale selected for the map was a mile to an inch, with a contour interval of 5 feet. It was prosecuted from early in February until the middle of May, when, upon the completion of the Gainesville atlas sheet, Mr. Munroe was recalled to Washington.

NORTHERN CENTRAL DIVISION.

This division has remained in charge of Mr. John H. Renshawe. Work has been prosecuted in the iron region upon the upper peninsula of Michigan, in southern Wisconsin, eastern Illinois, eastern Iowa, and southern central Kansas. The entire area surveyed was 15,363 square miles. Fourteen atlas sheets upon the scale of 1:62,500 and twelve upon the scale of 1:125,000 have been completed.

In order to afford assistance in the study of the iron deposits in the Marquette region of Michigan, a topographical survey was commenced early in the spring, Mr. F. J. Knight being placed in charge of the work. The scale adopted was one mile to an inch, with a contour interval of 20 feet. Triangulation was executed for control, resting upon a line measured by the United States Lake Survey, in the neighborhood of Marquette, and was extended westward through the center of the district. Topographic work commenced in July and continued until November, the entire area surveyed being 63 square miles.

Work in southern Wisconsin was resumed early in May by Mr. Van H. Manning, jr., with one assistant, and was actively prosecuted until the end of October, when three atlas sheets were completed. During the month of November Mr. Manning was engaged in assisting Mr. W. J. Peters, in Iowa.

Field work was resumed in Iowa in May by Mr. W. J. Peters, who was aided throughout the season by two assistants, and during the month of November, as above noted, he had the further assistance of Mr. Manning. The area surveyed comprised nine atlas sheets, forming a rectangular tract, lying between the latitudes of 41° 30′ and 42° 15′ and longitudes 90° 30′ and 91° 15′.

Among the plans projected for the season's work was that of making a somewhat detailed map of the city of Chicago and the country lying south and west from it, including the line of the proposed ship canal from Lake Michigan to the Illinois River. It was decided that the scale of this proposed map should be 1 mile to an inch, and the contour interval 5 feet within the city proper and 10 feet in the sheets lying outside. To this work was detailed Mr. D. C. Harrison, with one assistant, on July 1. Little surveying was found to be necessary in the closely built parts of the city, as the requisite data were in large part furnished by the location of the United States Lake Survey, city maps and plans, levels for sewer purposes, and surveys made by the various railroads centering there. All this matter was compiled and put upon the original sheets and the country adjoining the city was surveyed. The results of the season's work, which extended until late in November, consisted in the completion of two sheets, which include the entire area of the city and its suburbs to the south, and progress upon two sheets covering areas lying west of them, a total area of about 600 square miles.

The work in Kansas was organized upon a larger scale and promised a much larger output than during the preceding season. It was placed in charge of Mr. H. L. Baldwin, who personally conducted a triangulation party and executed the triangulation. Under his direction were organized two topographic parties, respectively in charge of Mr. W. H. Herron and R. M. Towson, each with two assistants. These parties took the field early in May and worked until late in November. Twelve atlas sheets, comprising about 12,000 square miles, were surveyed. The sheets lie between the meridians of 97° 30′, and 100° and the parallels of 37° and 38° 30′, comprising all the area thus inclosed, with the exception of three sheets lying along the south boundary of the State. The horizontal scale of the work remained the same as heretofore in Kansas, viz, 1:125,000, but the contour interval was reduced from 50 to 20 feet. The work was controlled by a belt of triangulation, which, starting from the western end of the belt executed in 1885, near Salina, Kan., by Mr. R. U. Goode, was extended somewhat south of west to Spearville, Kan., near the one hundredth meridan. In this neighborhood a base line was measured and the position of Spearville determined by astronomical means, thus closing up this belt very satisfactorily. To the points in this belt of triangulation the land-office corners adjacent were connected and the locations of the land-office surveys were thus made to serve as secondary locations.

SOUTHERN CENTRAL DIVISION.

This division has remained in charge of Mr. R. U. Goode. The Arkansas section was organized very much as during the preceding season, there being one topographic party, in charge of Mr. H. B. Blair, with three assistants, and a triangulation party under Mr. Hawkins. These parties took the field in May and worked until the 1st of December. The area surveyed lay in the northeastern portion of the Ozark Hills of Arkansas, the specific areas being selected in accordance with the wishes of Dr. J. C. Branner, director of the Geological Survey of Arkansas. Three sheets were surveyed, comprising about 3,000 square miles, and triangulation was extended not only to cover these sheets, but also to cover three additional sheets, so that, at present, triangulation is well in advance of the topographic work.

The organization of the Texas section remained as in previous years, but with certain changes in personnel. The triangulation was put in charge of Mr. Urquhart, who had formerly been Mr. Goode's assistant upon the work. One of the two topographic parties remained in charge of Mr. H. S. Wallace, while the other was placed in charge of Mr. R. O. Gordon, who had been detailed from the southeastern division for that purpose. Each topographic party was given two assistants. These parties took the field in April, and prosecuted work with good success until December. The output of the season consisted of three atlas sheets surveyed by each party, these sheets comprising the area lying between the parallels of 32° 30′ and 33° and the meridians of 96° 30′ and 99° 30′, with the exception of the Breckenridge sheet, together with the sheet lying between the parallels of 32° and 32° 30′ and 97° and 97° 30′. The triangulation party measured a verification base near Albany, Tex., and then extended triangulation over the sheets surveyed and over two additional sheets lying between the parallels 31° and 32° and the meridians 97° and 97° 30′.

Early in the winter it appeared desirable to commence the survey of the alluvial region of southern Louisiana. Being a region of alluvial deposition, it is of special interest to the geologist, while a knowledge of the peculiar formation of the ground seemed to be desirable in a study of the physics of the Mississippi River. The scale selected for this work was 1:62,500, and, owing to the extremely low relief of the country, the contour interval was fixed at five feet. The work was placed in charge of Mr. H. L. Baldwin, and nine men who could be spared from the office were detailed for this service. Work commenced in this area in the latter part of January. The best methods were quickly developed by Mr. Baldwin, and work was prosecuted rapidly and effectively. It was closed about the middle of April. The original plan contemplated the survey of ten sheets lying between the meridians of 89° 45′ and 91°, and latitudes 29° 45′ and 30° 15′. Eight of these sheets, including all except the two northwestern ones, were finished, the completion of the others having been prevented by floods due to crevasses.

DRAUGHTING DIVISION.

This division, which is in charge of Mr. Harry King, has for its function the preparation of map illustrations for publication, the compilation of base maps for the use of the office, and other incidental duties for which draughtsmen are needed. The following draughtsmen besides Mr. King have been employed during the year: Messrs. J. H. Klemroth, M. A. Cudlip, H. S. Selden, and J. B. Torbert. The principal work upon which these men have been engaged is the proof-reading of maps, the preparation of progress maps and maps showing various physical features of the United States, and the compilation of a map of the State of New York, and of maps of portions of Iowa for illustrative purposes.

INSTRUMENTS.

The instrument shop, as heretofore, has been in charge of Mr. Edward Kübel, with four assistants. As was stated in my last report, the resources of the shop are little more than sufficient to repair and keep in adjustment the large number of instruments in use in the Survey, and little new work can be executed by it. During the year it has, however, besides attending thoroughly and efficiently to repairs and adjustments, completed six first-class telescopic alidades and nearly completed a fine eight-inch theodolite.

ENGRAVING.

In my last report it was stated that three contracts for engraving were then pending: One with Messrs. Sinclair & Co., of Philadelphia, for one hundred sheets; one with H. C. Evans, of Baltimore, for thirty sheets; and one with Messrs. Harris & Sons, of Philadelphia, for twenty-one sheets. Work upon the last of these contracts has been completed; the other two contracts are not yet finished, although the work is far advanced. Contracts have been made during the year by this office with Messrs. Bien & Co., of New York, for twenty sheets of the general atlas, for the special map of Massachusetts upon the scale of 1:250,000, and for the nine-sheet map of the United States. Work upon the Massachusetts map has been completed. The other two contracts are not yet finished, although the work is far advanced towards completion. At the date of my last report two hundred and forty-nine sheets of the general atlas had been engraved, and a table was presented giving names and locations, scales, etc. Since that date ninety-five sheets have been engraved, including the reengraving of five sheets.

The following table gives details with regard to all sheets published up to the date of my last report:

Atlas sheets engraved to July 1, 1890.

	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		*Long.*				
		°	′	°	′			*Feet.*
Massachusetts and New Hampshire.	Newburyport	42	45	70	45	$\frac{1}{16}$ degree.	1 : 62500	20
	Haverhill	42	45	71	00	...do.....	1 : 62500	20
	Lawrence	42	30	71	00	....do.....	1 : 62500	20
	Lowell	42	30	71	15	....do.....	1 : 62500	20
	Groton	42	30	71	30	....do.....	1 : 62500	20
	Fitchburg	42	30	71	45	....do.....	1 : 62500	20
	Winchendon	42	30	72	00	....do	1 : 62500	20
Massachusetts, New Hampshire, and Vermont.	Warwick	42	30	72	15	...do.....	1 : 62500	20
Massachusetts and Vermont....	Greenfield	42	30	72	30	....do.....	1 : 62500	20
	Hawley	42	30	72	45	....do.....	1 : 62500	20
	Greylock	42	30	73	00	....do.....	1 : 62500	40
Massachusetts, Vermont, and New York.	Berlin	42	30	73	15	....do.....	1 : 62500	20
Massachusetts and New York...	Pittsfield	42	15	73	15	...do.....	1 : 62500	20
Massachusetts	Gloucester	42	30	70	30	....do.....	1 : 62500	20
	Salem	42	30	70	45	....do.....	1 : 62500	20
	Boston Bay	42	15	70	45	....do.....	1 : 62500	20
	Boston	42	15	71	00	....do.....	1 : 62500	20
	Framingham	42	15	71	15	....do.....	1 : 62500	20
	Marlboro	42	15	71	30	....do.....	1 : 62500	20
	Worcester	42	15	71	45	....do.....	1 : 62500	20
	Barre	42	15	72	00	....do.....	1 : 62500	20
	Belchertown	42	15	72	15	....do.....	1 : 62500	20
	Northampton	42	15	72	30	....do.....	1 : 62500	20
	Chesterfield	42	15	72	45	... do.....	1 : 62500	20
	Becket	42	15	73	00	....do.....	1 : 62500	20
	Provincetown	42	00	70	00	....do.....	1 : 62500	20
	Duxbury	42	00	70	30	....do.....	1 : 62500	20
	Abington	42	00	70	45	....do.....	1 : 62500	20
	Dedham	42	00	71	00	...do....	1 : 62500	20
	Wellfleet	41	45	69	55	....do.....	1 : 62500	20
	Plymouth	41	45	70	30	... do.....	1 : 62500	20
	Middleborough	41	45	70	45	....do.....	1 : 62500	20
	Taunton	41	45	71	00	....do.....	1 : 62500	20
	Chatham	41	30	69	45	....do.....	1 : 62500	20
	Yarmouth	41	30	70	00	....do.....	1 : 62500	20
	Barnstable	41	32	70	15	....do.....	1 : 62500	20
	Falmouth	41	30	70	30	... do.....	1 : 62500	20
	New Bedford	41	30	70	45	... do.....	1 : 62500	20
	Nantucket	41	13	69	57	....do.....	1 : 62500	20
	Muskeget	41	15	70	12	....do.....	1 : 62500	20
	Martha's Vineyard	41	15	70	27	....do.....	1 : 62500	20
	Gay Head	41	15	70	42	....do.....	1 : 62500	20
Massachusetts and Connecticut.	Webster	42	00	71	45	....do.....	1 : 62500	20
	Brookfield	42	00	72	00	....do.....	1 : 62500	20
	Palmer	42	00	72	15	....do.....	1 : 62500	20

Atlas sheets engraved to July 1, 1890—Continued.

	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		*Long.*				
		°	'	°	'			*Feet.*
Massachusetts and Connecticut	Springfield	42	00	72	30	$\frac{1}{16}$ degree	1 : 62500	20
	Granville	42	00	72	45	do	1 : 62500	20
	Sandisfield	42	00	73	00	do	1 : 62500	20
Massachusetts, Connecticut, and New York.	Sheffield	42	00	73	15	do	1 : 62500	20
Massachusetts and Rhode Island.	Franklin	42	00	71	15	do	1 : 62500	20
	Blackstone	42	00	71	30	do	1 : 62500	20
	Providence	41	45	71	15	do	1 : 62500	20
	Fall River	41	30	71	00	do	1 : 62500	20
Rhode Island	Burrillville	41	45	71	30	do	1 : 62500	20
	Narragansett Bay	41	30	71	15	do	1 : 62500	20
	Kent	41	30	71	30	do	1 : 62500	20
	Sakonnet	41	15	71	00	do	1 : 62500	20
	Newport	41	15	71	15	do	1 : 62500	20
	Charlestown	41	15	71	30	do	1 : 62500	20
	Block Island	41	00	71	30	do	1 : 62500	20
Rhode Island and Connecticut	Putnam	41	45	71	45	do	1 : 62500	20
	Moosup	41	30	71	45	do	1 : 62500	20
Rhode Island, Connecticut, and New York.	Stonington	41	15	71	45	do	1 : 62500	20
New Jersey	Franklin	41	00	74	30	do	1 : 62500	20
	Paterson	40	45	74	00	do	1 : 62500	20
	Morristown	40	45	74	15	do	1 : 62500	20
	Lake Hopatcong	40	45	74	30	do	1 : 62500	20
	Hackettstown	40	45	74	45	do	1 : 62500	20
	Plainfield	40	30	74	15	do	1 : 62500	20
	Sandy Hook	40	15	74	00	do	1 : 62500	10
	New Brunswick	40	15	74	15	do	1 : 62500	10
	Princeton	40	15	74	30	do	1 : 62500	10
	Asbury Park	40	00	74	00	do	1 : 62500	10
	Cassville	40	00	74	15	do	1 : 62500	10
	Bordentown	40	00	74	30	do	1 : 62500	10
	Barnegat	39	45	74	00	do	1 : 62500	10
	Whitings	39	45	74	15	do	1 : 62500	10
	Pemberton	39	45	74	30	do	1 : 62500	10
	Mount Holly	39	45	74	45	do	1 : 62500	10
	Long Beach	39	30	74	00	do	1 : 62500	10
	Little Egg Harbor	39	30	74	15	do	1 : 62500	10
	Atlantic City	39	15	74	15	do	1 : 62500	10
	Sea Isle	39	00	74	30	do	1 : 62500	10
	Dennisville	39	00	74	45	do	1 : 62500	10
	Cape May	38	45	74	45	do	1 : 62500	10
Pennsylvania	Doylestown	40	15	75	00	do	1 : 62500	20
	Quakertown	40	15	75	15	do	1 : 62500	20
	Germantown	40	00	75	00	do	1 : 62500	20
Maryland	Baltimore	39	10	76	30	do	1 : 62500	20
Maryland and District of Columbia.	East Washington	38	45	76	45	do	1 : 62500	20
Maryland, District of Columbia, and Virginia.	West Washington	38	45	77	00	do	1 : 62500	20
	Mt. Vernon	38	30	77	00	$\frac{1}{4}$ degree	1 : 125000	50

Atlas sheets engraved to July 1, 1890—Continued.

	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		*Long.*				
		°	′	°	′			*Feet.*
Maryland, Virginia, and West Virginia.	Harper's Ferry	39	00	77	30	¼ degree	1 : 125000	100
	Romney	39	00	78	30	do	1 : 125000	100
Maryland and West Virginia	Piedmont	39	00	79	00	do	1 : 125000	100
Maryland and Virginia	Frederick	39	00	77	00	do	1 : 125000	50
	Fredericksburg	38	00	77	00	do	1 : 125000	50
Virginia	Warrenton	38	30	77	30	do	1 : 125000	50
	Luray	38	30	78	00	do	1 : 125000	100
	Spottsylvania	38	00	77	30	do	1 : 125000	50
	Gordonsville	38	00	78	00	do	1 : 125000	100
	Harrisonburg	38	00	78	30	do	1 : 125000	100
	Goochland	37	30	77	30	do	1 : 125000	50
	Buckingham	37	30	78	30	do	1 : 125000	100
	Lexington	37	30	79	00	do	1 : 125000	100
	Natural Bridge	37	30	79	30	do	1 : 125000	100
Virginia and West Virginia	Winchester	39	00	78	00	do	1 : 125000	100
	Woodstock	38	30	78	30	do	1 : 125000	100
	Franklin	38	30	79	00	do	1 : 125000	100
	Beverly	38	30	79	30	do	1 : 125000	100
	Staunton	38	00	79	00	do	1 : 125000	100
	Lewisburg	37	30	80	00	do	1 : 125000	100
	Christiansburg	37	00	80	00	do	1 : 125000	100
	Pocahontas	37	00	81	00	do	1 : 125000	100
	Tazewell	37	00	81	30	do	1 : 125000	100
West Virginia	St. George	39	00	79	30	do	1 : 125000	100
	Hinton	37	30	80	30	do	1 : 125000	100
	Raleigh	37	30	81	00	do	1 : 125000	100
	Oceana	37	30	81	30	do	1 : 125000	100
West Virginia, Virginia, and Kentucky.	Warfield	37	30	82	00	do	1 : 125000	100
Kentucky	Prestonsburg	37	30	82	30	do	1 : 125000	100
Kentucky and Virginia	Whitesburg	37	00	82	30	do	1 : 125000	100
	Grundy	37	00	82	00	do	1 : 125000	100
Virginia and North Carolina	Hillsville	36	30	80	30	do	1 : 125000	100
	Wytheville	36	30	81	00	do	1 : 125000	100
Virginia, North Carolina, and Tennessee.	Abingdon	36	30	81	30	do	1 : 125000	100
Virginia and Tennessee	Bristol	36	30	82	00	do	1 : 125000	100
Kentucky, Virginia, and Tennessee.	Estillville	36	30	82	30	do	1 : 125000	100
	Jonesville	36	30	83	00	do	1 : 125000	100
	Cumberland Gap	36	30	83	30	do	1 : 125000	100
Kentucky and Tennessee	Williamsburg	36	30	84	00	do	1 : 125000	100
North Carolina	Morganton	35	30	81	30	do	1 : 125000	100
	Cowee	35	00	83	00	do	1 : 125000	100
North Carolina and Tennessee	Roan Mountain	36	00	82	00	do	1 : 125000	100
	Greenville	36	00	82	30	do	1 : 125000	100
	Mt. Mitchell	35	30	82	00	do	1 : 125000	100
	Asheville	35	30	82	30	do	1 : 125000	100
	Mt. Guyot	35	30	83	00	do	1 : 125000	100
	Knoxville	35	30	83	30	do	1 : 125000	100
	Nantehala	35	00	83	30	do	1 : 125000	100

Atlas sheets engraved to July 1, 1890—Continued.

	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		*Long.*				
		°	′	°	′			*Feet.*
North Carolina and Tennessee	Murphy	35	00	84	00	¼ degree	1 : 125000	100
North Carolina and South Carolina.	Saluda	35	00	82	00	do	1 : 125000	100
	Pisgah	35	00	82	30	do	1 : 125000	100
Tennessee	Morristown	36	00	83	00	do	1 : 125000	100
	Maynardville	36	00	83	30	do	1 : 125000	100
	Loudon	35	30	84	00	do	1 : 125000	100
	Kingston	35	30	84	30	do	1 : 125000	100
	Cleveland	35	00	84	30	do	1 : 125000	100
	Chattanooga	35	00	85	00	do	1 : 125000	100
South Carolina	Pickens	34	30	82	30	do	1 : 125000	100
South Carolina and Georgia	Walhalla	34	30	83	00	do	1 : 125000	100
Georgia	Dahlonega	34	30	83	30	do	1 : 125000	100
	Ellijay	34	30	84	00	do	1 : 125000	100
	Dalton	34	30	84	30	do	1 : 125000	100
	Suwanee	34	00	84	00	do	1 : 125000	100
	Cartersville	34	00	84	30	do	1 : 125000	100
	Marietta	33	30	84	30	do	1 : 125000	50
Georgia and Alabama	Ringgold	34	30	85	00	do	1 : 125000	100
	Rome	34	00	85	00	do	1 : 125000	100
	Tallapoosa	33	30	85	00	do	1 : 125000	100
Alabama	Stevenson	34	30	85	30	do	1 : 125000	100
	Scottsboro	34	30	86	00	do	1 : 125000	100
	Huntsville	34	30	86	30	do	1 : 125000	100
	Fort Payne	34	00	85	30	do	1 : 125000	100
	Gadsden	34	00	86	00	do	1 : 125000	100
	Cullman	34	00	86	30	do	1 : 125000	100
	Anniston	33	30	85	30	do	1 : 125000	100
	Springville	33	30	86	00	do	1 : 125000	100
	Birmingham	33	30	86	30	do	1 : 125000	100
	Talladega	33	00	86	00	do	1 : 125000	100
	Bessemer	83	00	86	30	do	1 : 125000	100
Wisconsin	Evansville	42	15	89	15	$\frac{1}{16}$ degree	1 : 62500	20
Iowa	Anamosa	42	00	91	15	do	1 : 62500	20
	Marion	42	00	91	30	do	1 : 62500	20
	Shellsburgh	42	00	91	45	do	1 : 62500	20
	Mechanicsville	41	45	91	15	do	1 : 62500	20
	Amana	41	45	91	45	do	1 : 62500	20
	West Liberty	41	30	91	15	do	1 : 62500	20
	Iowa City	41	30	91	30	do	1 : 62500	20
	Oxford	41	30	91	45	do	1 : 62500	20
Missouri and Illinois	Louisiana	39	00	91	00	¼ degree	1 : 125000	50
	St. Louis, East	38	30	90	00	$\frac{1}{16}$ degree	1 : 62500	20
Missouri	St. Louis, West	38	30	90	15	do	1 : 62500	20
	Mexico	39	00	91	30	¼ degree	1 : 125000	50
	Moberly	39	00	92	00	do	1 : 125000	50
	Glasgow	39	00	92	30	do	1 : 125000	50
	Marshall	39	00	93	00	do	1 : 125000	50
	Lexington	39	00	93	30	do	1 : 125000	50
	Independence	39	00	94	00	do	1 : 125000	50
	Hermann	38	30	91	00	do	1 : 125000	50
	Fulton	38	30	91	30	do	1 : 125000	50

Atlas sheets engraved to July 1, 1890—Continued.

	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		*Long.*				
		°	′	°	′			*Feet.*
Missouri	Jefferson City	38	30	92	00	¼ degree	1 : 125000	50
	Boonville	38	30	92	30	....do.....	1 : 125000	50
	Sedalia	38	30	93	00	....do.....	1 : 125000	50
	Warrensburg	38	30	93	30	....do.....	1 : 125000	50
	Harrisonville	38	30	94	00	....do.....	1 : 125000	50
	Tuscumbia	38	00	92	00	....do.....	1 : 125000	50
	Versailles	38	00	92	30	....do.....	1 : 125000	50
	Warsaw	38	00	93	00	....do.....	1 : 125000	50
	Clinton	38	00	93	30	....do.....	1 : 125000	50
	Butler	38	00	94	00	....do.....	1 : 125000	50
	Bolivar	37	30	93	00	....do.....	1 : 125000	50
	Stockton	37	30	93	30	....do.....	1 : 125000	50
	Nevada	37	30	94	00	....do.....	1 : 125000	50
	Springfield	37	00	93	00	....do.....	1 : 125000	50
	Greenfield	37	00	93	30	....do.....	1 : 125000	50
	Carthage	37	00	94	00	....do.....	1 : 125000	50
Missouri and Kansas	Atchison	39	30	95	00	....do.....	1 : 125000	50
	Kansas City	39	00	94	30	....do.....	1 : 125000	50
	Olathe	38	30	94	30	....do.....	1 : 125000	50
	Mound City	38	00	94	30	....do.....	1 : 125000	50
	Fort Scott	37	30	94	30	....do.....	1 : 125000	50
	Joplin	37	00	94	30	....do.....	1 : 125000	50
Kansas	Hiawatha	39	30	95	30	....do.....	1 : 125000	50
	Seneca	39	30	96	00	....do.....	1 : 125000	50
	Marysville	39	30	96	30	....do.....	1 : 125000	50
	Oskaloosa	39	00	95	00	....do.....	1 : 125000	50
	Topeka	39	00	95	30	....do.....	1 : 125000	50
	Wamego	39	00	96	00	....do.....	1 : 125000	50
	Junction City	39	00	96	30	....do.....	1 : 125000	50
	Lawrence	38	30	95	00	....do.....	1 : 125000	50
	Burlingame	38	30	95	30	....do.....	1 : 125000	50
	Eskridge	38	30	96	00	....do.....	1 : 125000	50
	Parkerville	38	30	96	30	....do.....	1 : 125000	50
	Abilene	38	30	97	00	....do.....	1 : 125000	50
	Garnett	38	00	95	00	....do.....	1 : 125000	50
	Burlington	38	00	95	30	....do.....	1 : 125000	50
	Emporia	38	00	96	00	....do.....	1 : 125000	50
	Cottonwood Falls	38	00	96	30	....do.....	1 : 125000	50
	Newton	38	00	97	00	....do.....	1 : 125000	50
	Iola	37	30	95	00	....do.....	1 : 125000	50
	Fredonia	37	30	95	30	....do.....	1 : 125000	50
	Eureka	37	30	96	00	....do.....	1 : 125000	50
	El Dorado	37	30	96	30	....do.....	1 : 125000	50
	Wichita	37	30	97	00	....do.....	1 : 125000	50
	Parsons	37	00	95	00	....do.....	1 : 125000	50
	Independence	37	00	95	30	....do.....	1 : 125000	50
	Sedan	37	00	96	00	....do.....	1 : 125000	50
	Burden	37	00	96	30	....do.....	1 : 125000	50
	Wellington	37	00	97	00	....do.....	1 : 125000	50
Arkansas	Dardanelle	35	00	93	00	....do.....	1 : 125000	50
	Fort Smith	35	00	94	00	....do.....	1 : 125000	50
	Benton	34	30	92	30	....do.....	1 : 125000	50

Atlas sheets engraved to July 1, 1890—Continued.

	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		*Long.*				
		°	′	°	′			*Feet.*
Arkansas	Hot Springs	34	30	93	00	¼ degree	1 : 125000	50
	Poteau Mountain	34	30	94	00	do	1 : 125000	50
Texas	Granbury	32	00	97	30	do	1 : 125000	50
	Stephenville	32	00	98	00	do	1 : 125000	50
	Eastland	32	00	98	30	do	1 : 125000	50
	Meridian	31	30	97	30	do	1 : 125000	50
	Hamilton	31	30	98	00	do	1 : 125000	50
	Brownwood	31	30	98	30	do	1 : 125000	50
	Coleman	31	30	99	00	do	1 : 125000	50
	Gatesville	31	00	97	30	do	1 : 125000	50
	Lampasas	31	00	98	00	do	1 : 125000	50
	San Saba	31	00	98	30	do	1 : 125000	50
	Brady	31	00	99	00	do	1 : 125000	50
	Taylor	30	30	97	00	do	1 : 125000	50
	Georgetown	30	30	97	30	do	1 : 125000	50
	Burnett	30	30	98	00	do	1 : 125000	50
	Llano	30	30	98	30	do	1 : 125000	50
	Mason	30	30	99	00	do	1 : 125000	50
	Bastrop	30	00	97	00	do	1 : 125000	50
	Austin	30	00	97	30	do	1 : 125000	50
	Blanco	30	00	98	00	do	1 : 125000	50
	Fredericksburg	30	00	98	30	do	1 : 125000	50
	Kerrville	30	00	99	00	do	1 : 125000	50
Montana	Fort Benton	47	00	110	00	1 degree	1 : 250000	200
	Great Falls	47	00	111	00	do	1 : 250000	200
	Big Snowy Mountain	46	00	109	00	do	1 : 250000	200
	Little Belt Mountain	46	00	110	00	do	1 : 250000	200
	Fort Logan	46	00	111	00	do	1 : 250000	200
	Helena	46	00	112	00	do	1 : 250000	200
	Three Forks	45	00	111	00	do	1 : 250000	200
	Dillon	45	00	112	00	do	1 : 250000	200
Yellowstone National Park	Cañon	44	30	110	00	¼ degree	1 : 125000	100
	Gallatin	44	30	110	30	do	1 : 125000	100
Yellowstone National Park and Wyoming.	Lake	44	00	110	00	do	1 : 125000	100
	Shoshone	44	00	110	30	do	1 : 125000	100
Oregon	Klamath	42	00	121	00	1 degree	1 : 250000	200
Colorado	East Denver	39	30	104	30	¼ degree	1 : 125000	50
	Crested Butte	38	45	106	45	1/16 degree	1 : 62500	100
	Anthracite	38	45	107	00	do	1 : 62500	100
Colorado and Utah	Ashley	40	00	109	00	1 degree	1 : 250000	250
	East Tavaputs	39	00	109	00	do	1 : 250000	250
	La Sal	38	00	109	00	do	1 : 250000	250
	Abajo	37	00	109	00	do	1 : 250000	250
Utah	Uinta	40	00	110	00	do	1 : 250000	250
	Salt Lake	40	00	111	00	do	1 : 250000	250
	Tooele Valley	40	00	112	00	do	1 : 250000	250
	Price River	39	00	110	00	do	1 : 250000	250
	Manti	39	00	111	00	do	1 : 250000	250
	Sevier Desert	39	00	112	00	do	1 : 250000	250
	San Rafael	38	00	110	00	do	1 : 250000	250
	Fish Lake	38	00	111	00	do	1 : 250000	250

Atlas sheets engraved to July 1, 1890—Continued.

	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		*Long.*				*Feet.*
		°	′	°	′			
Utah	Beaver	38	00	112	00	1 degree	1 : 250000	250
	Henry Mountain	37	00	110	00	....do	1 : 250000	250
	Escalante	37	00	111	00	....do	1 : 250000	250
	Kanab	37	00	112	00	....do	1 : 250000	250
	St. George	37	00	113	00	....do	1 : 250000	250
Utah and Nevada	Pioche	37	00	114	00	....do	1 : 250000	250
Nevada	Paradise	41	00	117	00	... do	1 : 250000	200
	Disaster	41	00	118	00	....do	1 : 250000	200
	Long Valley	41	00	119	00	..do	1 : 250000	200
	Granite Range	40	00	119	00	....do	1 : 250000	200
California	Alturas	41	00	120	00	....do	1 : 250000	200
	Modoc Lava Bed	41	00	121	00	....do	1 : 250000	200
	Shasta	41	00	122	00	....do	1 : 250000	200
	Honey Lake	40	00	120	00	....do	1 : 250000	200
	Lassĕn Peak	40	00	121	00	... do	1 : 250000	200
	Red Bluff	40	00	122	00	....do	1 : 250000	200
	Downieville	39	30	120	30	¼ degree	1 : 125000	50
	Chico	39	30	121	30	....do	1 : 125000	100
	Nevada City	39	00	121	00	....do	1 : 125000	100
	Marysville	39	00	121	30	....do	1 : 125000	100
	Jackson	38	00	120	30	....do	1 : 125000	100
New Mexico	Largo	36	00	107	00	1 degree	1 : 250000	200
	Chaco	36	00	108	00	....do	1 : 250000	200
	Santa Clara	35	30	106	00	¼ degree	1 : 125000	100
	Jemez	35	30	106	30	... do	1 : 125000	100
	Albuquerque	35	00	106	30	....do	1 : 125000	50
	Mount Taylor	35	00	107	00	1 degree	1 : 250000	200
	Wingate	35	00	108	00	....do	1 : 250000	200
New Mexico and Arizona	Cañon de Chelly	36	00	109	00	... do	1 : 250000	200
	Fort Defiance	35	00	109	00	....do	1 : 250000	200
	St. John's	34	00	109	00	....do	1 : 250000	200
Arizona	Marsh Pass	36	00	110	00	....do	1 : 250000	200
	Echo Cliffs	36	00	111	00	....do	1 : 250000	250
	Kaibab	36	00	112	00	....do	1 : 250000	250
	Mt. Trumbull	36	00	113	00	....do	1 : 250000	250
	Tusayan	35	00	110	00	....do	1 : 250000	200
	San Francisco Mountain.	35	00	111	00	....do	1 : 250000	250
	Chino	35	00	112	00	....do	1 : 250000	250
	Diamond Creek	35	00	113	00	....do	1 : 250000	250
	Holbrook	34	00	110	00	....do	1 : 250000	200
	Verde	34	00	111	00	....do	1 : 250000	200
	Prescott	34	00	112	00	... do	1 : 250000	200
Arizona and Nevada	St. Thomas	36	00	114	00	....do	1 : 250000	250
Arizona, Nevada, and California	Camp Mojave	35	00	114	00	... do	1 : 250000	250

Respectfully submitted.

HENRY GANNETT,
Chief Topographer.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF MR. G. K. GILBERT.

U. S. Geological Survey,
Geologic Branch,
Washington, D. C., June 30, 1890.

Sir: I have the honor to submit the following report on the work of the Geologic Branch for the fiscal year ending to-day.

At the beginning of the fiscal year the divisions of the Survey engaged in geologic work received, collectively, the title "Geologic Branch," and were placed in my charge. The change made at that time consisted in the shifting of a share of administrative supervision from the Director to the Chief Geologist, and involved no modification either of the internal organization of the several divisions or of the general plan of geologic work. Nevertheless a change in the character of the geologic work is now in progress, and as it involves a policy of administration enjoined by the Director, this place is appropriate for its characterization.

The investigations conducted by the Geologic Branch may be broadly grouped as local and general. The local geologic work consists in determining and recording the local distribution of formations, both horizontal and vertical. The horizontal distribution is recorded on maps, and the work of tracing out the boundaries of the superficial exposures of formations and making the graphic record is called "areal geology." The vertical distribution is indicated by means of structure sections, each of which represents the intersection of formations by a vertical plane having definite relations to the map. The map and sections are complementary, and together serve to record and convey information as to the local position and arrangement of rock masses.

The general geologic work consists in the development of the philosophy of the science. It furnishes classifications of rocks according to the manner of their formation and according to the order of their production; it furnishes theories of rock formation and of rock alteration; it furnishes classifications of topographic forms, explains their origin and shows their relations to geologic formations, to rock structures, and to the events of geologic history; it furnishes classifications of the various types of rock structure arising through deposition, displacement and volcanic action, and affords theories of their origin.

These two classes of work are interdependent. The philosophy of the subject can not be developed without the observation of local phenomena of distribution. Theories of rock formation, of metamorphism, of the genesis of topographic forms, of the sequence of strata, of mountain structure, and of volcanism, are all founded largely on local observations of the attitudes and relations of rock masses, and are developed and modified as the local data are multiplied. It is equally true that geologic maps and structure sections can not be prepared without the aid of geologic philosophy. The boundary lines of formations represented on the geologic maps are not seen at all points by the field geologist. Ordinarily the portion actually seen bears but a small ratio to the whole amount delineated; but the position of the remainder is legitimately inferred in accordance with the principles of geologic philosophy. Structures seen at a few points are interpolated through intervening spaces in accordance with the determined laws of such structures. Rock sequences determined at a few points to be locally associated with certain topographic features are elsewhere interpolated in proper relation to such features. Similarly, structure sections, representing the position and relations of rocks beneath the surface, are constructed with the aid of the general laws of structure, either from dips and other data observed at the surface of the ground, or else from these in combination with the records of a few deep borings.

Both local and general work have economic bearings. Most of the geologic formations subserve the uses of man in one way or another, and it is possible that a use will eventually be found for each. Rare substances, as, for example, the ores of metals, are associated, in the several districts where they occur, with certain formations or classes of formations or with certain structures. As the uses of different minerals are discovered through the progress of industrial arts, search for them is instituted, and as soon as their association with specific formations comes to be understood, intelligent search is restricted to those formations. It is one of the chief functions of the Geological Survey to indicate on maps the areas occupied by the various formations and to indicate in structure sections the distribution of formations beneath the surface, and thus guide and aid the search for minerals now known to have value or possessing a value which shall become known in the future. Successful search for rare substances is likewise dependent on correct theories of the manner in which they originate and accumulate. All prospecting and mining operations are guided by theories of some sort, and false theories mislead. It is the economic function of geologic science to discover the true theories and substitute them for the false. By adding to our knowledge of the methods of production and methods of accumulation of rare minerals, and of the laws of association of minerals with rock formations, the Geological Survey helps to answer for each mineral the question, In what formation should it be sought? By its general work it discovers the general laws of association; through its local work it discovers the local facts of distribution.

The local or areal work of the Survey and the general or philosophic work are thus seen to be dependent each upon the other, and to be equally united with the material interests of the country. They are coordinate functions of the Survey, and in the ideal organization a certain adjustment should be maintained between them. When the Survey was instituted the body of existing geologic generalizations and theories was large, and offered a sufficient basis for the execution of good areal work. Had this been the only condition demanding consideration, a wise general plan would have given great prominence at first to the areal work and associated structural work, maintaining this prominence until the geologic atlas was advanced far toward completion, adding general inquiries from time to time as their results were needed to guide the local work, and finally instituting a system of general discussions when the accumulation of local data gave broad basis for generalization. But the institution of work on such a plan was rendered impossible by another consideration. The areal work could not be prosecuted without maps on which to delineate the boundaries of formations. The complementary structure sections could not be constructed without hypsometrical data, and as but a few small districts were provided with topographic maps suitable for these purposes, the local work could not be immediately organized on a large scale. There were instituted, instead, a number of researches promising broad generalizations and other contributions to geologic philosophy, but making no direct contribution to the geologic atlas of the United States. At the same time the principal resources of the organization were devoted to the making of topographic maps as a basis for the areal work. The topographic work is now so far advanced that groups of atlas sheets are ready for the use of geologists in many districts, and the time has arrived for readjusting the relation between the local and general departments of geologic work. This is being accomplished in a gradual manner by the closing of various general researches at points where they can be advantageously interrupted, and by the enlargement, from time to time, of the corps of geologists engaged in areal delineation.

WORK OF THE GEOLOGIC DIVISIONS.

In the Atlantic Coast Division, under Prof. N. S. Shaler, there have been initiated, at various times, studies of the local geology of various islands and other limited districts on the coast, studies of the processes of coastal change, a study of the mode of formation of tidal marshes, and a study of ancient coast lines. These various investigations were begun without the aid of topographic maps, excepting the narrow belt furnished by the work of the U. S. Coast Survey. When the topographic survey of Massachusetts was so far advanced that the atlas sheets were available for the use of geologists, the study and mapping of the inland marshes were added to the similar work on tidal marshes, and it was arranged to carry the work over the whole State of Massachusetts. Afterward the scope of the work was still further enlarged so as to include the delimitation of all the surface formations, and for two years the principal energies of the corps have been directed to the preparation of a detailed atlas of the surface geology of all that portion of Massachusetts not included in similar work of the Archean Division. The surface of the State is so largely covered by the formations of the drift and the alluvial formations derived therefrom, that this atlas will exhibit the distribution of most of the available soils of the State.

Several of the studies of local geology were completed as soon as the maps became available, and have already been made the subjects of reports; but one, that of the coal field of Narragansett Bay, was held for some years in an unfinished state awaiting the completion of the topographic survey of the State of Rhode Island. Work upon it has been resumed during the fiscal year and is now in progress.

The primary work of the Archean Division, in charge of Prof. Raphael Pumpelly, is the discrimination and mapping of the crystalline formations of New England, and up to this time has been carried on chiefly in the State of Massachusetts. The discrimination and classification of the formations have proved, as was foreseen, a matter of great difficulty, but such success has been achieved, nevertheless, that the present work of the division consists largely in tracing, upon new ground, metamorphic formations now fully determined and identified in the western and central counties.

The Potomac Division, under Mr. W. J. McGee, has continued the work of discriminating and correlating the formations of the Coastal Plain from Maryland to Louisiana. There have been local studies in each of the States within this belt. Progress has been made in the correlation of the formations of the Gulf States, and it is believed that certain of these formations have also been traced through a portion of the plain bordering the Atlantic coast. Special attention has been given to the geologic relations of the important phosphatic deposits of Florida.

Through most of this region topographic maps are not yet available, and the field work is directed to the general classification of the formations, so that the map work can afterwards proceed under a systematic plan. In the Gulf States, however, data are now adequate for the delineation of the formations of large areas upon maps of moderate scale, and in the vicinity of Baltimore and Washington detailed geologic maps have been prepared. The mapped district near Baltimore belongs to the Coastal Plain in part only, and includes also a large area of crystalline rocks of the Piedmont district, which has been studied by Dr. George H. Williams.

The work of the Appalachian Division, under Mr. Bailey Willis, is restricted to the mountain belt lying east of the Piedmont and Coastal Plains from Maryland to Alabama. The topographic work is well advanced in this region, and the preliminary studies necessary to the understanding of the stratigraphy and mountain structure have been carried so far that the geologists are chiefly occupied with the delineation of formation boundaries on the map and the determination of local details of structure. The work of the year has been executed chiefly in eastern Tennessee and adjacent parts of Alabama, Georgia, and North Carolina; a small amount has also been done in Virginia and Maryland. The principal areas mapped belong to the region of faulted and folded Paleozoic rocks, but there are included also portions of the belt of crystalline schists lying to the southeast of the Great Appalachian Valley. On account of the exceeding difficulty of determining the age and structure of the crystalline terranes, explorations and reconnaissances have been pushed some distance in advance of detailed mapping.

As the crystalline schists usually can not be discriminated by the aid of fossil remains, and as the evidence of their original sequence is greatly obscured by metamorphism and by complicated displacements, the task of unraveling their structure is arduous, and progress is necessarily slow. As the areas they occupy in the United States are naturally divided into a number of districts, it is impracticable to have the entire field covered by one investigator. It is, nevertheless, important that the work be unified, and that the solution of the local problems in one district be made to aid the work in other districts. To this end a series of joint field excursions have been arranged among the students of crystalline schists. In a previous year Prof. Pumpelly, engaged upon the Massachusetts crystalline area, visited a portion of the Appalachian area with Mr. Willis. This year an excursion was made through another portion of the Appalachian area by Messrs. Pumpelly and Willis, together with Prof. Van Hise, who is occupied with similar studies in the Lake Superior district. As the year closes, Messrs. Pumpelly and Van Hise are examining, in company, the metamorphic rocks of the upper peninsula of Michigan and of the Iron Mountain region of Missouri.

At the other end of the geologic column the glacial formations defy the ordinary methods of classification. They can not be correlated by means of fossils, and the study of their stratigraphic sequence alone yields but imperfect results. It has been found necessary to give chief attention at first to their external forms and internal constitution, and through these to establish a primary classification based on modes of genesis. Geographic distribution could then be brought to aid stratigraphic sequence in the discovery of chronologic order. The broad outlines of the subject had to be sketched before the local details could be intelligently delineated, and this was the first work undertaken by the Division of Glacial Geology when it was organized under Dr. T. C. Chamberlin. It was accomplished by tracing a few great formations across the country from the coasts of New England and New Jersey to the valley of the Missouri, and establishing their relation to the history of Pleistocene changes. Subsequently the theory of glacial action was further developed along various lines, and field work has been directed to the tracing of features of secondary magnitude, but yet too extensive to be adequately presented on the sheets of the general geologic atlas. During the year individual moraines and associated formations have been traced and mapped in parts of Ohio, Indiana, Illinois, Iowa, Minnesota, and North Dakota, and a special reconnaissance has been carried to Missouri, Arkansas, and the western parts of Tennessee and Kentucky, for the purpose of discovering the relation of certain problematic formations of the Mississippi Valley to the glacial formations of the Pleistocene.

The Lake Superior Division, in charge of Prof. C. R. Van Hise, is engaged in the investigation of the Cambrian and pre-Cambrian rocks of northern Michigan, Wisconsin, and Minnesota. Its present work consists in the detailed tracing and mapping of formations whose relations have been already ascertained by extensive reconnaissances. Among the formations mapped are iron-bearing and copper-bearing rocks which have long been known, and whose classification has been the subject of much controversy. It is believed that the detailed work now in progress, under State and National auspices, will so elucidate the geologic structure that the remaining questions will be merely those of nomenclature.

Early in the fiscal year instructions were received from the Secretary of the Interior that an investigation be made of the zinc deposits of Missouri. Mr. Walter P. Jenney was engaged to take charge of the work, and he entered upon his duties on the 1st of September. The State of Missouri was, at that time, engaged in the organization of a Geological Survey, and as the investigation of the zinc deposits would naturally constitute part of the work of that Survey, it was manifestly advantageous that the State and National organizations cooperate. It was accordingly arranged that the State furnish Mr. Jenney with an assistant, and afford him other aid in his work, and that the results of his investigation be regarded as the common property of the two organizations. The zinc deposits are associated with deposits of lead in such way that the two can not be studied separately, and it was decided to include the lead ores in the scope of the investigation. As the natural distribution of the deposits is independent of political divisions, it was determined that it would not be advantageous to limit the work strictly to the State of Missouri.

The southwestern zinc district of Missouri was selected as the field for initial operations, chiefly because it was already partly covered by the topographic work of the Survey. Mr. Jenney began field work in October and continued until April, giving special attention to the problem of the genesis of the ore deposits and to their relations to the containing formations.

In Montana Dr. A. C. Peale continued the mapping of formations and the determination of structural relations within the area of the Three Forks atlas sheet. About 1,000 square miles were mapped, and it is to be expected that the geologic work on the atlas sheet will be completed during the present summer.

The geologic survey of the Yellowstone National Park, under Mr. Arnold Hague, is nearly completed. The only map work remaining to be done is the delineation of the Pleistocene formations, and this work was begun during the fiscal year. The field work of the year consisted chiefly in structural studies in the Absaroka Range, in the study of the ancient glaciation of the district, and in the investigation of the Pleistocene history of Yellowstone Lake.

The glaciation of the park is intermediate in type between the simple work of narrow ice rivers, illustrated on the flanks of mountain ranges in Colorado and Utah, and the complex work of the great ice sheet of the Laurentian basin. For purposes of comparative study, and in order that the local investigation might profit by the results of the more comprehensive work of the Division of Glacial Geology, Mr. Hague was joined in the field by Dr. Chamberlin, and a fortnight was devoted to a joint excursion.

A special study of the geology of the Crazy Mountains of Montana was made by Prof. J. E. Wolff, who had previously visited that range and discovered novel features of interest to students of volcanic rocks. His principal attention was given to a series of intrusive rocks, including theralite, a rock whose geologic occurrence was previously unknown, and he succeeded also in ascertaining the stratigraphic succession of the formations of the range and a general knowledge of its structure.

The Colorado Division, in charge of Mr. S. F. Emmons, is engaged in the investigation of problems directly connected with mining. It has made elaborate studies of a number of mining districts yielding precious metals, and of the Denver coal basin, giving chief attention to the laws of distribution of the economic minerals and the modes of their genesis. Over a small area about each mining district the distribution and relations of the various formations have been determined and geologic maps have been made, but these areas have not usually coincided with the rectangles of the geologic atlas of the United States. In the Crested Butte region of Gunnison County, however, the areal geology of two atlas sheets has been completed. As the field work of this division has heretofore outstripped its office work, this year has been devoted almost exclusively to the preparation of reports. Monographs on the Ten Mile and Silver Creek mining districts and on the Denver coal basin are nearly ready for publication.

The Cascade Division, in charge of Mr. J. S. Diller, was occupied chiefly with areal work, the mapping of the formations of the Red Bluff sheet, and this was nearly completed. A preliminary examination was also made of the mountainous district lying between the western limit of that sheet and the Pacific Ocean.

The Petrographic Laboratory, also in charge of Mr. Diller, occupied an unusual share of his attention by reason of the large number of technical questions submitted to it by various divisions of the Survey. The use of the microscope in the determination and study of rocks, although now regarded as strictly accessory to field investigation, is nevertheless increasing, so that the number of thin sections the laboratory was called upon to prepare this year was larger than ever before, and it was found necessary to make an addition to the force of skilled laborers.

Another function of the laboratory, the preparation of duplicate rock sections for educational purposes, was greatly advanced during the year, arrangements being made through contract for the collection of a large number of specimens which it was not found advantageous to acquire through the aid of the field parties of the Survey. Only a small number of rock varieties are still unsecured, and the work of trimming and otherwise preparing the specimens for distribution is well advanced.

The present work of the California Division, under Dr. G. F. Becker, is the comprehensive study of what is known as the Gold Belt of California. The plan of this work includes the complete mapping of a group of atlas sheets approximately coextensive with the Sierra Nevada, the determination of the age, structural relations, and dynamic history of the auriferous slates and the auriferous gravels, and, as a necessary incident, the elucidation of the general structure and history of the Sierra. During the year Dr. Becker's assistants have been engaged in tracing the boundaries of formations upon the map, and his personal attention has been given largely to problems connected with the metamorphisms of certain of the formations.

The work of the several geologic divisions briefly characterized in the preceding paragraphs is more fully set forth in the administrative reports of the chiefs of divisions appended hereto.

SPECIAL AND TEMPORARY INVESTIGATIONS.

It remains to report on the work of the Division of Geologic Correlation, which was placed in my charge at the time of its institution some years ago, and is still subject to my immediate supervision. From time to time a number of special and temporary researches, not directly connected with the correlation work, have been assigned to the Division of Correlation as a matter of administrative convenience. As these researches and the work of the Correlation Division are not elsewhere reported, they will be here described somewhat fully.

Work in Alaska.—As set forth in the last annual report, the U. S. Coast and Geodetic Survey gave the U. S. Geological Survey an opportunity to send a geologist to the Yukon Valley as an attaché to a Coast Survey party sent out to determine a portion of the Alaskan boundary. Mr. I. C. Russell was detailed for the purpose, and joined the Coast Survey party in San Francisco on the 1st of June, 1889. The following extract from his report defines his route:

> The expedition sailed from San Francisco on the steamship *Bertha* June 14, 1889, and reached Iliuliuk, Unalaska Island, June 27. We remained at Iliuliuk four days. Our effects having been transferred to the steamship *St. Paul*, we sailed for St. Michaels June 30, and, crossing Behring Sea, reached there July 7. We remained there until July 14, when, all arrangements for ascending the Yukon having been completed, the final stage in our journey was begun. The ascent of the river was made in the stern-wheeled steamboat *Yukon*, belonging to the Alaska Commercial Company, and built especially for the navigation of the rivers of Alaska.
>
> Our voyage up the Yukon was slow, but did not allow much time on shore. No stops were made, except to obtain wood or provisions, until arriving at Fort Yukon, and such brief opportunities as were available for land excursions were frequently at localities where geological exposures were poor.
>
> We reached the site of Fort Yukon on August 2, and there landed Mr. McGrath and his party for the purpose of making astronomical and magnetic observations, while the steamboat proceeded up the Porcupine River with Mr. Turner and his party. I accompanied Mr. Turner to within about 40 miles of his destination, which was as far as the steamboat could go, owing to low water in the river. On returning from the Porcupine River trip I remained a few days at Fort Yukon and then proceeded to Mr. McGrath's station on the Yukon at the boundary, arriving there on August 19. I remained with Mr. McGrath about a week and then continued the ascent of the Yukon, reaching the mouth of the Pelly River, the destination of the *Yukon*, on August 31.
>
> On arriving at Pelly River I made arrangements for continuing my journey with a party of miners, who were on their way from Forty Mile Creek to Juneau. We left the site of Fort Selkirk on September 1, and "poled" and "tracked" our open boat up the Yukon to the mouth of the Lewes, and then ascended that stream, passing through Lakes Lebarge, Tagish, Nares, and Bennett to Lake Lindeman. From Lake Lindeman, which is at the head of boat navigation, I crossed the Chilkoot pass on foot, and reached the head of Taiya Inlet, the extreme northern reach of Lynn Canal, on October 1. From there I proceeded to Juneau in an open boat, and took passage in the steamship *G. W. Elder* for Port Townsend, and thence proceeded to Washington, District of Columbia, by rail.

Mr. Russell reached Washington November 1. The time spent in Alaska and in the neighboring portion of the Northwest Territory was about three months, during which he traveled by steamboat, in open boats, and on foot about 2,500 miles. He had little opportunity for detailed geologic study, but the line of his reconnaissance, traversing the great interior plain of the Alaskan peninsula and crossing the glacier-clothed range at the south, enabled him to bring back general information of great value. His report deals with the distribution and limits of ancient and modern glaciation, with the direction of Pleistocene ice motion, with the processes of rock decay and rock disintegration under arctic conditions, with the nature and geologic function of the peculiar marshes called "tundras," with the type of mountain structure exhibited in the Yukon basin, and with the nomenclature of Alaskan rivers. A paper embodying his principal scientific results was presented to the Geological Society of America, and has been printed in the bulletin of the society.[1]

In the spring of 1890 the Survey availed itself of a second opportunity for geologic reconnaissance in Alaska at small expense to the Government. Arrangements were made for the exploration of a portion of the St. Elias Range under the joint auspices of the National Geographic Society and the U. S. Geological Survey, and Mr. I. C. Russell was appointed geologist and chief of the expedition, with Mr. Mark B. Kerr as topographer and first assistant. These gentlemen left Washington May 29, and proceeded to Seattle, Washington, where supplies were purchased and men hired. Mr. E. S. Hosmer joined the expedition as volunteer assistant. The party took steamer for Sitka, Alaska, on the 17th of June, arrived there on the 24th, andon the following day embarked on the U. S. S. *Pinta*, which, through the courtesy of the Secretary of the Navy, had been ordered to transport it to Yakutat Bay, where the work of the expedition begins.

Work in western Tennessee.—A local uplift of the strata in Stewart County, discovered many years ago by Prof. J. M. Safford while engaged on the Geological Survey of the State of Tennessee, has great interest to the geologist. Constituting a dome-like arch isolated in a region of level strata, it offers exceptional advantages for a special study of the phenomena of displacement. As the erosion of the arch has laid bare rocks stratigraphically lower than are elsewhere to be found between the Appalachian folds of eastern Tennessee and the Iron Mountain region of Missouri, the locality offers valuable data on the geographic distribution of Paleozoic sediments and fossils. As soon as the district had been topographically surveyed it was arranged that Prof. Safford make a careful and detailed survey of its geology. During the fiscal year he has spent about three months in field work, being assisted for various periods by Mr. W. T. Lander, Mr. P. M. Jones, and Prof. J. M. Hopkins. His party is now in the field.

Work in Texas.—A study of the Cretaceous formations in Texas, begun some years ago by Mr. Robert T. Hill and temporarily discontinued, was resumed last summer as a joint work of the Geological Survey of Texas and the U. S. Geological Survey. The upper and lower boundaries of the system were traced and mapped from the Colorado River northward to the Red River, and the principal

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[1] Vol. 1, pp. 99-162.

subdivisions also were outlined between the Brazos and Red Rivers. The larger share of the expense of the recent work was borne by the State Survey, and it is arranged that the most comprehensive publication of the scientific results shall appear in the forthcoming first annual report of the State Geologist.

Work in Connecticut.—In 1885 Prof. W. M. Davis made a field study of the trap ridges of Connecticut, reaching valuable conclusions as to the origin of the traps, and broaching a novel hypothesis as to their orogenic structure. This hypothesis has so important a bearing on general theories of mountain structure, that it was desired to give it such test as could be derived from a detailed survey of the region in which the trap ridges are best displayed, but the necessary topographic maps were not in existence. Last year the topographic work of the Survey covered a portion of the district, and preliminary copies of two sheets became available a few weeks ago. Upon these Prof. Davis began the mapping of formations of the Newark system and the included masses of trap. He is assisted by Messrs. E. O. Hovey, S. W. Loper, J. A. Merrill, and H. L. Rich.

Stratigraphic work in Missouri.—As part of a general plan of coöperation between the Geological Survey of Missouri and the U. S. Geological Survey, it was arranged that the stratigraphic column be carefully measured at a series of localities in Missouri, that full collections be made of the fossils contained in the several measured beds, and that fossils thus gathered be examined and reported on by the paleontologists of the national Survey. For the execution of this field work Mr. Gilbert van Ingen was selected, and he began operations early last month, his general plan of work being determined by the State geologist, Mr. Arthur Winslow. His work has been carried on in Pettis, Saline, and La Fayette Counties, and has yielded a large collection of fossils from various formations of the Carboniferous, together with the stratigraphic data necessary to give geologic value to their determination and discussion. He is still in the field.

Division of Geologic Correlation.—By reason of its peculiar function and peculiar organization, this division is not coördinate with any other in the Survey. Its function is the production of a series of essays on the classification of the rocks of the various geologic periods. It is proposed in these essays to discuss the principles of geologic correlation, or the general laws in accordance with which the chronologic relations of formations in different geologic provinces are and should be determined. The existing knowledge available for the chronologic classification of American formations and their assignment to the several recognized geologic periods will be summarized and digested. Through the discussion of principles it is hoped that such a general understanding will be reached that there will be practical unity of plan in all future American work of correlation. Through the summation of present knowledge it is believed that the most advantageous lines for future research will be indicated.

The members of the division are also for the most part members of other divisions of the Survey. Some of them belong to the Geologic Branch, but a greater number to the Paleontologic Branch. So far as possible each essay was assigned to the investigator whose previous studies best qualified him for its preparation, and this plan accomplishes the further object that the special training developed in the preparation of each essay and the erudition resulting from the necessary literary research will be acquired by the persons to whom they will be most useful in the conduct of future investigations.

An important part of the preliminary work of the essayists consists in the examination and analysis of the literature of the American formations belonging to the several periods. Another part consists in the examination in the field of those localities and geologic sections on whose phenomena the most important correlations have been based. These, with the writing of the memoirs, constitute the special duties of the essayists in connection with this division, but such work is to a great extent interwoven and inseparably connected with the current work of the various geologic and paleontologic divisions to which the essayists belong.

Prof. Van Hise, of the Lake Superior Division, is engaged in the preparation of an essay on the Archean and Algonkian. On account of the wide diversity of opinion as to the classification and nomenclature of these rocks, it seems important that he become personally acquainted with the rocks and their relations in a number of those regions where they have been studied and described by others. During the year he has visited areas of crystalline and metamorphic rocks in the Black Hills of Dakota, the Laramie Hills and Medicine Bow Mountains of Wyoming, the Front Range and San Juan Mountains of Colorado, the Uinta Mountains of Utah, and the Unaka Mountains of North Carolina. He is now about to visit crystalline areas in New Jersey, Massachusetts, and the Adirondack Mountains of New York. He has also given much time to a review of the literature, and the historical chapters of his essay have been written.

To Mr. Walcott, of the Paleozoic Division of Invertebrate Paleontology, were assigned the essays on the Cambrian and the Silurian. Most of his time during the year has been given to literary researches and the preparation of his essay on the Cambrian. He has also reviewed the literature of the Lower Silurian and has made two field excursions. In one of his excursions he visited, in company with geologists of the Canadian survey, a number of localities rendered classic by their relation to certain controversies as to the nomenclature of the Lower Silurian; in the other he visited, with the geologists of the Appalachian Division, a portion of eastern Tennessee where the sequence of the Cambrian rocks is well displayed.

Prof. H. S. Williams, who has undertaken the preparation of essays on the Devonian and Carboniferous, has been occupied almost entirely with an analytic study of the literature and with the preparation of the manuscript of his essays. He has given special attention to the gradual evolution of the modern principles of correlation as illustrated by the history of opinion regarding the upper Paleozoic rocks.

The discussion of the Jura-Trias formations was assigned to Mr. Russell, and he devoted much time to it during previous years. It seemed best, however, that he be diverted, at least temporarily, in order to carry on the Alaskan exploration for which the invitation of the U. S. Coast Survey afforded an exceptional opportunity. After his return to Washington it was decided to narrow the scope of his essay so as to cover the Newark system only, and his essay upon that is nearly completed. He has also in advanced preparation an index to the literature of the American Jura-Trias.

Dr. C. A. White, of the Mesozoic Division of Invertebrate Paleontology, who is charged with the discussion of the formations of the Cretaceous, has occupied much time during the year with the preparation of the manuscript of his essay. It is well advanced towards completion.

Mr. W. B. Clark, engaged in the preparation of an essay on the Eocene, devoted the early months of the fiscal year to field work for the purpose of familiarizing himself with the western lacustrine formations of that age. He visited a series of typical localities in Colorado, Utah, Wyoming, and Montana, and he also supplemented previous information by short excursions into Virginia and Maryland. The remainder of his time has been occupied with the preparation of the manuscript of his essay.

The essay on the Neocene has been undertaken by Dr. Dall, of the Cenozoic Division of Invertebrate Paleontology. During the year he has prepared a summary of the literature on the subject, and he has otherwise been occupied upon an elaborate comparative study of the Neocene faunas.

Dr. Chamberlin, of the Division of Glacial Geology, has accepted an invitation to prepare the Pleistocene essay of the series, and has done some preliminary work, but his time has been so absorbed by other duties that he has been unable as yet to begin the preparation of the essay.

To Mr. Ward, of the Division of Paleobotany, was assigned the preparation of an essay on correlation by means of fossil plants. As the general work of his division includes an elaborate plan for the systematic treatment of all paleobotanic data for the correlation of

American formations, and as several years are still required for this work, it will not be practicable for him to present immediately an essay coordinate in scope with those upon the formations of the various periods. It has therefore been arranged that he discuss the principles of correlation by means of fossil plants, in connection with a presentation of the data bearing on the age of the American Jura-Trias formations, and to the development of this narrower theme he has given much time during the year.

Certain of the data gathered by the various essayists are to be otherwise assembled and treated in essays to be prepared by Mr. McGee and myself, but no work upon these has been done during the year.

Herewith are submitted also the administrative reports of the several chiefs of the geologic divisions.

Very respectfully, your obedient servant,

G. K. GILBERT,
Chief Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF PROF. N. S. SHALER.

ATLANTIC COAST DIVISION,
Cambridge, Mass., June 30, 1890.

SIR: During the last year but two persons besides myself were permanently employed in the work of my division, Mr. J. B. Woodworth and Mr. C. W. Coman. In addition to these, the following named persons were temporarily employed during the field season: Messrs. Collier Cobb, R. S. Tarr, Aug. F. Foerste, C. P. Sinnot, Henry I. Richmond, W. H. Snyder, and Prof. Geo. H. Barton.

The field season of 1889 was mainly employed in work upon the surface geology of Massachusetts. The object of this task was to indicate on the fifty-six sheets of the Massachusetts atlas the distribution of the detrital materials which were brought into their present position during or since the last glacial period. The aim was not only to ascertain the matters of purely scientific importance connected with this distribution but also to determine the effect of the character and position of these deposits on the nature of the soil, the extent and distribution of the fresh water swamps and marine marshes, the supply of water available for municipal use, and other matters of an economic nature. This work was a continuation of that which was begun in the preceding fiscal year. The result of the labor has been that all save one and one-half sheets have been completed, and only demand a limited amount of revision to be ready for engraving. Besides the work on the sheets of the Massachusetts map, the Providence and Burrillville sheets in Rhode

Island have been completed and work on the Kent sheet is well advanced.

In addition to the principal tasks of my division as above described, a considerable amount of work has been done on certain subsidiary problems. The study of the under geology of the Narragansett coal field in Rhode Island and Massachusetts has been carried forward by Mr. A. F. Foerste, assisted by Mr. Henry I. Richmond. It is expected that the field work on this district will be completed during the coming fiscal year.

The heavy storms during the autumn of 1888 having exposed the section at Gay Head on Martha's Vineyard in an advantageous manner, a resurvey and careful delineation of this portion of the shore was made, principally by Mr. J. B. Woodworth, with the result that the interpretation of the deposits, as regards both their geological position and their dynamic accidents, was made much clearer than before.

In the geological survey of Massachusetts, made by Edward Hitchcock, the existence of beds in Marshfield presumably of the same age as certain deposits on Martha's Vineyard was indicated. It being important to determine the age and position of these deposits, Mr. C. P. Sinnot was detailed to examine them by means of artificial excavations. The considerable results of this inquiry will be incorporated in a future report.

In August, 1889, I made a foot journey from the mouth of the Genesee to the sources of that stream in order to secure a basis for comparison between the drift deposits of that region and those in Massachusetts which are to be the subject of a report.

In June, 1890, I made a journey to northern Georgia and Alabama, in order to secure through the study of the residual deposits of that region the basis for comparison in the interpretation of the iron ore accumulations of western Massachusetts, and also as to the topographic effects of glacial action in that district.

Mr. C. W. Coman has been employed during the winter season in modeling a portion of the drift in the town of Falmouth, Massachusetts, where the conditions of a distinct frontal moraine are well exhibited, and also in conducting a correspondence with the light-house and rescue-station keepers of the Atlantic and Pacific coasts, with a design to procure information concerning the drifting of volcanic pumice and fragments of asphalt to our shores. Incidentally, also, effort has been made to obtain from these officers such facts as they may have observed concerning the recent changes of the coast line. Through this correspondence an interesting body of information has been procured.

The following reports concerning the work of my division have been, by permission of the Director, published during this fiscal year in various scientific journals:

On the occurrence of fossils of Cretaceous age on the island of Martha's Vineyard, Massachusetts, with two plates: Bulletin of the Museum of Comparative Zoology, Vol. 16, No. 5, June, 1889, pp. 89-97.

On the soils of Massachusetts: Report of Massachusetts State Board of Agriculture, February 6, 1890.

On the Tertiary and Cretaceous deposits of eastern Massachusetts: Bulletin of the Geol. Soc. Am., April, 1890, vol. 1, pp. 443-452, pl. 9.

On the topography of Florida: Bull. Mus. Comp. Zool., March, 1890, vol. 16, No. 7, with map.

Notes on glacial climate: Proc. Boston Soc. Nat. Hist., January, 1890.

In addition to these a report on the Geology of Mount Desert, Maine, has been published in the Eighth Annual Report of the Director.

I have the honor to remain, very respectfully, your obedient servant,

N. S. SHALER,
Geologist in charge of Division.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF PROF. R. PUMPELLY.

ARCHEAN DIVISION,
Dublin, N. H., June 30, 1890.

SIR: I have the honor to report as follows upon the operations of the Archean Division during the fiscal year ending June 30, 1890.

The work was confined chiefly to Massachusetts and Vermont.

In Massachusetts, the geology of Berkshire County north of latitude 42° 30′ having been finished the year before, the geology of the western half of the county south of that line was studied by Mr. Dale as far as latitude 42° 15′, while between this line and the Connecticut boundary it was partially studied by Mr. Hobbs.

The geology of Worcester County was practically finished by Prof. Emerson and his assistants, Messrs. J. H. Perry and Charles S. Merrick.

In Vermont work was continued in the field study for mapping a broad belt across the Green Mountains. This was to supplement the work done previously on Hoosac Mountain in Massachusetts toward correlating the metamorphic rocks of New England east of the mountains with the fossiliferous rocks lying to the west.

For this region the topographic survey, essential in the absence of suitable maps, was continued by Mr. Smyth and finished as far as the Plymouth Valley. The geological work was carried on by Mr. C. L. Whittle, Dr. Wolff having been detailed to study the Crazy Mountains in Montana under another division.

In April I made a reconnaissance in the Unaka Mountains of North Carolina with Messrs. Willis and Van Hise.

During the winter the various members of the division were employed in digesting and mapping the results of the field season.

Of the geological map there were colored by Prof. Emerson the following atlas sheets in Massachusetts:

Completely: Chesterfield, Northampton, Belchertown, Barre, Worcester, and, except the narrow strip beyond the State line: Greenfield, Warwick, Granville, Springfield, Palmer.

Nearly colored: Hawley, Winchendon, Fitchburg, Webster, Marlboro.

In western Massachusetts the following sheets were colored:

Greylock, east half by Dr. Wolff, west half by Mr. Dale.

Berlin (Massachusetts portion), by Mr. Dale.

Pittsfield (Massachusetts portion), by Mr. Dale.

Sheffield, northern part by Mr. Dale, and southern part by Mr. Hobbs.

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

RAPHAEL PUMPELLY,
Geologist in Charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. W J McGEE.

POTOMAC DIVISION,
Washington, D. C., June 30, 1890.

SIR: I have the honor to submit the following report of operations in the Potomac Division during the fiscal year 1889–'90.

The work in Northeastern Iowa.—As announced in a preceding report there has been prepared in this division a report on the Pleistocene history of Northeastern Iowa. A draft of the manuscript of this report was completed during the last fiscal year and considerable progress had been made before the close of the year in the preparation of illustrations. It was, however, found inexpedient to complete the illustrations as soon as was anticipated when that report was prepared. During the past year the entire manuscript has been revised, the greater part has been rewritten, and the illustrations have been completed. One of the illustrations is a reproduction from a model of the territory constructed by the Mindeleffs during the present year. The copy for text and illustrations of the report has been transmitted for publication as a memoir accompanying the annual report of the Director.

Personal work in and about the District of Columbia.—Accounts of geologic investigations in this District have been submitted in previous reports. During the year these investigations have been pushed forward as rapidly as other work mentioned herein permitted. Rock exposures made from time to time in the rapid extension of the streets, and during grading, etc., in the northwestern part of Washington and contiguous parts of the District, have been examined from time to time, and sketches and photographs have been made of the more interesting exposures. A part of the work of Mr. Darton upon the East Washington atlas sheet, which is described in greater detail below, has been reviewed; and investigations into the deportment of the Potomac River mentioned a year ago have been continued. Moreover the exposures made for archeological purposes by Mr. W. H. Holmes, of the Bureau of Ethnology, have been critically examined in all stages of the work with the object of bringing together all the geologic evidences of the antiquity of man in the Potomac Valley.

Personal work in the southern Coastal Plain.—The month of November last was spent in Mississippi, Alabama, Georgia, and the Carolinas, in reviewing the operations of Mr. L. C. Johnson in the two States first mentioned and of Prof. Joseph A. Holmes in the Carolinas, and in extending into Georgia the studies already inaugurated by these gentlemen. The most interesting localities hitherto examined by Mr. Johnson were visited under his guidance, and a number of important localities in the Carolinas were examined in company with Prof. Holmes. The results of the trip were eminently satisfactory and led to some modification in plans of work in the southern Atlantic Slope and eastern Gulf States.

Dr. George H. Williams's work.—During the year Dr. Williams continued his researches into the petrography and geologic structure of the Piedmont crystallines, and his operations during the closing months of the year have been pushed into Virginia. Laboratory studies were constantly carried on in connection with his work. Dr. Williams's formal report is as follows:

> During the fiscal year 1889-'90 I have pursued my field and laboratory studies of the crystalline rocks of Maryland. Mapping of the areal distribution of these rocks, as well as the collecting of material for laboratory investigation, has been carried on in Harford, Carroll, Baltimore, Frederick, and Montgomery Counties, Maryland; in the District of Columbia, and in Fairfax County, Virginia.
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> Owing to the want of maps of all of this area, attention has been concentrated particularly upon such portions of it as have been topographically surveyed, viz: the region about Baltimore, the region about Washington, and the Frederick sheet. The work upon the Baltimore sheet has been completed and this map prepared for publication. In connection with this, a study has been made of the modifications in strike and structure which have been produced in the gneisses by the large intrusive mass of gabbro to the west of Baltimore. Incidentally to the work upon this sheet a detailed petrographical investigation has also been made of a rare type of eruptive rock composed wholly of pyroxene (pyroxenite), and the course of the alteration of this rock into masses of steatite (soapstone) has also been traced.
>
> Upon the Washington sheet considerable progress has been made during the last

spring. A large amount of material has been collected, which will be subjected to chemical and microscopical study during the next year.

On the Frederick sheet the Triassic boundary was partially traced; the region about Barnesville, especially Sugar-Loaf Mountain, was mapped and studied; the great trap dike (ironstone ridge) was traced entirely across the State, and many areas of limestone and sandstone were outlined. Incidentally to this work and to other mapping to the east of this sheet a study was made of the Sykesville granite and its inclusions.

Work on these and other portions of the Maryland crystalline areas has brought to light much material of mineralogical and petrographical interest which is now under investigation.

Mr. L. C. Johnson's researches in the South.—During the entire year Mr. Johnson has been extending his studies of the stratigraphy and economic resources of the State of Mississippi. During the months from July to October inclusive his field was the little known region of southeastern Mississippi, and the formations previously discriminated in western Mississippi and western Louisiana were traced out in easterly extension, their areal distribution approximately ascertained, and their stratigraphic equivalents in southern Alabama determined. The month of November was spent by Mr. Johnson with me in reviewing the observations of the preceding months and of earlier years in various parts of Mississippi and Alabama. At the close of this review Mr. Johnson resumed his line of travel in southeastern Mississippi, and proceeded by wagon across southern Alabama and thence to the phosphate region of Florida. Some months were spent in examination of the phosphate deposits. It was soon ascertained that two or three distinctive deposits occur; and with further work on the part of Mr. Johnson, and by Mr. Darton, who visited Florida for the purpose, three genetic classes of phosphate deposits were discriminated. The distribution of each was roughly determined and other facts of interest and economic importance were brought to light. The work in Florida was continued until early June, when Mr. Johnson repaired to Tuscaloosa, Ala. Mr. Darton about the same time returned to Washington. The remaining portion the year has been occupied by Mr. Johnson in correlating notes, summarizing observations, and preparing reports. In this work he enjoys the constant cooperation and assistance of Dr. E. A. Smith, State geologist of Alabama; and in consideration of this important aid he places at Dr. Smith's disposal for the use of the State Geological Survey of Alabama such general results of his observations as may be valuable to the State.

Mr. N. H. Darton's work.—During the entire fiscal year, with the exception of a brief period in July, Mr. Darton has been at work in different parts of the Coastal Plain. Early in August Mr. Darton, accompanied by Mr. Frank Marshall Smith, proceeded by boat from Washington down the east shore of the Potomac River nearly to its mouth, and thence up the west shore of Chesapeake Bay, examining the different formations exposed along the river and bay and tracing these formations as far inland as practicable. On nearing the head of Chesapeake Bay observation was extended to the eastern shore as well as the western, with the object of correlating the formations found farther southward with those already discriminated about the head of the bay, and described in some detail in the Seventh Annual Report. Special journeys were then made through South Amboy and other points on the Raritan River in New Jersey, for the purpose of studying the late Neocene or early Pleistocene formations which have not yet been finally classified; to the Yellow Rocks on the Delaware River near Trenton, for the purpose of examining the most northerly deposit of the Potomac formation yet identified with certainty; to the neighborhood of Conshohocken, Pennsylvania, for the purpose of extending my own observations upon isolated accumulations of both members of the Potomac formation; and to several points on the lower Susquehanna, for the purpose of measuring cross-sections and declivity during normal stage and during freshets. In October Mr. Darton resumed work in the District of Columbia; and during this and subsequent months developed the stratigraphy and traced out the areal distribution of formations in the region covered by the East Washington atlas sheet; before the end of the year the ante-Pleistocene geology of the region was represented upon a map which is now ready for publication, if it be deemed expedient to publish in advance of solution of the problems connected with the Pleistocene Columbia formation. About the end of the month Mr. Frank Marshall Smith was by authority of the Director transferred to the branch of irrigation; Mr. Darton has been without assistance in his subsequent field work. The inclement weather of the winter was chiefly spent by Mr. Darton in the office in preparing final reports upon work executed by him while connected with the Appalachian Division, in preparing his annual bibliography of geology for the year 1889, and in correlating and digesting notes. During the early spring his field work was resumed and extended into the area covered by the West Washington atlas sheet; the areal distribution of the Potomac formation was approximately ascertained and depicted on the map. Toward the end of March he proceeded to Baltimore, for the purpose of working out the stratigraphy and areal distribution of the formations east of the fall-line, in order that the Baltimore sheet, largely colored by Dr. Williams, might be completed; and during April the post-Archean portion of the sheet was roughly colored. During April Mr. Darton reviewed his work of last year upon the lower Potomac and Chesapeake Bay from Alexandria to Yorktown, Virginia. About the middle of the month he repaired to Florida, and made a general reconnaissance as well as some detailed examinations of the phosphate deposits of that State. A brief report upon this subject was prepared upon his return in early May for the information of the office; but since the results are preliminary only, no publication has been made. The latter part of May and early June were occupied in reviewing and revising his work on the Baltimore atlas sheet, which has been submitted for publication; the latter part of June was occupied in reconnaissance of the eastern shore of Maryland.

Prof. Joseph A. Holmes's investigations.—With the beginning of the year Prof. Holmes resumed his studies of the stratigraphy of the central portion of North Carolina; but his local work was interrupted by illness in July and not recommenced until he had reexamined with me a number of interesting exposures, and also extended some of his investigations in new fields; and the entire month of December was spent in tracing the Columbia, Appomattox, and Potomac formations through the Carolinas and Georgia. His work was again interrupted in January, but was resumed in May and has since been pushed forward energetically.

Dr. R. H. Loughridge's work.—During May authority was received from the chief geologist to employ Dr. Loughridge in constructing a section through the deposits of the Coastal Plain from Columbia, South Carolina, to the mouth of the Santee River. The work was immediately commenced and has been pushed forward rapidly; after reconnaissance in the vicinity of Columbia, Dr. Loughridge proceeded to Georgetown, South Carolina, and carried his reconnaissance thence into the interior on both sides of the river, visiting all valuable exposures, obtaining data of high value.

Review of the work upon the Coastal Plain.—Summarizing the foregoing accounts of work upon the Coastal Plain by Prof. Holmes, Dr. Loughridge, Messrs. Johnson and Darton, as well as by myself, it may be stated in brief that during the fiscal year the following lines of work have been carried well forward or completed: (1) the ante-Pleistocene formations of the area covered by the East Washington sheet have been discriminated and mapped; (2) the ante-Pleistocene and post-Archean formations of the area covered by the Baltimore atlas sheet have been discriminated, correlated with the Washington formations and mapped; (3) extended reconnaissances have been made on the lower Potomac and Rappahannock Rivers and Chesapeake Bay in Virginia and Maryland, and definite formations have been discriminated and correlated with those of Washington and Baltimore; (4) the Columbia, Appomattox, and Potomac formations have been traced across North Carolina; (5) the phosphate deposits of Florida have been discriminated on genetic grounds, their distribution approximately determined, and the age of part of them ascertained; (6) the stratigraphy of Mississippi has been connected with that of southern Alabama and western Florida by tracing on the ground in all available exposures; (7) a preliminary section through the Coastal Plain deposits in South Carolina has been measured; and (8) the distribution of the Columbia and Appomattox formations has been traced over the Carolinas, Georgia, and Alabama to Mississippi in sufficient detail to warrant general graphic representation of two important episodes in the late Cenozoic history of the continent.

New York map.—During the greater part of the year the attention of Messrs. J. H. Klemroth and J. B. Torbert has been diverted from the base map of New York (mentioned in preceding reports) and concentrated upon the illustrations of the report on Northeastern Iowa. Accordingly the map is not yet quite completed. The civil boundaries are nearly all drawn; the roads, towns, villages, etc., are completed over four-fifths of the area (including the more densely populated portion) and the greater part of the latter is completed. Difficulty has arisen in procuring data for the representation of the railways. Such data are attainable only in the office of the State railway commissioner and the State engineer and surveyor in Albany; and in order to obtain the necessary information Mr. Klemroth proceeded to Albany about the middle of June. His work there is not yet completed.

I have the honor to be, with great respect, your obedient servant,

W. J. McGee,
Geologist in charge.

Mr. G. K. Gilbert,
Chief Geologist.

REPORT OF MR. BAILEY WILLIS.

Appalachian Division,
Washington, D. C., June 30, 1890.

Sir: I have the honor to submit the following report of work in the Appalachian Division for the year ending June 30, 1890.

The object of the work of this division is to prepare geologic atlas sheets for publication. To this end the field work has been devoted to areal geology in regions of known stratigraphy, and attention has been given in a subordinate degree to unsolved stratigraphic problems. The method of work and supervision is as follows:

On the opening of a field season each assistant geologist in charge of a party has certain atlas sheets assigned him for study; the assignment is controlled by the character of the geology, determined by previous reconnaissance, and the knowledge possessed by the assistant. Each field party consists of one assistant geologist, usually one scientific field assistant, and two laborers. Shelter, subsistence and transportation are furnished. Arrived at the field of work, the geologist and assistant survey independently, traversing roads, streams and ridges in such manner as to secure the geologic data in the shortest possible time. The field notes are taken in cartographic form.

These are reduced to the topographic base, previously prepared by the Survey, and the record of areal geology is constantly kept up to the work performed.

During the field season each chief of party submits monthly a report, describing the nature of the work and the condition of the party; this is accompanied by a map, showing the areal geology of the region covered and the routes of observation.

At the close of the season, the parties are disbanded, and the assistants take up the work of final plotting and adjustment of the detailed notes. The result is a complete map of the area covered, showing on the authority of the assistant the subdivision and distribution of the rocks of geologic periods. In the following field season, this map is examined by myself, revised, if necessary, by the assistant who originally surveyed it, and it is then ready for transmission for publication. It thus appears that ordinarily eighteen months to two years elapse between the inception and completion of work on a given atlas sheet; and the responsibility for the results is fixed upon the chief of party and the chief of division.

In my last annual report it was stated that the geology of 13,000 square miles had been surveyed and would be revised in preparation for publication. The conclusions of the geologic conference, called by the Director, and continued study of areal maps led to the opinion that a greater amount of detail was practicable and desirable in the delineation of formations. As the standard was thus raised, the previously completed maps required to be extended in detail. As a result the present condition of work in this division is as follows:

- Submitted for publication:
  - Staunton, Virginia, sheet by N. H. Darton.
  - Ringgold, Georgia, sheet by C. W. Hayes.
  - Chattanooga, Tennessee sheet, by C. W. Hayes.
- Ready for publication, (with the exception of a metamorphosed area in the southeast corner):
  - Greenville, Tennessee, sheet by Arthur Keith.
- Surveyed; to be examined by the chief of division:
  - Winchester, Virginia, sheet by H. R. Geiger.
  - Woodstock, Virginia, sheet by H. R. Geiger.
  - Morristown, Tennessee, sheet by Arthur Keith.
  - Knoxville, Tennessee, sheet by Arthur Keith.
  - Loudon, Tennessee, sheet by Arthur Keith.
  - Maynardville, Tennessee, sheet by Arthur Keith.
  - Kingston, Tennessee, sheet by C. W. Hayes.
  - Cleveland, Tennessee, sheet by C. W. Hayes.
  - Stevenson, Alabama, sheet by C. W. Hayes.

The character of the geologic problem varies greatly in these different sheets. Those which approach the North Carolina region, as the Greenville, Knoxville, and Cleveland sheets do, include areas of the great mass of sandy formations called by Safford the Chilhowee. The relations of these rocks have been the subject of controversy and are very difficult to determine. Messrs. Keith and Hayes have not been satisfied to present as final their conclusions on the Knoxville and Cleveland sheets, and they are now engaged in a review of the evidence in the field.

On the 1st of July, 1889, the force of the division consisted of Messrs. H. R. Geiger, Hayes, Kieth, and myself. Mr. N. H. Darton, who had been transferred to the Division of the Coastal Plain, finished his work on the Staunton sheet in July. Mr. Geiger, assisted by his son, Mr. F. W. Geiger, resurveyed in detail the geology of the Winchester and Woodstock sheets. On completion of the manuscript maps of his work, he resigned, December 31, 1889.

Mr. Keith, assisted by Mr. R. E. Edes, took the field July 4, and remained in camp one hundred and forty-six days; in that period he surveyed the Knoxville, Loudon, and Maynardville sheets, about 3,000 square miles. In December he made a ten days' trip for reconnaissance purposes through southwestern North Carolina, and then returned to Washington.

Mr. Hayes took the field July 4 with Mr. M. R. Campbell as assistant, and camped for ninety-six days. In this period he surveyed the Kingston and Cleveland sheets with a corner of the Murphy sheet; the total area covered was 2,000 square miles. On October 8, Mr. Hayes disbanded camp and joined me at Hot Springs, North Carolina. Mr. Campbell went to Mr. Keith's party and Mr. Edes soon after returned home. The early part of November was passed by Mr. Hayes in revising his work of the previous season in limited areas of the Chattanooga and Ringgold sheets, and he then reported for office work.

My own work has been distributed as follows: From July to November I was in the field studying the Blue Ridge at Harper's Ferry and Luray, reviewing the geology of the Staunton sheet, as platted by Mr. Darton, and that of the Ringgold and Chattanooga sheets, by Mr. Hayes, and surveying with Mr. Hayes in the Big Butt range north of Hot Springs, North Carolina.

The field season over, I returned to Washington, worked on the freshly collected geologic data, and at the request of the Chief Geographer, Mr. Gannett, took part in discussions of the evolution of topographic forms.

In March experiments in the reproduction of geologic structures by compression of stratified masses under load were renewed and carried on to May 31. A report on the results, containing a statement of a hypothesis of competent structures and explanations of overthrust faults, has been submitted.

The preparation for publication of the results of survey of the French Broad belt has occupied my time when not otherwise engaged.

Mr. Hayes was occupied from February 22 to April 9 in writing on the geology of northwestern Georgia and northeastern Alabama.

With your consent, the article is to appear in the forthcoming report of the Alabama State Survey.

Dr. I. C. White has transmitted a paper, entitled "Comparative Stratigraphy of the Bituminous Coal-rocks of the Northern Appalachian Field," which is to be published as a bulletin of the Survey; it is a careful study of the relations of different members of the coal measures, and contains data of great value to those engaged in developing the coal fields. It is now in the hands of the printer.

Mr. Keith has given attention to the conditions which affect the efficiency of a geologic field party, and he has submitted memoranda on this point, on the Archean outline in North Carolina and on theories of the cause of Appalachian uplift. Mr. Hayes and Mr. Keith have both endeavored earnestly to do work of a high quality with economy of time and money. Their efforts and the results thereof are worthy of hearty commendation.

The division is indebted to Mr. Walcott for his assistance in studying the Chilhowee problem on the French Broad and in Chilhowee Mountain last October; and it is under obligations to Prof. Pumpelly and Prof. Van Hise for valuable suggestions on the evidence of origin and relative age of metamorphic gneisses and granites of the North Carolina mountains. These gentlemen spent two weeks of April in that region with me, and very greatly aided me toward an understanding of the most difficult question within my field.

The field work for 1890 was begun by Mr. Hayes on May 1 and by Mr. Keith on June 1. Mr. Hayes has reviewed the geology of Starr's and Bean's Mountains in the Cleveland sheet, and is working southward through the Dalton and Rome sheets toward Alabama. He is assisted by Mr. Campbell. Mr. Keith has returned to the study of Chilhowee Mountain; in July he will come north to survey the Harper's Ferry and Luray sheets in Virginia. He will work this year without assistance.

I shall take the field July 1 in Tennessee, to examine the original work of last year.

Respectfully submitted.

BAILEY WILLIS,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF PRESIDENT T. C. CHAMBERLIN.

GLACIAL DIVISION,
Madison, Wis., June 30, 1890.

SIR: I have the honor to submit the following report of field and office work of the Glacial Division during the fiscal year ending June 30, 1890:

The opening of the fiscal year found Mr. Frank Leverett engaged in the study of the moraines that cross the Wabash River south of its great bend in western Indiana. This work was completed on July 3, and on the following day was begun the tracing of a morainic belt in Illinois, stretching southwesterly and marking, it is affirmed, the southern boundary of the good corn land of that State. This was traced from Edward County west to Montgomery County. A belt was then explored northwesterly on the watershed of the Sangamon and the Illinois rivers to Beardstown, on the latter stream, and thence northwesterly to the Mississippi at Burlington, Iowa, observations relating chiefly to the topographic aspect of the drift and the loess-like silts that mantle the region.

From July 15 to the 20th Mr. Leverett was engaged in the completion of a map showing the distribution and correlation of the moraines of the regions about the head of Lake Michigan and in the preparation of manuscript relating thereto. On July 22 he returned to western Indiana, and spent about three weeks in the study of the complex system of moraines, bowlder belts, and sand ridges that occur in the district between the Kankakee and Wabash rivers, and which, from the obscurity of the phenomena and the extent to which the drift is covered with eolian sand, had not previously afforded satisfactory correlation of the drifts. Some advance was made, but a satisfactory solution yet remains to be found.

About the 10th of August he began work in eastern Indiana connecting with the territory examined at the close of the field season of 1888, and continued until the latter part of November, attention being devoted to the tracing out of the moraines, bowlder belts, and silt-covered tracts of southeastern Indiana and southwestern Ohio. The examination was extended eastward to the Scioto River, and included the district adjoining on the south that examined by myself in previous years. Field work was closed at Chillicothe, Ohio, November 24, and the winter months were spent at Boston, Massachusetts, in the preparation of manuscript on the work of the previous field season, the greater part of which has already been submitted to me.

Field work was resumed on May 9, in the Scioto Valley, and has continued to the present date. Attention has been given to the tracing out of the moraines of the Scioto glacial lobe and to the lines of glacial drainage associated with it. Attention has also been given to the margin of attenuated drift outside of the outermost well defined moraine, and its relationship to the latter has been a subject of study.

Mr. Warren Upham was engaged from July 10 to October 27 in field work in North Dakota and southern Minnesota, tracing the course of successive marginal moraines and correlating them with moraines previously traced by him and others in Minnesota and adjoining regions, and in determining the relationship of these to the glacial Lake Agassiz which formerly occupied the basin of the Red River of the North. In the course of this work Mr. Upham traversed the portion of North Dakota which extends from the lacustrine region mentioned westward to the James and Souris rivers, mapped its moraines, and made descriptive notes upon its topographic features and its various drift formations. He also traversed portions of the Leaf Hills in Minnesota and of the country lying north and east of this to Lake Itasca, Leech Lake, and Brainard, thereby considerably extending his former studies of this district.

During the remainder of the year Mr. Upham was engaged in writing, in draughting his maps of Lake Agassiz, and in compiling the heights determined by railroad surveys in the Red River Valley and a large and contiguous region, this latter work being important, as these elevations were the basis of his extensive leveling of the shore lines of the extinct lake, and the accuracy of these depends upon the trustworthiness of the railway elevations. The large amount of carefully determined data thus prepared has been submitted as a bulletin of the Survey, entitled "Altitudes between Lake Superior and the Rocky Mountains."

Prof. Rollin D. Salisbury spent essentially all of July and August in a study of the Quaternary and associated deposits of the middle Mississippi and the lower Ohio valleys, in southern Illinois, southeastern Missouri, eastern Arkansas, and western Kentucky and Tennessee. His endeavor was to trace the silts and other valley deposits from the margin of the glacial drift southward and to determine their relationship to the deposits that do not connect themselves with the drift. In pursuance of this he examined carefully the border of the glacial drift and the valley silts along the Mississippi in the southern portion of Illinois and in southeastern Missouri. He also spent some time upon Crowley's Ridge in eastern Arkansas. In western Tennessee and Kentucky he examined the "orange sands and gravels" and the loess deposits along the Mississippi and the Tennessee and on the uplands and the divide between the two.

During the last few days of August and the first of September he aided me in a study of the valley deposits of the Delaware and Susquehanna rivers at and below the border of the glacial drift.

During the winter he made some microscopic studies of silts collected during the preceding season. The rest of his time, so far as employed by the Survey, was given to the study of material previously collected.

Mr. I. M. Buell was engaged during the first month of the fiscal year in reducing the material of previous field seasons to the form of a preliminary report and in the preparation of maps for field use. From August 1 to September 15 he was engaged in field work in Jefferson, Dane, Rock, Green Lake, Marquette, and Columbia counties, Wisconsin, devoting his attention chiefly to the topographic contours and to the bowlder belts derived from knobs of quartzite, quartz porphyry, and granite protruding through horizontal Paleozoic strata. During the fall a small amount of additional work was given to the Waterloo bowlder district. During the winter Mr. Buell's time, so far as in the employ of the Survey, was devoted to the preparation of manuscript, and particularly to the preparation of topographic maps of the region of bowlder trains under investigation.

Profs. George H. Stone and J. E. Todd, so far as engaged upon the Survey, have been employed in completing the preparation of their manuscript reports upon field work previously done.

About the middle of July I visited the Yellowstone Park at the request of Mr. Arnold Hague, geologist in charge of that district, for the purpose of a joint study of the glacial formations of that region, and was occupied in this work until about the 10th of August. About the middle of August I joined Prof. Salisbury in his field in western Kentucky and Tennessee for the purpose of joint study and consultation. Afterwards I made a very brief study of some doubtful points in Indiana, in the field of Mr. Leverett, and later, as previously indicated, made an examination of the valley drift on the Delaware and Susquehanna rivers, adjacent to the glacial margin. The rest of my time, so far as in the employ of the Survey, has been devoted to administrative work and to counsel respecting geological questions that have arisen within the province of the Survey, the chief of which have been directly submitted by yourself.

Very respectfully submitted.

T. C. CHAMBERLIN,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF PROF. C. R. VAN HISE.

LAKE SUPERIOR DIVISION,
Madison, Wis., June 30, 1890.

SIR: I beg to submit the following report of the operations of the division of the Survey under my charge for the fiscal year ending to-day:

FIELD WORK.

The field work of the year has been in two general lines: atlas-sheet mapping of certain areas in the Lake Superior region, and a general study of the pre-Cambrian formations of the United States. This latter work was taken up at the request of the Director, with the aim of preparing an account of the present state of knowledge of the pre-Cambrian formations of North America.

Field work has been done by Dr. W. S. Bayley, Prof. C. W. Hall, Mr. George E. Luther, Prof. Arthur Lakes, Mr. F. P. King, and myself. My work has been almost wholly given to the general study mentioned, as has also that of Prof. Lakes. The parties in charge of Dr. Bayley and Mr. King have been engaged in areal work. In the early part of the season Prof. Hall was a member of my party, and later his place was taken by Mr. Luther.

Before beginning my general work, it was necessary for me to spend a few days in northeastern Minnesota and northern Michigan, in order to supervise and arrange for the areal work there being carried on. This occupied me from the 9th to the 18th of July, inclusive.

It was my desire during the field season to visit the localities in the West which would throw most light upon the relations of the pre-Cambrian formations and the value of the work already done. Guided by the literature extant, I selected the Black Hills, the Laramie Hills, Uinta Mountains, Wahsatch Mountains, Medicine Bow Mountains, San Juan Mountains, and the Front Range of Colorado.

In the Black Hills I had the assistance of Prof. Hall. We thoroughly traversed the pre-Cambrian core from east to west and north to south; followed a zigzag course which crossed and recrossed the boundary line between the two pre-Cambrian series as mapped by Newton, and encircled the granitic area in the southern part of the Hills. In the Laramie Hills, Medicine Bow, and Wahsatch Mountains, I had the assistance of Mr. Luther. In the Laramie Hills, the Medicine Bow Mountains and the Uintas, only a single section was made. In the Wahsatch Mountains the cañons of the Ogden and Weber Rivers, and those of Mill, Little and Big Cottonwood Creeks were all traversed. In Southwestern Colorado sections were made from south of Needleton to Silverton, and from Red Mountain to Ouray. In the main Colorado Range, I went from Mount Vernon to Idaho Springs, to Gray's Peak, and thence down Clear Creek Cañon. The above work occupied my time from July 24 to September 17.

In continuation of general work, March 29 to April 15 was spent in studying the southern Appalachians, in company with Prof. Pumpelly and Mr. Willis. We made sections from Atlanta to the Chattahoochee River in Georgia; along the French Broad from Hot Springs to Marshall, North Carolina; across the country from Hot Springs, North Carolina, to Fullens, Tennessee; and along the Doe River, from Johnson City, Tennessee, to Cranberry, North Carolina.

The final days of the year, from June 20 were spent in a general examination of the pre-Cambrian of Missouri.

Dr. Bayley left Waterville, Maine, July 2, with Mr. King as volunteer field assistant, for L'Anse, Michigan. The party as here organized consisted, besides these two, of Charles Oley (compassman) and two packers.

In previous years Dr. Bayley had covered the area between Lake Superior and the Duluth, South Shore and Atlantic Railroad west to about meridian 88° 30′. The season was spent upon portions of the atlas sheets between parallels 46° and 47° and meridians 88° 30′ and 89° 30′. The boundary lines between the Eastern Sandstone, Keweenaw series, copper-bearing, iron-bearing, and granitic series were carefully followed. The area covered during the season's work embraced T. 48 N., Rs. 36 and 37 W.; T. 47 N., Rs. 36, 37, 38, and a part of 39 W.; T. 46 N., Rs. 36, 37, 38, 39, 40, 41, and parts of 42 W.; T. 45 N., Rs. 36, 37, 38, 39, 40, 41, and parts of 42 W.; and T. 44 N., Rs. 36 and 37 W., all in Michigan—about 720 square miles. About 425 miles of section line were followed on foot by Dr. Bayley and compassman. Ledges were found to be somewhat rare in the country traversed, but fortunately so scattered over the entire area as to well illustrate the distribution of the rocks. On September 20 the party was disbanded. Areal work in this region in charge of Mr. Charles Oley was again begun May 14. Mr. F. P. King, volunteer field assistant to Dr. Bayley's party of the previous year, took charge of the party June 9, and work is continuing at the present time.

The only field work done by Prof. C. W. Hall, aside from that before mentioned in the Black Hills, was a small amount of work in Minnesota required in order to fill gaps in his mapping, already nearly completed, of the granites and gneisses of central and southern Minnesota.

During this month Prof. Arthur Lakes, of Golden, Colorado, has occupied about ten days in traversing Coal, Ralston, and South Bowlder Creeks, in the Front Range of Colorado, in order to give additional information as to the divisibility of the pre-Cambrian in this region.

OFFICE WORK.

Aside from the attention devoted to field work and routine duties, my whole time has been given to the preparation of an account of the present state of knowledge of the pre-Cambrian of North America, already mentioned. The work in this connection has been in two directions: a study of the material collected in my field work, as well as that of the Fortieth Parallel Survey, and a review of the literature of the subject. Incidental to the first part of this subject a paper upon "The pre-Cambrian Rocks of the Black Hills" has been prepared. In the study of the literature all of the official reports of Canada, the Eastern States, and the Governmental surveys of the West, also a large number of serials, have been examined. This work is yet incomplete, although far advanced. In all cases concise summaries have been made of everything bearing upon the structural relations, divisibility, correlation, and genesis of the rocks, which are either pre-Cambrian or are referred to the pre-Cambrian. Following this part, in cases where it seemed advisable, these results have been compared with those reached by other writers upon the same region and an estimate given of the value of the conclusions viewed by the light of present knowledge.

Dr. Bayley was engaged from September 25 until the 1st of December upon a final review of his bulletin on the Eruptive and Sedimentary Rocks of Pigeon Point, Minnesota. Aside from minor duties the remainder of the year, so far as it has been given to survey work, has been spent in a general study of the so-called gabbros of the Lake Superior region, with a view of preparing a bulletin which shall discuss the character of these rocks, the relations of their structures to the methods of their occurrence, and their age.

In my report of last year it was said that Prof. C. W. Hall was engaged in the preparation of two bulletins: one on "The Gneisses, Crystalline Schists, and Associated Rocks of the Minnesota River Valley," and the other on "The Granites and Associated Diabasic Rocks of Central Minnesota." A fire at Pillsbury Hall, in Minneapolis, in the early part of the year, destroyed a part of the manuscript and damaged many of the specimens. This has greatly delayed this work, but Prof. Hall announces that the first of these is nearly ready for submission.

The time of Mr. Luther has been given, aside from field work and the routine work of the office, chiefly to assisting me in my review of the literature of the pre-Cambrian of North America.

PUBLICATIONS.

In the Washington office, or in press, are the following papers from the division:

The Penokee Iron-bearing Series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise. Monograph No. XIX.

Abstract of above. Tenth Annual Report.

The Greenstone-Schist Areas of the Menominee and Marquette Regions of Michigan, with an Introduction by R. D. Irving, by George H. Williams. Bulletin No. 62.

The eruptive and sedimentary Rocks of Pigeon Point, Minnesota, and their contact phenomena, by W. S. Bayley. Bulletin.

During the year only two papers have appeared. These are: The pre-Cambrian Rocks of the Black Hills, by C. R. Van Hise (Bulletin of the Geological Society of America, vol. 1, pp. 203-244): The Origin of the Soda-Granite and Quartz-Keratophyre of Pigeon Point, by W. S. Bayley (Am. Jour. Sci., 3rd ser. vol. 39, pp. 273-280). In the report of the office work the papers in preparation have already been mentioned.

I am sir, very respectfully, yours,

C. R. VAN HISE,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF DR. W. P. JENNEY.

DIVISION OF ZINC,
Washington, D. C., June 30, 1890.

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

The Division of Zinc was organized September 1, 1889. From that date until taking the field the time was employed in a study of literature relating to the geology of the lead and zinc deposits of the Mississippi Valley and in organizing the work. Field work was commenced October 10, 1889, in the vicinity of the city of Joplin, in southwest Missouri, and continued until the latter part of April, 1890, at which date I returned to Washington. During May and June, 1890, I was employed in the study of the material collected in the progress of the work.

Arrangements having been made with the Missouri Geological Survey for cooperative work, Mr. James D. Robertson, assistant geologist, was detailed to assist me in the field, his salary and expenses being paid by the State. He was thus occupied from October until the latter part of June.

The work under my charge may be divided into:

First. A determination of the geological formations carrying ore, involving the determination of the general geology of the district, the identification of the different strata or "ore horizons" favorable to the occurrence of workable bodies of ore, together with the vertical range of the ore deposits in the geological column.

Second. An investigation of the original source from which the ore has been derived.

Third. A study of the deposition of the ore in the strata, including the paths or channels which the ore-depositing solutions have followed, the manner in which the ore has been deposited, and the chemical reactions that have taken place.

Fourth. The laws governing the occurrence of the ore, especially with reference to the economic development of ore bodies already known, and as a guide in prospecting for ore in formations recognized as favorable.

Fifth. An investigation of the ores of zinc, the associated ores of lead, and the minerals occurring with the ore, with the varied decompositions, alterations, and redepositions of these minerals.

Sixth. An investigation of the rocks associated with the ore, the alteration of rocks by solutions accompanying the deposition of the ore, the silicification and dolomitization of limestones and the removal of limestone strata by surface waters.

Seventh. The determination and delineation in colors on the map, of the area covered by the different geological formations carrying ore.

During the last year no work was done in mapping the areas covered by the different formations, as it seemed best to postpone this work until the completion of the topographical survey of the mining region.

In the progress of the field work the rich and productive district surrounding the city of Joplin, in southwest Missouri, received the most attention; excursions were made into the zinc district of Marion and Boone counties, in northern Arkansas, and the lead mines at Bonne Terre. Doe Run and Mine La Motte, in southeastern Missouri, were visited.

Mr. Robertson gave his attention specially to the collection of data from the various artesian wells sunk in the southern part of Missouri and southeastern Kansas, in order to obtain exact information of the thickness and order of superposition of the different geological formations underlying the lead and zinc area. He also aided in collecting minerals, ores and fossils.

I have received assistance in the progress of my work from Prof. Edward M. Shepard, occupying the chair of natural science at Drury College, Springfield, Missouri; also from R. A. Blair, of Sedalia, Missouri, member of the State Geological Board. I am indebted for laboratory work to Prof. W. B. Potter, of Washington University, St. Louis, and for the determination of fossils to Dr. Gustav Hambach, of the same university.

All of which is respectfully submitted.

WALTER P. JENNEY,
Geologist in Charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF DR. A. C. PEALE.

MONTANA DIVISION,
Washington, D. C., June 30, 1890.

SIR: I have the honor to submit the following report of the operations on the Montana Division for the year ending June 30, 1890:

FIELD WORK.

The field work of the year was confined mainly to the area represented on the southwest quarter of the Three Forks topographic sheet. With the exception of about 50 square miles this area was geologically mapped during the season.

Camp was established at Bozeman, July 5, where I was joined by Mr. George P. Merrill, curator of geology in the National Museum. Actual field work was begun July 9, when Mr. Merrill accompanied me on a trip to the northwestern portion of the area included on the map. This trip involved about 200 miles of travel and occupied about ten days. The last ten days of July and the first week in August were spent in the examination of the region north of Virginia City and west of the Madison River. The remainder of August was spent on the eastern side of the Madison, mainly in the Madison range and adjacent parts of the Madison valley. The month of September was devoted to the region lying south of Virginia City and on the west side of the Madison valley, the field party being disbanded at Bozeman September 20. During the season, from July 20 to September 20, an area of about 1,000 square miles was examined geologically.

OFFICE WORK.

The office work of the year has been devoted mainly to the geological coloring of that portion of the map examined during the season, to the correlation and study of various sections made during the last two or three seasons, and to routine office work.

December 5, 1889, I received an appointment, without compensation, as special agent of the Eleventh Census, in charge of the collection of statistics of mineral waters of the United States, and work in this connection has necessarily occupied a considerable portion of my time.

The division is under obligations to the petrographic laboratory for the preparation of 509 thin sections from specimens of igneous rocks, and to Mr. George P. Merrill, of the National Museum, for microscopical identifications of specimens and for efficient help in the field.

Very respectfully,

A. C. PEALE,
Geologist in Charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. ARNOLD HAGUE.

YELLOWSTONE PARK DIVISION,
Washington, D. C., June 30, 1890.

SIR: I have the honor to submit herewith the following report of operations conducted under my supervision during the year ending June 30, 1890.

Field work in this division during the year has been confined to the Yellowstone Park and the country immediately adjacent to it in which the geological conditions are much the same as those found within the national reservation. It has always been my plan to make the region included within this survey depend more upon the problems presented than upon the legal boundaries of the park. It may be said, however, that the proposed new boundaries embrace a well defined physical and geological area.

Acting under instructions, Mr. J. P. Iddings, accompanied by Mr. W. H. Weed, left Washington late in June, 1889, and proceeded to Bozeman, Montana, to make the necessary preparations for the season's field work in the park. After the equipment of the party, Mr. Iddings marched to the Mammoth Hot Springs and established camp in Swan Lake valley to await my arrival.

On July 2 I met Mr. J. E. Wolff, in New York, and traveled with him to Bozeman, Montana, where he outfitted for work in the central elevated portion of the Crazy Mountains. I joined Mr. Iddings in Swan Lake valley, and after a few days spent in geological work in the region, proceeded to Yellowstone Lake, where a permanent camp was established on the lake shore near the outlet, a locality easy of access from all points in the park. The field corps for the summer consisted of Mr. J. P. Iddings and Mr. W. H. Weed, assistant geologists permanently attached to the party; Mr. Louis V. Pirsson, volunteer assistant, and Mr. E. H. Shuster. In connection with the investigation of the Crazy Mountains Mr. Wolff was accompanied by Mr. J. H. Ropes, of Massachusetts, as volunteer assistant, who rendered valuable aid in field work. After the completion of Mr. Wolff's work, Mr. Ropes accompanied my parties in the park until the close of the season.

From the permanent camp Mr. Iddings, with a small party, left for the east side of the lake to work in the foothills of the Absaroka Range lying between the lake and the one hundred and tenth meridian, the eastern boundary of the park.

Returning to the Mammoth Hot Springs on July 19, I met Prof. T. C. Chamberlin, who, at my request, came from Wisconsin for the purpose of discussing with me several matters connected with the glaciation of the park and the post-glacial erosion of the plateau. I had been studying for a number of years the effect of ice action on the park plateau and was desirous to have the opinion of one who is considered by all so high an authority on glacial matters. I felt that Prof. Chamberlin's observations, not only in the northwest, but along the foothills of the Rocky Mountains in Montana between the park and the Canadian boundary, would be of the greatest assistance to me. We went up the valley of the Yellowstone to Junction valley, where the Lamar River joins the main Yellowstone, thence over the summit of Mount Washburne and along the Grand Cañon of the Yellowstone, following the river to the outlet of Yellowstone Lake. After remaining here a few days we proceeded along the west shore of the lake, crossing the Continental Divide between Yellowstone and Shoshone lakes, and out into the valley of Snake River by the way of Lewis Lake. Returning we followed the shore of Shoshone Lake, and thence on to the Upper Geyser Basin via Heron Creek.

Prof. Chamberlin remained with me a fortnight when, owing to engagements, he felt compelled to return home, much to my regret. His visit was most satisfactory to me and I think of value to him. He confirmed in nearly all essential points my views in regard to the general glaciation of the plateau and the movement of a broad ice sheet, which, entering the park at the northeast corner from the Snowy Range, crossed Junction Valley and pushed southward along the east side of Mount Washburne, following up the valley of the present cañon of the Yellowstone and out into Hayden valley.

About the middle of August I left the lake for the central portion of the Absaroka Range, desirous of studying the mountains at the source of the Stinking Water and the divides between the latter river and Clark's Fork of the Yellowstone. Mr. Iddings accompanied me the first part of the trip in order that we might discuss together some matters in connection with his recent work in the mountains. Later he went to the northeast corner of the park and spent the remaining part of the season in the Absaroka Range, along the boundary of the park, studying the centers of volcanic action and their relations to the Archean and Paleozoic rocks which at the northern end of the range reach the surface from beneath the great mass of volcanic material. Early in September I returned to the permanent camp.

During the early part of the summer Mr. Weed had been at work in the neighborhood of Yellowstone Lake, studying its recent history and mapping the geological formations along the shore. In this work he was assisted by Mr. E. H. Shuster and by Mr. Philip Sawyer, of the Irrigation Survey. Mr. Sawyer was engaged in making a topographical survey of the lake shore, and it was found advisable for Mr. Weed and Mr. Sawyer to work together, they being able to help each other in many ways.

The month of September I spent on the lake, most of the time along the southern shore, studying questions in relation to glaciation and the probable former outlet of this vast sheet of water, which at one time was considerably larger than we find it to-day.

After returning from the sources of Snake River the remaining part of October was occupied in the geyser basins, the work of the season being brought to a close at the Mammoth Hot Springs during the last days of the month.

While at work in the geyser basins Mr. Weed was enabled to make his annual examination of the changes which had taken place during the preceding year among the geysers and hot springs. This makes the fifth annual study of the principal hot spring areas, and the results, when correlated, will furnish a series of most interesting observations.

After the completion of his explorations Mr. Wolff met me at the Yellowstone Lake and together we went over the results of his investigations upon the eruptive rocks of the Crazy Mountains. I feel sure that when his work is ready for publication it will be found eminently satisfactory. His studies among the laccolites of both andesites and theralites and the innumerable dikes and offshoots from them and their structural features in relation to the Cretaceous strata which dip away from the laccolites in all directions, will prove most interesting to all students of dynamic geology.

Mr. George P. Merrill, curator of geology in the National Museum, visited the park during the summer for the purpose of making collections of the most characteristic typical rocks of the region, to be used as exchanges. At the same time he desired to obtain such material as would illustrate the work of the Geological Survey in the park. In this work I took a deep interest and was able to assist him in the way of designating the rocks and the localities where they could be collected. He obtained a large suite of specimens from the Fossil Forest, Obsidian Cliff, and other well known localities.

In many ways the season was a successful one, the only serious drawback being the dense smoke which settled over the park, not only from forest fires to the westward, but from fires burning within the reservation. It was an exceedingly dry summer and the first year in my experience that I had known fires to burn over such large areas within the Yellowstone reservation. The smoke was so dense and settled down so low that it was for days impossible to see more than 200 or 300 yards. This past season the areal survey of the park, as far as its present legal boundaries are concerned, may be said to have been completed. During the summer all unsurveyed areas have been examined and many detached pieces of work finished. The only work which still remains to be done relates to Quaternary geology, the recent history of the Yellowstone Lake, and such investigations as arise in connection with certain special geological problems connected with the volcanic phenomena and the relations of the volcanic plateau to the surrounding earlier mountain ranges.

OFFICE WORK.

All members of this division of the Geological Survey returned to Washington by November 15 and have been engaged throughout the rest of the fiscal year in duties pertaining to the office, mainly in working up the results of the previous season in the field and in the continuation of investigations in connection with the geology of the park.

Mr. Iddings was mainly occupied with microscopical researches upon the crystalline rocks of the region, studying the relationship between their structural conditions and mode of occurrence.

Mr. Weed gave much time to working up his observations on the constant but gradual changes going on in the thermal springs of the region.

My own time was occupied with various problems connected with the geological history of the park, more especially with the origin and manner of extravasation of the broad, extensive flows of volcanic lavas which make up the Absaroka Range. I was also occupied with questions relating to the glaciation of the park plateau. Since early spring I have devoted most of my time to the preparation of the monograph upon the geology of Eureka, which had been for various reasons laid aside, but which I now purpose to complete before following up any other geological investigations.

During the winter the topographical department furnished me with photographic copies of the new map of the Yellowstone Lake, which is in many respects admirable and far in advance of the map which we previously possessed. On this map it will be quite possible to locate the glacial deposits and lake benches along the shores and ridges of the Quaternary lake.

In the American Journal for July, 1889, I published a short article entitled "Notes on the Occurrence of a Leucite Rock in the Absaroka Range, Wyoming Territory." The rock was found the preceding year during an exploration of the Absaroka Range, and as it presents an exceptional mineral composition and a mode of occurrence quite unlike that of most leucite rocks, I described it with considerable detail as being of special interest to students of volcanic rocks. It is only the second occurrence noted of leucite in the United States.

Mr. Iddings read a paper before the Philosophical Society of Washington, January 18, 1890, on "The Mineral Composition and Geological Occurrence of certain Igneous Rocks in the Yellowstone National Park," which has recently been published in the proceedings of the society. In the paper the geology of Electric Peak and Sepulcher Mountain is briefly sketched and the eruptive rocks described and discussed petrographically and chemically. The chemical composition and the mutual relationship of these rocks is especially considered and a graphic method of illustrating the chemical variations is presented. The work may be considered in some sense as an abstract of a bulletin which Mr. Iddings has prepared as a publication of the Geological Survey on the eruptive rocks of these two closely connected mountains.

Mr. Iddings has also prepared a short article in conjunction with Mr. Samuel L. Penfield, of the Sheffield Scientific School of Yale University, on "The Occurrence of Fayalite in the Obsidian of Lipari." He recognized the fayalite as occurring under conditions precisely similar to those in the Yellowstone Park. Specimens from the two localities can hardly be distinguished. As the occurrence of fayalite was entirely unknown under such conditions in Europe, the determination is of interest both to mineralogists and geologists.

In February Mr. Iddings, having obtained leave of absence, left Washington for a two months' trip to Europe, with a twofold object in view: First, to visit some of the classic fields of volcanic activity in southern Italy and the islands of the Mediterranean for the purpose of making comparative studies with the volcanic phenomena of Yellowstone Park; and, second, to consult with some of the leading petrographers of England and Germany upon topics of interest to all students of crystalline rocks. He returned to his field of duty May 1.

Very respectfully, yours,

Arnold Hague,
Geologist in Charge.

Mr. G. K. Gilbert,
Chief Geologist.

REPORT OF MR. S. F. EMMONS.

Colorado Division,
Washington, D. C., June 30, 1890.

Sir: I beg to submit herewith my report of work done in the division under my charge during the year 1889-'90.

OFFICE WORK.

The work during this year has been almost exclusively office work, the permanent members of the division having done no regular field work. It has consisted in the study and examination of specimens and notes gathered during the field work of former years, in drawing up some general deductions of immediate interest in the form of occasional scientific papers, and in the preparation for the press of manuscript, maps, and illustrations for the several monographs now in progress. These are (1) one on the Ten-Mile and Silver Cliff mining districts, (2) one on the Denver Coal Basin, and (3) one on the

Geology and Mineral resources of the Crested Butte region of Gunnison County, Colorado.

The two first named monographs are now nearly completed, but it has been judged advisable to postpone sending them to the press until some additional data be gathered on geological points not as yet quite clear. This it is proposed to accomplish during the coming summer months.

Work upon the third report is now being taken up, the coloring of the geological maps and the microscopical and chemical study of the various rock masses examined going on contemporaneously.

In addition to his regular office work upon these monographs Mr. Eldridge has spent considerable time in compiling data upon artesian wells and the distribution of coal in the arid region by special order of the Director.

FIELD WORK.

A little field work has been done during the year by temporary assistants for special purposes.

During July and August, 1889, Mr. George L. Cannon, jr., made an examination of the breccia deposits of the Middle Park of Colorado for the purpose of collecting rock specimens and fossil remains which would lead to the determination of the true age and geological horizon of these beds and their relation to similar beds in the Denver basin.

In the month of August, by the kind permission of Dr. C. A. White, his assistant, Mr. T. W. Stanton. made for me a collection of molluscan fossils from the Paleozoic limestones near Glenwood Springs, Colorado, where, it was thought, from certain forms that had been discovered by Dr. J. S. Newberry, that Devonian beds—not yet discovered in the Rocky Mountain region—might exist.

By the kindness of Prof. O. C. Marsh his experienced and talented assistant, Mr. J. B. Hatcher, was allowed to make an examination of the so-called Denver beds during the month of November, for the purpose of settling by an invostigation of their vertebrate life the mooted question as to the age of this important series; but little was accomplished, unfortunately, owing to the unusually early fall of snow which effectually concealed the beds to be examined.

During part of the months of May and June of the present year Prof. A. Lakes, of the Golden School of Mines, has been engaged under my direction in making an extensive and, so far as possible, exhaustive collection of plant remains from the same beds, so that all possible data should be available for discussing the important question of their position in the geological column. This question has, as you are well aware, an economic as well as scientific bearing, since the beds in question occur above the coal-bearing formation of the West and have been considered by some geologists to form part of it.

PUBLICATIONS.

In addition to the regular routine work of this division, its members have from time to time embodied special results of immediate interest, arrived at in the course of their work, in papers published under the auspices of scientific societies.

At the December meeting of the Geological Society of America I read a paper on orographic movements in the Rocky Mountains, embodying facts bearing upon the structural history of the region incidentally gathered during the last ten years by myself, with a summary of the evidence previously obtained by others.

At the Washington meeting of the American Institute of Mining Engineers in February I submitted some notes upon the Gold Deposits of Montgomery County, Maryland, the results of somewhat superficial observations, but embracing facts which I thought might be of value in the development of the gold resources of the surrounding district.

Mr. Whitman Cross published in the American Journal of Science for May, 1890, an article entitled "Note on some secondary minerals of the amphibole and pyroxene groups," which was an incidental result of his studies of the eruptive rocks of the Silver Cliff district. A further result of these studies is embodied in a nearly completed memoir upon the interesting and imperfectly understood structural modifications of acid lavas known as "spherulites," which will probably appear in the form of a Survey bulletin.

Mr. George H. Eldridge published in the American Journal of Science for October, 1889, an article "On the grouping of the Middle Cretaceous, introducing the new term 'Montana' Cretaceous into geological nomenclature."

In November he read before the Washington Philosophical Society a paper on "Certain peculiar structural features of the region about Denver, Colorado."

He has also prepared for the use of the Director a map showing the distribution of artesian wells in the United States, and an article upon such wells throughout the world. Also for the use of the Director a map showing the development of coal in the arid region, so far as at present known.

He has also in preparation an article on the relations of the so-called normal and reversed faults.

Very respectfully,

S. F. EMMONS,
Geologist in Charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. J. S. DILLER.

CASCADE DIVISION,
Washington, D. C., June 30, 1890.

SIR: I have the honor to submit the following report of work done in my division during the fiscal year ending June 30, 1890:

FIELD WORK.

Accompanied by Mr. J. Stanley-Brown, I left Washington July 1. The field material having been transferred from Ashland, Oregon, to Red Bluff, California, the party was organized at that place and field work began July 11. The party consisted, besides myself, of Mr. Stanley-Brown and three camp men, and we continued in the field nearly three months.

The plan of operations for the field season contemplated (1) the completion of the field work within the Red Bluff district, excepting the detailed division of the auriferous slates, and (2) a reconnaissance of the mountainous country between the Red Bluff district and the sea, and both were accomplished.

The method of field work has been to traverse the country along the streams at right angles to the strike of the sedimentary rocks, noting the character, magnitude, and position of the rock masses, and tracing their terranes directly upon the topographic map. In this way many sections were examined and the best of them measured, using tape, compass, and aneroid.

The portion of the Red Bluff district lying upon the eastern side of the Sacramento valley was already mapped and a preliminary survey had been made of the remainder in 1887. The party first reviewed the section of the Cretaceous rocks exposed upon the eastern side of the Sacramento valley at Tuscan Springs and along Deer Creek, and then proceeded to map the same rocks upon the western side of the valley.

The streams descending from the Coast Range to the Sacramento River expose excellent sections across the belt of Cretaceous rocks and afford ample opportunity for measuring their thickness and studying their succession. As the boundary lines between the Cretaceous and the metamorphic rocks upon the west and the newer formations of the Sacramento valley upon the east were traced, sections were made along the streams across the belt.

The first section examined was upon Zonis Creek, where a number of aucellas and other fossils were collected. Along Elder Creek, the next stream to the northward, a section nearly ten miles in length was measured and numerous fossils collected. Advancing to the northeast, the section along Red Bank Creek, Cold Fork, Salt Creek, Dry Fork, Middle Fork, and Roaring River were successively studied but not measured.

The section so well exposed on the North Fork of Cottonwood and long celebrated for its wealth of fossils, was measured. From the mouth of Eagle Creek two sections were measured to the metamorphic rocks, one by way of Eagle Creek and the other by way of North Fork and Byron Gulch. The total length of the section, not counting the duplicated portion, is about seven miles.

While studying the Cretaceous rocks between Salt Creek and the North Fork of Cottonwood Creek a special investigation, including the preparation of a detailed map, was made of a remarkable series of sandstone dikes found in that region. Numerous photographs were taken and specimens collected for further research.

In the course of the work upon the Cretaceous belt excursions were made to North and South Yallo Bally Mountains and their ancient glacial fields were mapped.

Having outlined the Cretaceous exposures at Honetown, Texas Springs, and Oregon Gulch, the party proceeded westward along the Hay Fork road through the pass between Yallo Bally and Bully Choop, tracing the Cretaceous beyond the one hundred and twenty-third meridian, which is the western limit of the Red Bluff district. Northward in the Weaverville region half a dozen isolated masses of Cretaceous rocks were studied and mapped.

The country lying between Hay Fork and the coast is extremely rugged and traversed only by trails. It is said that no fairly passable wagon road crosses the Coast Range within 130 miles north of the fortieth parallel. Considerable excitement has been aroused by the discovery of coal at a number of points among the mountains. In response to the demands for its investigation, as well as to prepare the way to extend a series of sections already begun from the Great Basin to the Pacific, I made a reconnaissance of the region.

We left the Red Bluff and Hay Fork stage road 7 miles east of the latter place and proceeded by way of Post Creek and Scott's Ford of South Fork of Trinity River over South Fork Mountain, and down Mad River to Ericson's. Crossing the low gap to the Van Duzen River, we descended to Bridgeville and Hydesville, from which point we reached the mouth of Eel River and the coast about 100 miles from Hay Fork.

A few fossils were collected near Bridgeville and a larger lot by Mr. Stanley-Brown at Rio Dell.

On our return we crossed the river lower down, that is, farther northwestward, and examined the coal deposits at Hyamperne and Cox's Bar, reaching the vicinity of Weaverville in time to complete the survey of the isolated masses of Cretaceous before disbanding, October 1, at Red Bluff.

OFFICE WORK.

Since returning to Washington I have been continuously engaged in the office, studying the observations and collections made in the field, advancing the educational series of rocks, and attending to various administrative and other duties connected with the petrographic laboratory.

The results of the field work are largely cartographic, but for want of greater detail in delineating the various members of the auriferous slate series the Red Bluff sheet has not yet been offered for publication.

A paper on "Sandstone Dikes," chiefly upon those studied in Tehama and Shasta Counties, California, has been prepared and published as a bulletin of the Geological Society of America. (Vol. 1, pp. 411-442, pls. 6-8.)

A paper has been nearly completed upon the Cretaceous rocks of northern California and the adjacent portion of Oregon. It embraces the observations upon the rocks of that system made during several field seasons.

Mr. Stanley-Brown has been engaged much of the time in a practical study of photo-micrography. He has platted the surveyed routes of the measured sections, noting the dips and strikes observed, and by graphic methods constructed the sections for the determination of the thickness of the strata involved. He has made a series of specific gravity determinations of sandstones from California and of other rocks from Texas, and has assisted me greatly in preparing the illustrations for my paper on sandstone dikes and the Cretaceous rocks of Northern California. Copies of the geologic maps of the Lassen Peak and Red Bluff districts were prepared for Prof. Eugene W. Hilgard, of Berkeley, by Mr. Stanley-Brown, and he has rendered much aid also in the determination of minerals sent to the laboratory for identification.

PETROGRAPHIC LABORATORY.

The work of the petrographic laboratory is twofold: (1) the investigation of material submitted with inquiry, and (2) the preparation of material for study.

Of the material brought to the laboratory for investigation the following may be mentioned: A small collection of stones used by the Indians in making implements was determined for Mr. W. H. Holmes. Mr. H. L. Reynolds submitted, with inquiry, some greensand and metallic implements found in various mounds along the Atlantic slope. A small collection of rocks found in the vicinity of Providence, Rhode Island, was determined for Prof. Thomas J. Battey. A microscopic examination was made of the olivine contained in the Kiowa (Kansas) meteorite, for Prof. F. W. Clarke. Volcanic dust from the Missouri River, a few miles above Omaha, was examined for Prof. J. E. Todd, and compared with similar material found at a number of localities in Nebraska and Kansas, as well as Montana. Several eruptive rocks from Virginia were examined for Mr. Nelson H. Darton, and a note upon them was published in the American Journal of Science, vol 39, April, 1890, p. 270.

A specimen of lithographic limestone collected near Burnet, Texas, by Mr. A. R. Roessler was examined microscopically and was submitted to the Engraving Division for practical test.

During the year much has been done towards the completion of the educational series of rocks. Eighty-seven varieties had been previously obtained and during the year the collection of forty-seven has been secured. Many of the specimens are already in Washington, others are on the way, and in a short time the series will be complete.

Acknowledgments are due to the following gentlemen for assistance during the year in collecting the educational series of rocks: Prof. C. R. Van Hise, of Madison, Wisconsin; Dr. W. S. Bayley, of Waterville, Maine; Prof. C. W. Hall, of Minneapolis, Minnesota; Prof. N. S. Shaler and Mr. C. L. Whittle, of Cambridge, Massachusetts; Drs. George H. Williams and W. B. Clark, of Baltimore, Maryland; Drs. M. E. Wadsworth and A. C. Lane, of Houghton, Michigan; Prof. R. T. Hill, of Austin, Texas; Mr. E. G. Paul, of Greason, Pennsylvania; Messrs. Waldemar Lindgren, Nelson H. Darton, and Arthur Keith, of Washington, District of Columbia; Marsh & Co., of Gypsum, Ohio; Mr. M. Cummings, of Akron, New York; Grose Bros., of Lee, Massachusetts; Mr. Charles K. Worthen, of Warsaw, Illinois; Prof. W. P. Headden, of Rapid City, South Dakota; Mr. Charles L. Reese, of Charleston, South Carolina; Mr. Heth Canfield, of St. Augustine, Florida, and Mr. E. E. Howell, of Rochester, New York.

The specimens collected are only roughly trimmed in the field. The final trimming is done in the petrographic laboratory, thus securing as much uniformity as possible in the size and shape of the specimens, and at the same time providing the collection with a lot of chips for those who may desire to obtain them. When the specimens are received in Washington they are trimmed by Mr. Hunnell and stored away in numbered receptacles prepared especially for them. As soon as the specimens are all in and their order in the series fully determined their catalogue number will be painted upon them, so that if their labels are lost they can be readily identified by reference to the catalogue.

The descriptive bulletin to accompany the educational series of rocks is now well advanced in the course of preparation and will probably be completed by the time the series is ready for distribution.

In the petrographic laboratory an attempt is being made to gradually accumulate a working collection of hand specimens and their sections of typical rocks from all parts of the world for the use of the petrographers of the Survey. As acquisitions are procured chiefly by exchange and donation a large correspondence is rendered necessary and progress is slow.

Messrs. W. S. Hunnell, Hermann Ohm, and Fred C. Ohm have been continuously employed in the laboratory. Mr. Hunnell has trimmed the specimens for the educational series, collected four varieties of rocks near Baltimore, and assisted in the preparation of thin sections. Messrs. Ohm have been engaged all the time upon thin sections. Since June 9, in response to the increasing demand for thin sections, they have been assisted by Mr. E. G. Paul.

During the year four thousand and eighty-two thin sections have been prepared in the laboratory. Three of them were of extra large size and six hundred and sixty-six had to be sawed from hand specimens. Nine specimens were cut and polished.

The work of the division has been materially advanced by the cooperation of the paleontologists of the Survey. Dr. C. A. White, assisted by Mr. T. W. Stanton, identified a large number of Cretaceous fossils collected in northern California and Oregon and determined as far as possible the particular portion of the system to which they belong. Mr. C. D. Walcott studied a small collection of supposed Carboniferous fossils from within the Cretaceous belt along the western side of the Sacramento Valley, and Mr. W. H. Dall determined the species and age of a series of fossils collected by Mr. Stanley-Brown and myself near Bridgeville and Rio Dell, in Humboldt County, near the coast. Prof. Lester F. Ward reported upon a few leaf impressions collected at Hyampona and Redding Creek Basin of Trinity County, California.

The division has received many favors from the National Museum, especially its department of physical geology and lithology under Mr. G. P. Merrill, who has generously furnished us with material for comparative study.

Acknowledgments are due to Prof. F. W. Clarke, chief chemist and Dr. T. M. Chatard, chemist, who prepared for me four analyses of sandstone and one of diorite. Mr. Henry Gannett has rendered much assistance in procuring maps for our work. Mr. J. P. Iddings, Mr. Whitman Cross, and Dr. A. C. Peale have loaned us specimens and otherwise aided the division.

Very respectfully, your obedient servant,

J. S. DILLER,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF DR. G. F. BECKER.

CALIFORNIA DIVISION,
San Francisco, Cal., June 30, 1890.

SIR: The work of my division during the last year has been substantially confined to the gold belt of California.

Early in July I set out with Mr. H. W. Turner upon a reconnaissance of the southern portion of this area, accompanied by a pack train. We started from Mariposa and proceeded to Mount Dana, by Hite's Cove and Big Meadows. From Mount Dana we went to Mono Lake, through Lundy, and traveling northward for a few miles recrossed the range through the Virginia Pass. Following down Return Creek for some distance, we turned to the northwest and entered an exceedingly rough country, which has not been even approximately mapped and into which, so far as I know, no scientific expedition had penetrated. This region is very mountainous and intersected by immense cañons. It is almost bare of soil, except narrow strips of meadow surrounding innumerable small glacial lakes, and the topography, combined with the polished condition of the naked granite, makes traveling very difficult indeed. After a most tortuous journey we at length reached the Hetch-Hetchy Valley. On the way we once came upon the Grand Cañon of the Tuolumne, here 4,000 feet deep, and climbed down into it. From the Hetch Hetchy we followed the trail to Sonora.

The studies made upon this trip were principally on the granites of the range—structural features and glaciation. The region of Mount Dana presents very complex phenomena of metamorphism, and there are several other patches of metamorphics, but all of the region, excepting possibly one per cent., is granite of one sort or another.

At Sonora I left the party for San Francisco, and after a few days, early in September, turned my attention to a remarkable belt of serpentine, over fifty miles in length, which extends from near Placerville northward to beyond Washington, in Nevada County. This belt I studied at numerous points, particularly with a view to determining the various rocks from which the mineral was derived. This study, which occupied me until the beginning of October, completed my own field-work for the season.

Mr. Turner took the pack train to the Bidwell Bar sheet after I left him at Sonora, and for the remainder of the field season devoted himself chiefly to the regular mapping of the formations there and on the Jackson sheet.

Mr. W. Lindgren was employed throughout the season in mapping the geology on the Placerville and adjoining sheets, so far as this could be done with the information at command. Certain subdivisions of areas can not be finally traced until the studies in lithology, metamorphism, and paleontology are completed.

During the summer some new fossil localities were found. Prof. W. P. Blake informed me in conversation that he had observed fossils in the limestone of Hite's Cove, and on our reconnaissance Mr. Turner and I collected remains there which determine the age of the beds. I also engaged a professional collector, Mr. C. D. Voy, during the earlier months of the fiscal year to make careful search for fossils in areas which had been noted as hopeful. A fair amount of success attended this effort.

In December my headquarters were transferred to Washington, and during the next month my assistants followed me there. We devoted the winter months to the arrangement of collections, to the study of some five hundred slides which had been made of rocks of the Gold Belt, and to studies of structural problems arising in the geology of the Gold Belt.

In April Mr. Lindgren returned to the field and resumed the cartographic geology of the Placerville, Sacramento, Colfax, and Nevada sheets. He has completed the cartographic geology of the Sacramento sheet and hopes before the end of the season to finish the Placerville and Colfax sheets.

Mr. Turner took the field May 1 and has been occupied in mapping a difficult portion of the Jackson sheet.

I reached California in the middle of June and made a short but important examination of Riddle's, Oregon, before the close of the year.

With the consent of the Director, I have assigned to Messrs. Turner and Lindgren the task of preparing a report on the descriptive geology of the Gold Belt.

The geology of the Quicksilver Deposits of the Pacific Slope, Monograph 13, though printed earlier was not generally distributed until the autumn of 1889. In the August, 1889, number of the American Journal of Science I published a paper on silicic acids, tending to show that the principal mineral compounds are to be regarded as polysilicates, orthosilicates, and mixtures of these salts; while the existence of disilicic acid is doubtful, and the metasilicates in many cases, at all events, are mixtures or double compounds. In May, 1890, I published in the same journal an elementary proof of the earth's rigidity, which consists of a proof of the great resistance to tidal deformation exhibited by the earth, similar to Sir William Thomson's demonstration, and equally conclusive, but involving only elementary mathematics. Mr. Lindgren has published in the Proceedings of the California Academy of Sciences "Petrographical Notes from Baja California, Mexico."

Yours respectfully,

G. F. BECKER,
Geologist in Charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. ALPHEUS HYATT.

DIVISION OF LOWER MESOZOIC PALEONTOLOGY,
Cambridge, Mass., June 30, 1890.

SIR: I have the honor to report that my official connection with the Survey began on July 19, 1889, and the first duty assigned to me was a preliminary examination of the Trias and Jura in New Mexico. I had during the summer of 1888, while in company with Mr. I. C. Russell, of the U. S. Geological Survey, made preliminary examinations of a number of good exposures of these two systems in California, Nevada, Idaho, Wyoming, and South Dakota, and collected fossils, crossing the line of outcrops from west to east. The New Mexican region was not only new so far as the paleontologist in charge was concerned, but was also the typical locality at which the Jura had first been discovered in this country and has never since been thoroughly explored by any geologist; it was not even known that any largely represented fauna of the Jura existed there.

After my arrival at Las Vegas in New Mexico, I was conveyed thence to Liberty, New Mexico, by the kindness of Mr. Joseph Waddingham, of the Pablo Montoya Grant, reaching that place on the 31st of July, having stopped to examine the Trias and Jura near Fort Bascom while on the way. Being assisted by friendly letters from Mr. Frank Springer, of Las Vegas, a well known paleontologist, I received many favors from his correspondents, and especially from Mr. E. D. Bullard, of Liberty. By his aid I was able to obtain the services of two Mexicans and a suitable outfit, and started from Liberty August 9. During the interval from August 1 to August 9 I had utilized considerable spare time by making daily visits to Mesa Tucumcari and succeeded in obtaining an ample collection from this typical Jurassic locality. After our departure from Liberty we remained a couple of days at the foot of this mesa in order to finish a geological section showing in detail the different divisions of the Trias and Jura which are exposed on its sides. The thick accumulation of soil on the plains in this part of New Mexico conceals in large part the underlying rocks. These are, however, exposed in some places and can be seen to be brown, unfossiliferous sandstone entirely distinct from the Red Beds and the Jura sandstones which together form the denuded sides of the mesas. A line of bluffs about 50 miles in length marking the northern edge of the Llano Estacado, a vast elevated plain south of Liberty, afford the most extensive and promising exposures and our course was consequently directed toward them.

On our way to these bluffs, the Mesa Redonda, the first mesa of considerable size south of Tucumcari, was visited and a geological section on its northern side was obtained, but fossils were not abundant with the exception of the Gryphea, the typical fossils of the Jura in this region. Several days were occupied in the exploration of Apache Cañon on the borders of the Llano Estacado and in making sections there and at Monte Revuelto, a projecting point of the Llano a few miles farther eastward. In both places fossils were in fine preservation and very abundant. After a return to Liberty for supplies the explorations were continued by visiting the group of mesas known as La Trinchera, to the east of Tucumcari, and by crossing and making sections of the Mesa Rica, and then proceeding to the neighborhood of El Cuervo post-office, where the Trias is largely developed. Fossils being imperfect or scarce or entirely absent in these localities, our course was changed to the south towards the most westerly part of the bluffs of the Llano Estacado at Mesa de la Laguna, Colorado. This being the highest point of this region an opportunity for the study of a very complete section of the Trias and Jura was afforded.

The results of all these studies demonstrated the undisturbed character and syncronism of the deposits throughout the country traversed. The Red Beds or Trias yielded no fossils, and were conformable to the Jura above, but their distinctness from the sandstones of the Jura was obvious at all localities.

The fossils occurred only in the highest parts of the Jura and the undisturbed sediments enabled me to determine accurately the relative positions of the clay beds containing Gryphea and the fossil-bearing rocks above these which contained a large and characteristic littoral fauna. Fossils were not abundant along the northern exposures, neither just north of the Red or Canadian River at Fort Bascom nor at any of the mesas near the southern bank of that river, excepting always the typical Gryphea. Even this, however, disappears on the north side of the Mesa Rica and in the mesas to the westward of the Trinchera. There was also a dearth of fossils on the north side of Mesa Rica as compared with the south side of the same mesa at Cañon Honda, and specimens were more abundant along the eastern bluffs of the Llano Estacado than at the Mesa de la Laguna Colorado to the westward. The center of the fauna lies therefore at or near Monte Revuelto, but no horizons were discovered at this locality which were not also present at Mesa Tucumcari and other places visited to the north and west of this. Returning from the northward from the Llano Estacado, the outfit was sent back to Liberty from Cabra Spring post office on September 7. I returned from this place to Las Vegas by way of the valley of the Rio Gallinas in an open wagon, having good opportunities for observing the country, and walked over two series of exposures in the sides of the mesas along the route, but no fossils were to be found, even the Gryphea being absent. This confirmed the conclusions noted above and demonstrated to my satisfaction that the exploration had taken the best routes practicable in the short time that could be spent in the field. The collections were large, considering the necessary limitations imposed by the means of transportation on pack saddles, and have afforded ample materials for demonstrating the age of the fauna. From Las Vegas I proceeded to Las Vegas Springs in order to review the section made by Dr. Hayden and described in his annual report for 1867, 1868, and 1869 as containing a full series of Jurassic rocks and then started for Cambridge, Massachusetts, on September 11.

OFFICE WORK.

After my arrival the geological notes made in New Mexico were worked up and the geological sections drawn to a scale and prepared for draughting. A considerable portion of October was occupied in providing a proper place for the unpacking and study of the collections, which consisted of an extensive series collected by Mr. I. C. Russell and myself in 1888, which had been previously forwarded to me, and the New Mexican collections made as described above. Ample room having been at last obtained in the month of November, the work of unpacking, sorting, preparing, labeling and identification was begun and has been continued without interruption until the present date. Progress is necessarily slow, no assistance in the clerical work of this department having been employed. The New Mexican fossils have, however, reached a creditable state of advancement, a considerable number of the species having been named and described in manuscript and the exact age of the fauna determined.

The fossils collected in 1888 from the Trias and Jura have also been placed in good order, many of them accurately determined and named, establishing some very interesting and novel facts in the history of the Trias and Jura in this country. These results, however, can not be given in this report since they would require demonstration by means of illustrations and more or less lengthy descriptions. The whole number of species hitherto known and published as coming from these two systems in this country have been largely increased, perhaps almost doubled by the collections referred to, but the most important facts are the exact determination of the ages of certain Jurassic horizons such as that above alluded to in New Mexico which is the equivalent of the Porlandian of Europe and that of a limestone occurring in the Jura at Taylorsville which belongs to the middle Jura and is probably Oolite. Secondarily the support given to the views already expressed by several authors, that the Trias and Jura would be easily separated when their faunas were known in spite of their geological conformity and unfossiliferous character in many places, and that the collective appellation, Jura-Trias, should be abandoned.

Incidentally the determination of the age of the strata occurring in parts of California not yet visited by the undersigned has been undertaken in consequence of collections made under the direction of Dr. G. F. Baker and forwarded to me by Dr. C. A. White, and a certain amount of preliminary work has been successfully done in this direction.

It has also become evident from specimens existing in the collections of San Francisco and at Columbia College, New York, that the fauna of the Lower Lias occurs in the Jura of the west, probably in the West Humboldt Range and to the south and west of this in California and possibly also not far from and to the west of Colfax in the Sierras.

Several fossils of Oolitic affinities said to have come from California, having the aspect of one of the same group collected from the western flank of the Sierras and now preserved in the collections of the Museum of Comparative Zoology, have been found in the Museum of Natural History Society at San Francisco through the kindness of Prof. Joseph Le Conte. These facts would not be worth mentioning if our knowledge of the Jura in America were not so meager that any positive indications of the presence of fossils which can be used to direct future explorations and determine the exact age of the horizons of this little known system, become of appreciable value.

By the kind permission of Alexander Agassiz, Director of the Museum of Comparative Zoology, the extensive foreign collections in the Trias and Jura of his museum have been placed at my disposal for the comparison of our American species with the typical European forms. The great advantages thus gained will be appreciated by all professional paleontologists, especially those engaged in similar work but obliged to rely solely upon foreign publications. It will require considerable time to bring these collections int oproper shape for this purpose, since much of the material has been acquired in separate lots from different collectors and needs to be concentrated and arranged. This work has been begun and an appreciable advance made during the last year.

NEEDS OF THE DIVISION.

The paleontologist in charge has been debarred from publishing even in preliminary form the results of his explorations in New Mexico on account of the amount of time consumed in office work, and no creditable and complete exposition of the results of such researches can be prepared for final publication without illustrations.

From what has been said above it is obvious that explorations should be made for the purpose of discovering the Lias, the lowest series in the Jura, and at the same time to study if practicable the upper limits of the Trias in the same localities.

Respectfully submitted.

ALPHEUS HYATT,
Paleontologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF PROF. O. C. MARSH.

DIVISION OF VERTEBRATE PALEONTOLOGY,
New Haven, Conn., June 30, 1890.

SIR: I have the honor to submit the following report of the work of this division during the last year:

In compliance with your letter of general instructions, I have continued the systematic work of collecting vertebrate fossils and investigating those of special interest to science. This work has gone on systematically and with success during the year.

The work of determining more accurately the relation between the Cretaceous and Tertiary formations in the West has been continued during the last year. The importance of this question and the plan formed for its solution were explained in the last annual report, and some of the results attained were then stated. The investigation has since been prosecuted systematically, but the difficulties of the problem are not yet removed. The extensive collections of vertebrate fossils obtained from the Laramie deposits during last year afford, however, for the first time, a substantial basis for comparison with those from above and below. The vertebrate fauna of the typical Laramie is now known to be one of the most extensive and varied yet found in any formation, and its characteristics have an important bearing on the vexed question of the age of the strata.

To gain light on this problem, I made last autumn a reexamination of some of the Mesozoic formations on the eastern flank of the Rocky Mountains, in Dakota, Wyoming, Nebraska, and Colorado, especially with a view to ascertain their relations to each other and to later deposits. The horizon of the Atlantosaurus beds of the upper Jurassic, and of the Ceratops beds of the upper Cretaceous, were traced for several hundred miles from north to south, and wherever exposed were found to be well marked by the remains of the gigantic reptiles preserved in each. These two horizons are so distinct and characteristic that they may serve for standards of their respective formations. Each contains a distinct vertebrate fauna, remarkable first of all for the great development of reptilian life, which is unsurpassed by that in any other part of the world. Mammalian life was also well represented in each, but low in type, and diminutive in size. The break between the Laramie vertebrates and the corresponding fauna of the early Eocene is profound, and the transition series remains to be discovered.

The monograph on the Sauropoda, illustrated by ninety lithographic plates and about two hundred and fifty woodcuts, is so near completion that its publication may be expected during the next year. The memoir on the Brontotheridæ, with sixty lithographic plates and more than one hundred and fifty woodcuts, will soon follow. The publication of these two volumes has been delayed by discoveries of great importance in the West, which required prompt and systematic investigation to make even the preliminary results accessible to the scientific public.

The explorations which have led to these discoveries and others of less note during the last few years have brought to light a very large number of vertebrate fossils which may be of great value to science. To prepare these specimens, many of which are still imbedded in rock, for examination and the careful study necessary to make known their true nature requires time and skillful workmanship. This work well done is done once for all, but without it important specimens may prove of little value, or even be destroyed. This branch of laboratory work must follow work in the field, and is of scarcely less importance. Good progress has been made in it during the last year. After such preparation the specimens are ready for the artist as a necessary aid to the investigator. In this way alone can the records of ancient life best be read and made known.

The other field work in the West has been continued with good success, especially in the Miocene of Dakota.

Important explorations in the Pliocene of Florida were made during the winter by my able assistant Mr. J. B. Hatcher, who has done so much to bring to light the extinct vertebrates of the West.

The extensive collections obtained are mainly under investigation at New Haven, and will furnish valuable material for the monographs now in preparation. The progress on these volumes during the last year has been continuous and satisfactory.

Very respectfully,

O. C. MARSH,
Paleontologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF MR. CHARLES D. WALCOTT.

DIVISION ON PALEOZOIC INVERTEBRATE PALEONTOLOGY,
Washington, D. C., July 1, 1890.

SIR: I have the honor to present the following report of operations conducted under my charge during the fiscal year ended June 30, 1890:

FORCE.

The personnel of the division has consisted of Prof. Joseph F. James, Mr. John W. Gentry, and Mr. Ira Sayles, assistant paleontologists. Besides the above, Mr. William P. Rust and Mr. Henry Bufford have been employed as field collectors, and Prof. Henry

S. Williams, of Cornell University, has, as heretofore, been attached to the division in connection with a special investigation on the Devonian and Carboniferous groups.

FIELD WORK.

The field operations for the year were, (1) the study by Prof. Henry S. Williams of the Devonian fauna and strata of New York State; (2) the study of the stratigraphy and the collection of the faunas of the Lower Paleozoic rocks of the northern portion of the valley of Lake Champlain; (3) an examination of the typical localities of the Quebec group in the vicinity of Quebec, Canada; (4) the examination of the Cambrian rocks of Chilhowee Mountain, Tennessee; (5) the examination of the typical stratigraphic sections of the New York Survey of 1836-1840; (6) the collecting of Cambrian, Silurian and Devonian fossils by collectors at various localities within the United States.

Prof. Williams's field work was limited to the study of the Middle Devonian fauna and strata of New York State in Livingston County.

In connection with the subject of correlation and proposed review of existing knowledge of the Cambrian and Silurian groups, I examined some of the typical sections of the New York Survey of 1836-1840 in the valley of the Mohawk and in Jefferson and Oswego counties. In company with Prof. W. H. Benedict a rapid examination was made of a section of sandstone at Port Henry, New York, that resulted in the discovery of the fauna of the lower horizon of the Potsdam sandstone formation. With Mr. W. P. Rust as collector I reviewed the section measured by me in 1885 at Chazy, Clinton County, New York, and then crossed to the Isle la Motte to complete the study of the section of the Chazy rocks. With the data obtained from the Chazy and Isle la Motte sections the study of the Phillipsburgh series of rocks in the vicinity of the United States and Canada boundary, between the shore of Lake Champlain and the village of St. Armand, Canada, that was begun in 1889, was continued. Leaving Mr. Rust to collect fossils, I proceeded to Quebec, Canada, to meet Dr. A. R. C. Selwyn, director, and Dr. R. W. Ells, assistant geologist, of the Canadian Geological Survey. They guided me to the typical localities of the Quebec group, and pointed out the evidence upon which they had based their conclusions that the typical Quebec group of Logan included strata of Cambrian and Silurian age. After this examination was completed I made a special study of the Lower Calcareous beds of the Levis series, opposite Quebec, and discovered that the Upper Cambrian, or Potsdam fauna occurs entirely in loose bowlders embedded in a matrix that carries the fauna of the Lower Silurian or Calciferous formation of New York. After examining the section at Montmorenci Falls, I next proceeded to Lake Memphremagog, to join Dr. Ells at Knowlton's Landing. He kindly took me over the sections of Lower and Upper Silurian strata in the vicinity of the lake, and then we drove from the lake west across the Sutton Mountain anticlinal, crossing the Green Mountain axis and the lower Cambrian strata on each side of the anticlinal. Dr. Selwyn joined me at Highgate Springs, Vermont, in August, and we went over the lower Cambrian section of northern Vermont, and also the Lower Silurian sections near the United States and Canada boundary. I then completed the section of the Phillipsburgh limestone, and a little later Dr. Selwyn joined me to go south to Granville and Salem, Washington County, New York, where we examined a section of Cambrian and Lower Silurian strata. My visit to Canada and that of Dr. Selwyn's to Vermont and New York, was for the purpose of correlating the geologic formations of Vermont and Canada on the western side of the Green Mountains.

In September I studied the sections exposed in the cañons of Lorraine and Salmon rivers and also various outcrops of strata between the Trenton limestone and the Medina sandstone in Jefferson and Oswego counties, New York, for the purpose of obtaining data to use in the correlation of the formations between the Trenton and the Medina terranes. In October some ten days were given to a hasty examination of certain rocks between Hot Springs, North Carolina, and Maysville, Tennessee. This was undertaken in connection with Messrs. Willis and Hayes, of the Appalachian Division, for the purpose of determining the relative geologic age of the series of quartzites and accompanying shales referred to the Chilhowee quartzite by Prof. Safford.

Mr. William P. Rust, of Trenton Falls, New York, has been employed as a collector in central, western, and eastern New York and western Vermont. In Alabama Mr. Henry Bufford was employed as a collector at intervals during the year.

Prof. Joseph F. James examined the sections and made collections from the Cambrian and Lower Silurian strata at various points in Wisconsin, Iowa, and Minnesota. He studied the section of the Maquoketa shales in Iowa, and collected an extensive series of fossils on the Little Maquoketa River. Towards the close of the field season he collected a large number of fossils from the Lower Silurian at Lexington, Frankfort, Highbridge and Danville, Kentucky.

Under the direction of Prof. Williams, Mr. Ira Sayles collected from the Devonian formations of New York during the earlier part of the year, and also in May and June of 1890.

OFFICE WORK.

Prof. Henry S. Williams continued the study and elaboration of the collections of Devonian fossils, especially the fauna of the Tully limestone of New York State. This fauna was compared with the

Middle and Upper Devonian faunas of England, Belgium, Germany, Russia, and Canada, and a brief account of the results of the studies was presented to the Geological Society of America in December, 1889. He also spent considerable time in preparing a report on the principles of correlation and in a preliminary study of the literature of the present century bearing upon the geology of the Devonian and Carboniferous groups of America. During the year he examined and submitted a report to Dr. J. C. Branner, State Geologist of Arkansas, upon the determinations of the horizons of the upper Paleozoic fossils obtained by the Arkansas survey. A preliminary examination was also made of a large collection of Carboniferous fossils from Missouri collected by Mr. W. P. Jenney.

After the close of the field season Mr. James continued the preparation of abstracts of geological papers relating to the lower Paleozoic rocks, giving special attention to the literature bearing upon the Niagara and Maquoketa formations. A notice of the latter in connection with his field observations was published in the American Geologist, June, 1890. He also assisted in the general routine work of the laboratory and office.

On my return from the field in October I reviewed the paper on the fauna of the Olenellus zone, and selected a large amount of material for the draughtsman to work upon from the middle Cambrian or Paradoxides zone of the Atlantic coast. In connection with the Division of Correlation a preliminary examination was made of the literature pertaining to the Hudson, Lorraine, and Cincinnati terranes and an examination made of the fossils obtained during the field season from the Hudson and Lorraine rocks. As a result of this study a paper was prepared on the subject of the value of the term Hudson river group in geologic nomenclature and read before the American Geological Society, at New York, December 27, 1889. During the month of January the work of the office consisted mainly in the accumulation of reference material from the upper and middle Cambrian faunas by the examination of large collections now in the laboratory. Specimens were selected from them and a set obtained of nearly all described species from every locality mentioned by authors. February 1 a review was begun of the literature relating to the Cambrian rocks of North America. This was continued to the end of the fiscal year in connection with the routine work of the division.

A small collection of fossils from the lower Carboniferous strata of Glenwood Springs, Colorado, was examined and reported upon to Mr. S. F. Emmons, of the Geological Survey, and a preliminary study made of a large collection of Lower Silurian (Ordovician) fossils from Cañon City, Colorado, a short report upon which was made to Mr. Emmons.

Mr. J. W. Gentry remained in charge of the office during my absence from the city in the summer, and attended to the general clerical work of the division during the year.

Mr. H. A. Conner has been mainly employed in unpacking, recording, and packing the collections received during the year.

As honorary curator in charge of the collections of invertebrate Paleozoic fossils of the U. S. National Museum I looked after the general collections, and gave attention to the transfer of material from the Geological Survey to the collections of the Museum. There has been transferred and credited upon the accession book of the Museum for the year 91 genera and 138 species, represented by 918 specimens.

During the year there have been published twelve papers growing out of the general studies of the division:

The Cuboides Zone and its Fauna, by H. S. Williams; Bull. Geol. Soc. of America, vol. 1, 1890, pp. 481-499.

The Maquoketa Shales and their Correlation with the Cincinnati Group of Southern Ohio, by Joseph F. James; American Geologist, vol. 5, 1890, pp. 335-356.

A Fossil Lingula Preserving the Cast of the Peduncle; Proc. U. S. Nat. Mus., vol. 11, 1888, p. 480. Read before the Biological Society of Washington, December 3, 1887. Signatures issued September 3, 1889.

Descriptive Notes of New Genera and Species from the Lower Cambrian or Olenellus Zone of North America; Proc. U. S. Nat. Mus., vol. 12, 1889, pp. 33-46.

Description of a New Genus and Species of Inarticulate Brachiopod from the Trenton Limestone; Proc. U. S. Nat. Mus., vol. 12, 1889. Advance sheet, December 10, 1889. One page.

A Review of Dr. R. W. Ells's Second Report on the Geology of a Portion of the Province of Quebec, with Additional Notes on the "Quebec Group;" Am. Jour. Sci., 3d ser., vol. 39, 1890, pp. 101-115.

A Review of the Report of the State Geologist of New York for the year 1888; Am. Jour. Sci., 3d ser., vol. 39, 1890, pp. 155, 156.

Study of a Line of Displacement in the Grand Cañon of the Colorado in Northern Arizona; Bull. Geol. Soc. Amer., vol. 1, 1889, pp. 49-64. Twelve figures. Read before the Society August 29, 1889.

The Value of the Term "Hudson River Group" in Geologic Nomenclature; Bull. Geol. Soc. Amer., vol. 1, 1890, pp. 335-355. Read before the Society December 27, 1889.

Very respectfully,

CHAS. D. WALCOTT,
Paleontologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF DR. C. A. WHITE.

MESOZOIC DIVISION OF INVERTEBRATE PALEONTOLOGY,
Washington, D. C., June 30, 1890.

SIR: I have the honor to submit the following administrative report of the work of the division under my charge for the year ending June 30, 1890.

On July 1 Mr. T. W. Stanton, who had recently been appointed Assistant Paleontologist, reported to me for duty and immediately entered upon the work of this division.

FIELD WORK.

The work upon which I had previously been engaged requiring that further field observations, especially upon the Lower Cretaceous of the Southwest, should be made, I proceeded to San Antonio, Texas, leaving Washington on July 6, taking Mr. Stanton with me. My objective point being the town of Presidio, Texas, which lies upon the bank of the Rio Grande, and at a considerable distance from the nearest railroad, I applied to General David S. Stanley, in command of the U. S. Military Department of Texas, for aid in reaching that point. He promptly furnished myself and Mr. Stanton with conveyance and escort from Fort Peña Colorado, Texas, to Presidio, Texas, and also gave me much valuable information concerning the region I wished to examine. All this aid was rendered without expense to the Survey, and was of great advantage in the prosecution of my work.

Upon arriving at Presidio I began a series of field examinations within the region round about, by which material additions were made to our knowledge of the Lower Cretaceous formations and their relation to underlying and overlying formations.

Upon completing these examinations I proceeded northward to New Mexico for a similar purpose. San Antonio, New Mexico, was the point from which my work was prosecuted in that Territory, and my examinations were extended as far eastward as the town of White Oaks, in Lincoln County. This work also added much to previous knowledge of the Cretaceous formations of that part of the continent.

From New Mexico I proceeded northward to Colorado, making examinations in the valley of Arkansas River and in the vicinity of Denver, reviewing work that I had formerly done there and connecting the results with those obtained elsewhere.

From Denver I directed Mr. Stanton to go to Glenwood Springs, Cañon City, and other points in Colorado to make examinations and collect fossils, when I returned to Washington, arriving September 5.

Upon the completion of the work which I had directed Mr. Stanton to do, he returned to Washington and reported for duty in the office on September 9.

In pursuance of my plan for adding to the collections of Cretaceous fossils for purposes of both paleontological and geological study, I sent Mr. Stanton again to the field with instructions to make as full collections as practicable, especially from the Ripley Group, in northern Mississippi. He left Washington on October 5 and returned on November 20, having satisfactorily carried out his instructions and bringing to the office very important collections.

Desiring to continue collecting and geological observations in the West, I again sent Mr. Stanton to the field, directing him to proceed to Colorado and Wyoming for that purpose. He left Washington on June 9, and is now at work in Colorado.

OFFICE WORK.

The principal work intended for publication that has been prosecuted in the division during the year is that which has been done upon the memoir on the Cretaceous formations of North America, which was begun some time previously. This work is now approaching completion, and it is expected that it will be ready for the printer by the close of the present calendar year.

A considerable number of collections which have been sent to this division by Dr. G. F. Becker, Mr. S. F. Emmons, and Mr. J. S. Diller for examination with a view to using the results to aid them in their field work, have been studied and reported upon through your office. In this work I was materially assisted by Mr. Stanton.

Mr. Stanton has also spent much time upon the collections which he obtained from the field as well as upon others, preparing them for study, and arranging them for installment in the U. S. National Museum. He has also, together with Mr. Boyle, done much work in arranging the fossil collections in the Museum cases.

Mr. Boyle has continued his bibliographical work during the year, at such times as he was not called off by other duties, especially those pertaining to the clerical work of the division, which devolve mainly upon him.

During my absence, from February 15 to April 28, inclusive, Mr. Boyle and Mr. Stanton continued the stated work of the division and the preparation and arrangement of the fossil collections.

During the year the two following publications of which I am the author have appeared, both of which are largely based upon information derived from the work of the Survey:

The lower Cretaceous of the Southwest and its relation to underlying and overlying formations. Am. Jour. Sci., vol. 38, December, 1889, pp. 440-445.

The North American Mesozoic. Address as vice-president of Section E of the American Association for the Adancement of Science at Toronto, August, 1889. Proc. Am. Assoc. Adv. Sci., vol. 38, pp. 1-24.

Respectfully submitted.

C. A. WHITE,
Geologist in charge.

Hon. J. W. POWELL,
Director of the U. S. Geological Survey.

REPORT OF MR. W. H. DALL.

DIVISION OF CENOZOIC PALEONTOLOGY,
Washington, D. C., June 30, 1890.

SIR: I have the honor to submit the following report on the work of the Division of Cenozoic Paleontology during the year ending June 30, 1890.

FORCE.

The force of the division has comprised, beside laborers temporarily employed in field work, William H. Dall, paleontologist in charge; R. E. C. Stearns, paleontologist; Gilbert D. Harris, assistant paleontologist; Frank Burns, skilled laborer.

These persons have been continuously employed on field or office work during the year.

Dr. Stearns has been chiefly engaged in the routine work, of which he has had general supervision, both as regards the fossils and the recent shells, under my direction. Many of the replies to letters asking for information have been draughted by him, and his familiarity with the land and fresh water forms have rendered his services in this particular especially valuable. The amount of routine work is necessarily very great, but Dr. Stearns, beside pursuing at intervals his studies of the fossil fresh water fauna of the central desert region and its relations to the existing fauna, has also completed an extended report on the collections and stratigraphy of the Pliocene beds of San Diego, California, at which he spent a good deal of time and labor two years ago. This report will have a good deal of value when that part of the coast is reached in the correlation work.

Mr. Harris has assisted in the routine work and has been also able to give a few weeks to field work on the Yorktown, Virginia, peninsula, all that our scanty allotment would permit of undertaking. This work has been carried out in an exceptionally satisfactory manner, geologically speaking, and will be incorporated in the correlation essay. For the rest Mr. Harris has been busy collating and sifting the geological literature of the Plio-Miocene, under my direction, for the purposes of the prospective essay, which, as elsewhere mentioned, has been carried as far as Virginia, in the circuit of the coast.

When not engaged in field work Mr. Burns has been sorting and arranging the material collected, which has more than sufficed to keep him busy and monopolize his energies during the year.

ROUTINE WORK.

The routine work of the division consists largely of assorting, cleaning, classifying, naming, labeling, cataloguing, and arranging for easy reference the fossils of Cenozoic age, collected by members of the Survey or presented by persons interested in geology, and collected together at the National Museum.

Another branch of the work consists in reporting on such specimens as are brought in by members of the Survey desirous of knowing the age of the strata from which they were obtained, or by private persons interested in paleontology who desire to have their collections named.

The labor of furnishing information on these and cognate subjects to inquirers from all parts of the country is by no means small, but in all cases where it would not interfere with necessary official work I have regarded it as a proper thing to do, as it assists in promoting an interest in and knowledge of paleontology and often results in the free gift to the Survey of valuable material or scientific information. A list of persons assisted by correspondence, etc., is appended. The material referred to this division for report has in all cases been promptly attended to, no arrears of this sort existing at the end of the year.

Fair progress has been made on the arrearages of material which existed before I took charge of this division, and in providing cases and facilities for work on this material we are indebted to the authorities of the Smithsonian Institution and National Museum.

The final registration of material for the year ending June 30, 1889, was 6,323 entries, corresponding to about 20,000 specimens. That for the last year has comprised about 6,000 entries equivalent to about 18,000 specimens, which is a satisfactory total. As we have no clerk writing a hand suitable for exhibition labels and such matters, the services of Mr. S. R. Bond, of the Museum staff, by permission of the Director of the Museum, have been utilized from time to time.

As facilitating the work of the Survey in this direction, with your approval, I have continued to act as honorary curator of the Department of Mollusks, U. S. National Museum, as for many years past.

FIELD WORK.

Owing to the condition of the allotment for the purposes of this division for the current year but little was hoped for in the way of field work at the beginning of the season. However, by the generous cooperation of Mr. T. H. Aldrich, of Blocton, Alabama, we were enabled in November to send Mr. Frank Burns to the interesting region near Alum Bluff, western Florida, where he remained until January with very excellent results, both in tracing the Miocene farther west than it had been before identified, and in making a rich collection of its contained fossils.

Later in the season Mr. Joseph Willcox returned to Florida for a short time and continued his cooperation with this division which has been of mutual use and convenience for several years past.

In the month of June Mr. G. D. Harris was sent by me to the vicinity of Yorktown, Virginia, to make some collections from the Miocene of that region and verify some stratigraphic details which were in doubt. He was absent about two weeks with satisfactory results.

On several occasions during the season I have visited the collections at Baltimore, Philadelphia, etc., to compare our collections with types of those described by earlier authors in order that they might be properly authenticated.

COOPERATION WITH OTHER SURVEYS AND STUDENTS OF PALEONTOLOGY.

A considerable series of fossils from the Tertiary of Arkansas were identified and reported on at the request of Dr. John C. Branner, State Geologist of Arkansas. The fossils themselves are for the present deposited in the National Museum.

Sundry fossils have been reported on for Prof. R. T. Hill, of the Texas State Geological Survey.

A collection of the prominent types of Tertiary fossils of America for educational purposes has been made up and sent to Simpson College, Iowa, at the request of the authorities.

A few characteristic forms were sent to the Normal School of the Brothers of Mary, Dayton, Ohio.

Conferences have been had with Rev. Father Orban, of the Catholic University, Washington, with a view to determining plans of installation for the illustrative collection of the scientific department of the University, which is in contemplation.

A large collection belonging to the University of Alabama, which, before my connection with the Survey, had been loaned to it, has been carefully packed and returned to the University.

Cooperation by correspondence and otherwise has been extended during the last year to the following persons, among others:

G. P. Ahern.
T. H. Aldrich.
H. G. Askew.
Horace Beach,
F. C. Bennett,
W. G. Binney.
E. de Boury.
H. Boussin.
F. C. Browne.
Harold Carlisle.
W. B. Clark.
J. M. Clarke.
T. D. A. Cockerell.
Dr. J. G. Cooper.
Cowperthwait & Co.
W. E. Crane.
Prof. A. Dugés.
J. W. Denton.
Dr. C. S. Dolley.
Dr. P. Fischer.
M. L. de Folin.
John Ford.
W. F. Ganong.
T. Greegor.
C. A. Hargraves.
R. T. Hill.
H. Hemphill.
Prof. A. Heilprin.
A. A. Hinkley.
H. G. Hodge.
W. Hough.
R. T. Jackson.
Rev. H. Jaske.
Prof. J. Keep.
Geo. F. Kunz.
Dr. J. Lindahl.
Jas. E. Litel.
Geo. F. Marston.
C. J. Maynard.
W. G. Mazyck.
H. S. McCandlish.
Dr. E. A. Mearns.
Dr. J. H. Morrison.
A. de Monterosato.
M. D. Oehleet.
Dr. A. S. Packard.
H. A. Pilsbry.
C. E. Pleas.
W. J. Raymond.
John Riddell.
Dr. W. H. Rush.
J. A. Singley.
C. T. Simpson.
H. P. Smith.
Dr. E. A. Smith.
W. J. Spillman.
Dr. V. Sherki.
J. A. Stevenson.
Rev. G. W. Taylor.
Prof. J. L. Tilton.
Bryant Walker.
G. W. Webster.
W. W. Westgate.
J. J. White.
Prof. R. P. Whitfield.
M. B. Williamson.
Jos. Willcox.
Prof. A. Winchell.
Rev. H. W. Winkley.

Total of sixty-nine individuals, being an increase of twenty-four over the preceding year.

In addition to these the fossils and recent shells of the United States Commission, collected on the voyage around Cape Horn, were reported on at considerable length, for the series of reports describing the results of the voyage of the Fish Commission steamer *Albatross.*

SPECIAL RESEARCHES.

The part of this division in the correlation essays was the Plio-Miocene formation of the United States.

The notes on the literature have been completed. The rough draft of the historical review has been completed as far as Virginia, beginning at the northeastern extreme of the United States. The revision of the fauna of the Floridian section has proceeded as far as the Orthodont Gasteropods, which have been completed. The general review, of course, awaits the conclusion of the preliminary parts above noted. In this matter I have had valuable assistance from Mr. G. D. Harris, assistant paleontologist of the Division of Cenozoic Paleontology. I have already alluded to the report on the mollusks and brachiopods of the *Albatross* voyage, prepared at the request of the U. S. Fish Commissioner. This has appeared as part of the proceedings of the U. S. National Museum, comprising 144 pages of text and 10 plates, illustrating species, many of which are found in our Atlantic Tertiary beds. It contains also a discussion of the classification of the bivalve mollusks on the basis of the development of the hinge as illustrated in paleontological succession, as well as the recent forms. This discussion was separately published in the American Journal of Science for December, 1889.

There has also been printed by the U. S. National Museum, as No. 37 of its series of bulletins, the preliminary catalogue of shell-bearing mollusks and brachiopods of the southeastern coast of the United States, with illustrations of many of the species referred to in my report for the year ending June 30, 1889. This comprises a volume of 221 pages, with 74 plates, and includes a series of tables which show the geological and geographical range of over seventeen hundred species, illustrated by over a thousand figures. Most of these forms may occur in our later Tertiaries besides those which are actually known to do so, for which reason the numerous figures will be of use to all students of the paleontology of our later Tertiaries.

The investigation into the mollusk fauna of the Plio-Miocene of Florida, undertaken some years ago, has been carried as far as the end of the Orthodont Gasteropods, forming about half of the contemplated paper. This, as Part I, is actually being printed by the Wagner Free Institute of Science, Philadelphia, and will form volume 3 of their transactions, with about 150 pages of text and 12 plates, small folio, to be completed by a second part at a convenient time hereafter.

It will thus appear that routine work has not absorbed all the energies of the division, and that the progress being made in elucidating our invertebrate Cenozoic fauna is not unsatisfactory.

In conclusion, I would express my appreciation of the hearty manner in which those associated with me in the work of the division, without exception, have striven to increase its quantity and elevate its quality, by which endeavors the progress made has been rendered possible.

Very respectfully,

Wm. H. Dall,
Paleontologist.

Hon. J. W. Powell,
Director U. S. Geological Survey.

REPORT OF MR. LESTER F. WARD.

DIVISION OF PALEOBOTANY,
Washington, D. C., July 1, 1890.

SIR: I have the honor to submit the following report of the operations of the Division of Paleobotany during the fiscal year ending June 30, 1890.

FIELD WORK.

A large amount of the field work was accomplished during the year.

Prof. F. H. Knowlton left Washington on the 1st of July to investigate the fossil forests of New Mexico and Arizona and the paleobotany to the north and south of the Atlantic and Pacific Railroad. He made successful expeditions to the copper regions near Abiquiu and the Nacimiento Range in New Mexico, as well as to certain deposits in the vicinity of Las Vegas; he also visited most of the important fossil forests of Arizona and Nevada, as well as the celebrated one in California, near Calistoga Springs. Considerable time was spent by him in the vicinity of the San Francisco Mountains. From all these points Prof. Knowlton made valuable collections both of silicified woods and of other plant remains. He returned on October 24, having shipped all of his collections, consisting of five boxes, all of which reached Washington in safety. They will form the basis of a more scientific knowledge than has been heretofore gained of the character of the fossil forests and fossil plants in general of the Southwest. His efforts were especially directed to the collection of available material for the study of the internal structure of the silicified wood of those regions, concerning which, as yet, only a superficial knowledge has been obtained.

In the spring of the present year Prof. Knowlton having learned that the lignite deposits near the town of Brandon, in the State of Vermont, had been reopened, asked for instructions to visit those deposits, with a view to making a collection of the vegetable remains known to be abundant there and upon which alone a determination of the age of these lignite beds seems to depend. He accordingly spent the last half of May in making this investigation, which has resulted in very greatly enriching the flora of that deposit. The material obtained by him will receive early attention.

Mr. Charles S. Prosser was in the field from August 20 until September 30 investigating the Devonian plant-bearing beds of the State of New York. At Ithaca he collected a fine series of the problematical *Ptilophyton Vanuxemii* and its associated forms. In Ontario and Yates Counties the Genesee shales were carefully examined for fossil plants, and occasional specimens were found in various parts of the formation. A horizon in the upper part of the shales was noted in which fossil plants are more generally common than in the remainder of the formation and which contained several new species. It was found that this plant zone of the Genesee shales extends from Ithaca to the western part of Ontario County, and it is probable that it continues farther west in western New York. Previous to this fossil plants had been noted in the upper part of the Genesee shales near Ithaca, but the discovery of this plant zone, together with its distribution in western central New York, is an addition to the stratigraphical geology of the State. Plants were also collected in the Oneonta group (Hamilton) near Oxford, New York. Mr. Prosser's investigations carried him also into some of the northern counties of Pennsylvania, and collections were made from these parts. The material obtained by him reached Washington in safety in sixteen boxes.

In my report for the previous year mention was made of an investigation that was commenced in June, 1889, around the coasts of Martha's Vineyard and Nantucket. Two problems are there presented, first, the study of fossil-leaf impressions at Gay Head and the adjoining bluffs at the western end of Martha's Vineyard, and, secondly, the investigation of certain submerged forests at various points on the coasts of both islands.

To Mr. David White was intrusted the greater part of the work in this field, but I accompanied him on the initial trip in June, and again joined him on July 19, and remained with him until August 14, when we both left the field. Mr. White devoted the greater part of his time, until I arrived, to a thorough examination of the Gay Head section and of Weyquosque Cliff, on the south side of the island, as well as others in Chilmark and other parts of the coast, with a view to making a collection, if possible, of the leaf prints which have been reported from Gay Head for a very long time, but not in sufficient quantity or quality to be of any use in the determination of the age of that section. His investigations were in the highest degree successful, and an excellent series of the fossil plants was collected.

From July 19 to August 14 Mr. White and I devoted ourselves to a thorough geological reconnaissance of both islands and a study of the so-called submerged forests. These latter were not as distinct as we had hoped to find them, but everything was done that the nature of the case would permit, and collections were made which may throw some light upon the history of these islands.

The importance of the discoveries at Gay Head, which has become more and more apparent as the material has been elaborated, and the necessity for a continuance of the work, determined me to have it resumed as early as possible. Accordingly, on the 20th of June of the present year, I sent Mr. White a second time to this field with instructions to make further collections and a thorough study of the relations of these beds to those of the adjoining islands, Block Island and Long Island, and if possible to connect them with the Amboy clays of the State of New Jersey, with the flora of which that of Gay Head is identical.

During the months of May and June, 1890, considerable work was done upon the Triassic formation of Maryland and Virginia.

Early in May Mr. D. L. Shoemaker, proprietor of the Seneca sandstone quarry, brought me a specimen which had been taken from his quarry and which I at once recognized as what has been called Dendrophycus; although its vegetable and even its organic nature is still in dispute. It was a much finer specimen than I had seen or seen a figure of, and I decided to visit the quarry, which I did on the 14th in company with Mr. Prosser. We made a careful examination of the manner in which it occurs in the red sandstone of that formation, and collected a number of additional specimens.

An expedition was planned for a study of the Trias, which was carried out from June 2 to 20. The party consisted of Prof. Fontaine, Mr. Prosser, and myself, and the journey was made in a spring wagon with two horses. We first visited the Seneca sandstone quarries; traversed the belt to the Sugar Loaf Mountain, the Monocacy River, and Point of Rocks; crossed the Potomac at the last named place and followed the western margin of the belt to Leesburgh; passed diagonally over it to Manassas and Brentsville at its eastern margin, and again diagonally across, in a southwesterly direction, to Weaversville and Warrenton, which latter place lies considerably to the westward of its western margin; struck it again in the vicinity of Culpeper and followed it to Orange Court House and Barboursville, where it was supposed to terminate; but in proceeding to Charlottesville we rediscovered it within a few miles of that place at a point not hitherto reported. From Charlottesville we proceeded to the Richmond coal field; following the left bank of the Rivanna River, struck the coal field at Dover Mines, or Manakin, visiting the Carbon Hill mines in that vicinity; crossed the James River by ferry above Dover mines and proceeded to Midlothian and Clover Hill. We visited nearly every shaft that has been sunk in the Richmond coal field, some of the mines being now in operation, and made a thorough study of the material which is brought up from these pits. Fossil plants were found in greater or less quantity at nearly all points. Excellent localities for collecting were noted, especially at Carbon Hill, at the Gowrie shaft, and the New Stonehenge shaft near Midlothian, and in the Clover Hill region at the Bright Hope and Raccoon shafts. Remains of fossil fishes were found at the Sinking shaft at Midlothian, and at numerous other points.

The expedition was in the nature of a reconnaissance, and time did not permit of extended collections, but its chief object was to select localities which will hereafter be visited by members of the party, probably chiefly by Prof. Fontaine.

Prof. Fontaine reports the following additional field work accomplished by him:

> During the past summer I was occupied in examining and collecting from the basal beds of the Carboniferous formation of Virginia, the so-called Vespertine of Rogers.
>
> My object was to discover in these strata localities containing fossil plants, and to collect from them the flora of the formation. Several localities in Montgomery, Tazewell, and Pulaski Counties were visited and collections were made from them.
>
> These localities in Montgomery County gave a large number of specimens. Besides in the above named counties examinations were made on the line of the Chesapeake and Ohio Railroad, more especially at Lewis Tunnel, in Alleghany County, and a considerable collection of fossil plants was made there also.

OFFICE WORK.

The force of the division that have remained throughout the year are: Mr. David White, Mr. Charles S. Prosser, Prof. F. H. Knowlton, assistant paleontologists, Miss L. M. Schmidt, copyist, and Mr. F. von Dachenhausen, draughtsman, the last detailed from the Division of Illustrations. Those assistants who were employed only a portion of the year are as follows: Mr. Charles Bogan, laborer, from July 1 to 16; Mrs. J. A. Luce, copyist, July 1 to August 19; Mrs. A. W. Todd, copyist, July 1 to September 30; Prof. Leo Lesquereux, paleontologist, July 1 to October 25, the date of his death; Dr. George Latimer, clerk, July 1 to February 23; Miss Margaret Latimer, copyist, February 24 to March 18; Miss Emma Heiston, copyist, January 17 to March 31; Mr. T. E. Williard, laborer, April 1 to June 30; Mr. A. V. Gisiger, copyist, April 24 to June 30.

The classification of the office work of the division, as made in my last administrative report, will also be adopted in the present report, viz: first, the preparation of illustrations of fossil plants; second, the identification of fossil plants; third, the preparation of manuscript; fourth, proof-correcting; fifth, bibliographic work; sixth, catalogue work. To this may be added: seventh, care of collections.

(1) *The preparation of illustrations.*—There has been only one draughtsman at work on the fossil plants during the year, Mr. F. von Dachenhausen. The large and original series of Laramie types collected by me a number of years ago was completed by him during the month of November. The original drawings which were enlarged, have all been photographed and reduced to their natural size; three sets of these photographs are used in my work of identification, and these three sets have been mounted and arranged for study.

From this date until near the close of February, Mr. von Dachenhausen was engaged in drawing the fossil plants collected by Mr. White, at Gay Head, which are not yet completed. On February 26 he commenced work upon the manuscript plates of Prof. Lesquereux's monograph of the flora of the Dakota group. Prof. Lesquereux's drawings not being sufficiently adapted to the photo-engraving process, it has been found necessary for Mr. von Dachenhausen to go over all of the fainter lines with a dark pencil. A considerable number of the descriptions in Prof. Lesquereux's monograph are of specimens which belong to the collection of Mr. R. D. Lacoe, of Pittston, and none of these were figured. The great importance of having these specimens figured induced me to request Mr. Lacoe to loan the same for the purpose, which he very generously has done, and since April 5 Mr. von Dachenhausen has been engaged a considerable part of his time in making original drawings of them. They are now completed and will soon be returned to Mr. Lacoe.

In addition to this work Mr. von Dachenhausen has inked in a considerable number of drawings relating to internal structure prepared by Prof. Knowlton. He has also assisted me greatly in the study of several collections which have passed through my hands during the year by preparing pencil sketches to show the nervation of the more obscure specimens.

(2) *The identification of fossil plants.*—As soon as the types of the Laramie flora had been all drawn and the drawings photographed and mounted for study, I resumed work, upon a broader basis and in a more thorough manner, on my monograph of the Laramie group. Prior to this I had confined myself to the dicotyledonous leaves, omitting the lower forms. I was then in condition to take up all the forms and study them in their systematic order. I have devoted a considerable portion of nearly every day since that time, when not in the field, to the study of this flora and the identification of these Laramie types; and although much remains to be done great progress has been made with the work.

In addition to my work on the Laramie types I have examined, in a preliminary manner, and made a provisional report upon three collections that have been submitted to me by geologists who desired to know the bearing of the vegetable remains upon the age of the groups in which they were discovered. These collections were as follows:

1. A box of fossil plants from Prof. J. C. Branner, State geologist of Arkansas, made in October last. 2. A collection made by Mr. George F. Becker, from the Pliocene of California, submitted to me in March. 3. A large collection made by Mr. Emmons's assistants in Colorado, and submitted to me early in April. Upon this last I was engaged to the exclusion of other work of this class during the most of April and May.

In connection with his other work Mr. David White has spent a large part of his time in the study of the collections of fossil plants made by himself at Gay Head. He has selected the types for illustration and has determined the greater number of the species. He read a paper upon the subject at the meeting of the Geological Society of America held at New York in December, and hopes to prepare a bulletin for publication by the Geological Survey, after having completed his investigations the present year.

Since Mr. Prosser's return from the field he too has been engaged, as time would permit, upon the study of his collection of Devonian plants, and a paper is in course of preparation on the distribution of the plant zone, mentioned above, of the Genesee shales, and embracing a description of its fossil plants.

At the end of April Mr. Walter P. Jenney turned over to my Division a large collection of Carboniferous plants made in Missouri, and requested a report such as to indicate the probable position of the strata in which they were found. Mr. White immediately commenced a study of this collection and completed his report before leaving for the field.

Prof. Leo Lesquereux was engaged at the time of the final attack, from the effect of which he died, upon the study of the fossil flora of the Dakota group and in the preparation of his monograph of that flora.

Prof. Fontaine has been employed in the study, identification, and illustration of the Cretaceous plants collected by him in the vicinity of Tuscaloosa, Alabama.

(3) *The preparation of manuscript.*—In my last administrative report I gave an account of the progress which I had made in the preparation of my essay on the homotactic correlation of American plant-bearing strata. The manuscript of the pre-Carboniferous had been completed, and that of the Carboniferous was in an advanced stage of preparation. It remained to discuss the elaborate tables which had been prepared of that formation, and this was done during the month of July. To enable me to do so I found it necessary to have an additional table prepared, showing numerically the foreign distribution of American Carboniferous species. This was typewritten and engrossed, completing the essay down to the close of the Carboniferous.

Work upon this essay was resumed toward the close of November, after my return from the field. Taking up the formations in their ascending order I found the American Trias next to require attention. The literature of this subject is so scattered and difficult of access that more than two months were consumed in compilation and in ascertaining what fossil plants had been found in that formation. Tables of distribution of these fossil plants were prepared by Messrs. White and Prosser early in the month of February, from data that I had collected, and near the middle of that month I resumed work upon the manuscript. To facilitate this work two phonograph-graphophones were furnished me, one of which I have used for dictation, the other being employed exclusively in reproducing the manuscript. Miss L. M. Schmidt was intrusted with the reproducing instrument and soon acquired great facility in this work, transferring it directly to the typewriter. By this means I have been able to accomplish much more in the same time than I could have done by the usual methods of manuscript writing; but the other work which it was necessary for Miss Schmidt to perform in the division put a limit to the amount of manuscript that she could transfer, so that it has not been possible to advance much more rapidly than formerly with the essay. The great gain has been, however, that it required only a small portion of my time to dictate the amount that can be transcribed each day, leaving me a much larger amount of time to be devoted to the study of fossils and to other work. This, in the growing condition of collections, has proved to be of the greatest advantage; and, indeed, it has become an absolute necessity that I should have more time for the study of fossils. The rough draft of the manuscript relating to the Trias was completed near the end of May, and the greater part of it was revised before I left, and engrossed during my absence in June.

Early in November the manuscript and drawings of Prof. Lesquereux's unfinished monograph of the flora of the Dakota Group was sent to me, at my request, by Mr. L. Lesquereux, jr., son of Prof. Lesquereux, and later the collections that had been purchased by the Survey from Mr. Charles Sternberg, and those from Prof. Snow were also sent for use in completing this manuscript. The work of revising, editing, and perfecting this volume was intrusted to Prof. F. H. Knowlton, who has devoted a large part of his time during the year to this work. The difficulties which he has encountered have been very great. Prior to the purchase of the Sternberg collection and to the receipt of the Snow collection, Prof. Lesquereux had submitted this monograph for publication; but desiring to have it constitute as complete a representation of the flora of the Dakota group as possible, I requested him to reopen it and to embody in it the results of his study of these collections. He did so, and besides this he added a great amount of matter derived from a collection loaned him by Mr. Lacoe. It was while engaged in the gigantic task of embodying all this information in the unfinished monograph that Prof. Lesquereux's health gave way and his death occurred.

Naturally enough the material was left in a state of confusion. Many of the determinations were only provisional, many of the descriptions incomplete. There were figures without descriptions or names, and there were specimens which had been named without either descriptions or figures. Many of the numbers were incapable of identification in any of the lists that could be obtained. Finally a large number of the specimens were entirely wanting, and no names or descriptions were attached, and it required a long time and much correspondence and investigation to ascertain where these missing fossils were. The greater number of them were found to be in Mr. Lacoe's collection, and, as already mentioned, Mr. Lacoe was so good as to loan them to the Survey to be used in the preparation of this manuscript. Prof. Knowlton is entitled to great credit for the skill and success with which he has unraveled the intricacies of this difficult work. The manuscript has been carefully corrected, many new descriptions added, many new drawings made, and new plates formed, and the whole embodied in a large, comprehensive, and systematic work. With the exception of the redrafting of the table of distribution, the manuscript is now complete; but, owing to the large number of corrections and interlineations, it is thought best to have it all engrossed upon the typewriter before it is submitted for publication.

Dr. J. S. Newberry has been engaged during the year in the preparation of two monographs for publication by the Survey. One of these is to contain the descriptions and illustrations of a large number of fossil plants of the Cretaceous and Tertiary of the West, largely from the Laramie group. Many of the plates containing the illustrations of these fossils have long been printed; additional ones are being prepared, and the text for the whole completed. This work is now in an advanced state. The other volume relates to the flora of the Amboy clays, upon which Dr. Newberry has long been engaged, and which is now also approaching completion.

(4) *Proof correcting.*—Proof of the index of my paper on the Geographical Distribution of Fossil Plants commenced to arrive on the 9th of September.

Prof. Knowlton's Bulletin on the Fossil Wood and Lignite of the Potomac Formation was published during the year, and the proofs were corrected in my office during the first half of October.

(5) *Bibliographic work.*—This work has been continued by Mr. White, when not in the field, during the entire year, and rapid progress has been made. Blank library cards have been obtained, and the work of transferring the data to such cards has been commenced. The plan is to publish the catalogue directly from these cards as manuscript, and therefore as soon as all these cards are written the work will be ready for the press. This, of course, will require considerable time, partly because it is a large work and partly because Mr. White has other official duties to perform. When not in the field or at work on his collections he is engaged in correcting and perfecting the original rough cards that have been in use from the beginning. After these are corrected they are placed in the hands of the typewriter operator, who transfers them in typewriting to the new cards of larger size.

(6) *Catalogue work.*—The work of cataloguing the books and papers relating to fossil plants has been continued throughout the year

by all the force that was not specially employed on other work. As it had been some time since any of these newly written slips had been installed in the general catalogue a very large amount of this work had accumulated, and on his return from the field Mr. Prosser, early in October, commenced the work of revising and putting away this accumulated material. As the cataloguing has been done, to a large extent, by unskilled hands, whereby many errors are necessarily committed, and as there is great diversity among the different authors with regard to the mode of writing the names, the work of correcting the slips is very great, and these last accumulations were not finally installed until the 1st of February.

On the completion of this work the general slip index of fossil plants was considered to be sufficiently advanced to render it practicable to commence the work of preparing a general list of all the species, such list to be used as a basis for future work on the synonymy. Before this list could be begun, however, it was found necessary to go through the index and select what are called type slips, viz, the slips that are to be finally adopted as the correct ones and to be written in the list. As there are now in the slip index about one hundred and sixty thousand slips, and as there are probably not more than ten thousand species of fossil plants, it will be seen that upon an average the index contains sixteen slips to each species, and from these slips the one type slip must be selected. It will generally be the first slip in the chronological order of their publication; but in many cases the original slip is not typical and one of later date is selected. All this involves a great amount of literary research, and Mr. Prosser has been engaged in this work since the last date mentioned.

A large number of works still remain uncatalogued and these are, for the most part, the most difficult ones and have been postponed from time to time, in the hope that eventually a competent cataloguer might be appointed in the division capable of reading the foreign languages and of cataloguing them in an intelligible manner. I have several times expressed a desire for the appointment of such an expert, and as it seemed impossible to complete the work without one, I renewed my application in April last and finally obtained, through the Civil Service Commission, the services of Mr. A. V. Gisiger, who reported for duty on the 24th of May. Mr. Gisiger is a man of good education, equally familiar with the German, French, English and Italian languages; he was placed under Mr. Prosser's immediate charge and assigned to the work of cataloguing the foreign books, which work he still continues to perform to Mr. Prosser's entire satisfaction and my own.

(7) *Care of the collections.*—The number and magnitude of the collections of fossil plants that have been coming to the Division of Paleobotany for several years past has finally made it imperative

that there should be some one specially intrusted with their care and with the duty of opening boxes, arranging collections, labeling specimens, keeping a record of the materials, and in general seeing to it that all specimens should be accessible, and that no error or confusion should exist among these various collections.

In March last I applied for an assistant to do this work, and on April 1 Mr. T. E. Williard was appointed for this purpose. He commenced work immediately under the special direction of Prof. Knowlton and is still employed upon it.

Very respectfully, your obedient servant,

LESTER F. WARD,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF PROF. SAMUEL H. SCUDDER.

DIVISION OF FOSSIL INSECTS,
Cambridge, Mass., June 30, 1890.

SIR: The first quarter of the last official year was spent in the field. Florissant, the crest of the Roan Mountains, and the lower White River valley in Colorado, and Green River City and Fossil, in Wyoming, were all visited with more or less success. I was accompanied by two assistants, Mr. Joseph L. Goodale and Mr. Carleton E. Davis, besides a man who served as cook and teamster. At Florissant, we found that far more labor is required now than formerly to reach the richer insect-bearing shales, nearly or quite all the easy exposures having been worked; though, with plenty of heavy labor in removing the overlying strata, the actual supply is practically inexhaustible. About seven hundred specimens were obtained here, more than one third of them Hymenoptera. At Green River City, Wyoming, a new locality was discovered from which in a short time over two hundred specimens were collected, indicating that a great deal may be obtained by careful search, although the original pocket from which specimens had hitherto been procured is entirely exhausted. At Fossil, Wyoming, little was obtained.

The principal object of the summer's work, however, was the exploration of the lower White River of Colorado and the adjacent country for beds containing insects. There had been found on the crest of the Roan Mountains, forming the watershed between the White and Grand rivers, a few leaves of plants by Dr. A. C. Peale which Lesquereux had determined as identical with those of Florissant, and it seemed not unlikely that a party searching specially for insects on this crest, regarded by the geologists of the Hayden Survey as capped by the Green River shales, would be rewarded with success. Beds containing fossil insects were also detected by Mr. William Denton twenty-five years ago at two points said to be 60 miles apart on the lower White River, but had never since been recovered.

We accordingly procured an outfit at Grand Junction, and made our way to the summit of the divide by a rough road leading to Rangely on the White River, and after examining with some care a considerable range of territory, made our way to Rangely and then to the Utah border where we camped and explored for a fortnight, returning by the road we came and renewing our work on the summit of the Roan Mountains.

On the Roan Mountains we found insects at several different horizons, but only in one spot in any remarkable number. This was in the highest beds about five miles east of our camp, and had we been able to remain longer, we should undoubtedly have been able to trace this bed over a considerable extent of territory; it was on the whole the richest locality we found during the entire summer and the fossils were similar in character to those of the White River beds, but it was not the same bed as the one which yielded plant remains to the earlier parties, the presence of which was recognized at another spot just before our final departure.

On the White River we were unable to identify with certainty the exact locality where Denton obtained his fossils, but we undoubtedly struck the same beds, which occur for at least 25 miles up and down the river in the buttes overlooking it. Insects were obtained at a great many horizons, but the greatest success was met with in working the very highest and very lowest beds. The general result was the discovery that insect-bearing strata here cover hundreds of square miles of territory, in some places so abundantly that one may find hundreds of specimens within a square meter. A great portion of the shales, however, at certain places, notably in the next to the highest layers about a thousand feet above the river bottom, are strewn so thickly with dipterous and especially syrphid larvæ as to cover the entire surface in great masses, obscuring all other insect remains; but enough was seen to show that this region is the richest and most extensive for fossil insects that has ever been found in any part of the world.

Most of the time having been given to search over considerable areas both here and on the Roan Mountains, the actual collections were not so great as they might have been, but about one thousand specimens were brought home, besides a considerable amount of material from the better beds of the Roan Mountains, which has not yet been fully examined. As nearly two-thirds of these were Coleoptera, the difference in general character between these western Colorado localities and Florissant is evident.

During the rest of the year much time has been given to assorting and cataloguing the collections of the summer. The Hemiptera have been carefully elaborated, a work of many months, and work upon the rynchophorous Coleoptera has begun. A classed and annotated bibliography of fossil insects was completed during the year and submitted for printing as a bulletin. The catalogue of described fossil insects mentioned in previous reports is practically completed in its first draft, and only requires revision, which can proceed with some rapidity. Much time has been given to the revision of drawings of fossil insects and to the proof of the volume on Tertiary insects now passing through the press as volume 13 of the Hayden series of geological reports, which treats of over six hundred insects.

The work of the artist has been divided this year principally between the Hymenoptera and Hemiptera. Fifty-nine drawings of the former have been finished in ink, including the completion of those not finished last year; seventy-eight similar drawings of Hemiptera have been made, largely for the illustration of the plant lice, and one of Neuroptera, besides five pencil drawings to illustrate a butterfly and one picturing a beetle.

Respectfully submitted.

SAMUEL H. SCUDDER,
Paleontologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF PROF. F. W. CLARKE.

DIVISION OF CHEMISTRY,
Washington, D. C., July 3, 1890.

SIR: During the fiscal year 1889-'90 the work in the Division of Chemistry and Physics has made satisfactory progress. The personnel of the division has remained in general the same as in the preceding year, except that the vacancies caused by the resignations of J. E. Whitfield and Charles Catlett in the spring of 1889 were filled by the appointment as assistant chemists of H. N. Stokes and E. A. Schneider. Towards the close of 1889 the San Francisco laboratory was discontinued, and in January, 1890, Dr. W. H. Melville was transferred thence to the laboratory in Washington.

On the chemical side the work of the division is naturally divided into the routine of analysis for other divisions and its own purely scientific researches.

Of analyses, two hundred and thirty-nine have been reported during the year, including series of rocks from Colorado, California, the Yellowstone Park, etc.; over fifty samples of Florida phosphates; and the usual number of iron, manganese, and other ores; coals, waters, clays, and so on. No special note need be made here concerning the details of this routine. The researches, however, have been more than ordinarily important and demand fuller consideration.

Throughout the year, jointly with Dr. Schneider, I have been carrying out an elaborate investigation upon the chemical constitution of certain magnesian silicates. Talc, the chlorites, several micas, vermiculites, and serpentine have been the special objects of study, and entirely new lines of attack upon the problem of their chemical structure have been opened. The new methods of investigation devised in the course of this research will now be applied to other series of silicates.

Early in the year I also made a careful computation of the relative abundance of the chemical elements in the earth's crust, reaching conclusions of geological interest.

The investigation begun over a year ago by Dr. W. F. Hillebrand upon the composition of uraninite is now finished. Uraninites from Connecticut, North Carolina, and Colorado were analyzed, and also a fine series of Scandinavian uraninites, kindly sent to us by Prof. Brögger and Baron Nordenskiöld from Stockholm, and important results were reached.

Mr. L. G. Eakins has analyzed seven new meteorites during the year. They represent the Travis County, Texas, stone; irons from Erath County, Texas, Ellenboro', North Carolina; the pallasite from Kiowa County, Kansas; the stone which fell on May 2, 1890, in Winnebago County, Iowa, and two meteorites from Chili.

Dr. W. H. Melville, in addition to his routine work upon the California collections, has made a considerable number of valuable crystallographic measurements and a very complete and interesting investigation, both chemical and morphological, upon crystallized metacinnabarite from New Almaden.

Finally, Mr. H. N. Stokes has examined a remarkable mineral resin from Montana and a unique petroleum from Cuba, the latter being peculiar in its odor, which very closely resembles the perfume of red cedar. He is now engaged upon a revision of the silicic ethers, a research of fundamental importance to a proper understanding of the silicates.

Of field work for mineralogical progress, a moderate amount has been done. In August I visited localities at Bolton, Massachusetts, and in the iron region of Lake Champlain. A little later Dr. Hillebrand went to the Far West and made large collections at Silver City and Georgetown, New Mexico; Clifton, Bisbee, Tucson, Yuma County, Phœnix, Prescott, and Jerome, Arizona. His collection of vanadium minerals from Arizona is of surprising beauty and richness. He also visited the locality for dumortierite at Clip, Arizona, and brought in a large supply of material. In April Mr. Eakins made a short trip to Greenville County, South Carolina, and examined certain granite veins of that region.

The physical laboratory, as heretofore, has been in charge of Drs. Carl Barus and William Hallock. During the year Dr. Barus has been chiefly occupied with questions relating to the thermodynamics of liquids; questions which have obvious geologic interest. A large number of experiments were made with liquids boiling below 300°, under pressure within 700 atmospheres, and at temperatures less than 310°. The results throw much light upon the nature of the isometrics, or lines of constant liquid volume, when temperature and pressure vary.

For the special study of the isometrics of liquids Dr. Barus has devised the most powerful methods. A screw compressor, capable of generating pressures much above 2,000 atmospheres, has been constructed, and through half a year of use has given complete satisfaction. In this connection the gauges used for measuring high pressures and the conditions of their accuracy have been minutely studied. Incidentally, the effect of pressure on electromotive force was investigated.

Direct work on the isometrics of liquids is now far advanced, covering intervals of 2,000 atmospheres and 200°. Steps have been taken to obtain additional apparatus by which the pressure range can be extended to 3,000 atmospheres, with temperature varying from −50° to 400° C. An apparatus for measuring the difference in specific volume of solid and liquid slag in the region of fusion has been constructed and will be thoroughly tested in the near future. The same is true of the methods devised for studying the relations between pressure and melting point through long ranges of pressure.

Finally, Dr. Barus has succeeded in expressing the viscosity of the three states of aggregation absolutely: that is, conformably with a given uniform scale. The results show an astounding range of variation in what might be appropriately called the solidity of our material environment.

Dr. Hallock has continued his study of the expansion of rocks by heat, and eighteen bars of six typical building stones have been prepared for examination. For comparison with them the coefficient of expansion of a standard brass bar was directly determined, and much work was done in the preparation of apparatus. Up to date the six rocks have been examined in duplicate by the comparative method and are now ready to be checked by direct determination. Dr. Hallock has also rendered much assistance to other members of the division.

Very respectfully,

F. W. Clarke,
Chief Chemist.

Hon. J. W. Powell,
Director U. S. Geological Survey.

REPORT OF MR. R. S. WOODWARD.

MATHEMATICAL DIVISION,
Washington, D. C., June 30, 1890.

SIR: I have the honor to submit the following report concerning work done in the Mathematical Division during the year ending June 30, 1890.

As explained in previous reports, the work of the Mathematical Division may be broadly designated as falling under two heads, viz: (1) work auxiliary to the operations of the Divisions of Topography, and (2) miscellaneous work whose character is chiefly mathematical.

WORK FOR THE DIVISIONS OF TOPOGRAPHY.

The usual attention was given during the year to current computations in aid of the topographic work. Much time also was given to the business of consultation with the topographers and geographers of the Survey concerning the technical details of their operations.

A paper giving a detailed statement of methods essential to be followed in the measurement of horizontal angles was prepared for the guidance of the topographers and geographers in the execution of secondary triangulation.

Six new theodolites made by Fauth & Co. in accordance with specifications drawn by me were examined during the year. Considerable time was spent, also, in giving assistance to members of the Survey in the practical use of these instruments.

Specifications were prepared for two new astronomical transits of the best modern type.

As a member of the Survey board of special examiners for the U. S. Civil Service Commission, several sets of examination papers were drawn up for use in the topographic aid's examinations conducted by the Commission. The papers submitted by candidates in these examinations were also examined and rated by me.

In the latter part of October, 1889, I went into the field and determined the latitudes and longitudes of Speareville, Kansas; Boisé City, Idaho, and Cisco, Texas. The longitudes were determined with reference to St. Louis, Missouri, the observations at this point being made by Prof. H. S. Pritchett, director of the observatory of Washington University. During May and the early part of June of the present year I was again in the field for the purpose of determining the latitude and longitude of a point in El Paso County, Texas, and fixing from such point the position of the one hundred and fifth meridian in that county. The longitude of this point in Texas was also determined by the aid of Prof. Pritchett and his admirable equipment at St. Louis. In the field work, which, in addition to the astronomical observations and computations, required a considerable amount of triangulation, I had the valuable assistance of Mr. A. P. Davis, topographer of the Survey.

Since the details of this astronomical work will be made the subject of a special report, it will suffice here to give simply the definitive latitudes and longitudes of the observing piers, which are substantial masonry structures, used at the several places.

Astronomical coordinates of observing piers.

	Latitude.			Longitude.		
	°	′	″	°	′	
Speareville, Kansas	37	51	06.34	99	45	10.05
Boisé City, Idaho	43	35	57.98	116	13	04.04
Cisco, Texas	32	23	31.45	98	58	55.56
Sierra Blanca, Texas	31	10	27.63	105	21	24.96

MISCELLANEOUS WORK.

The miscellaneous work of the division, though requiring a considerable amount of time in the aggregate, consisted mostly of short investigations for or consultation with other members of the Survey. On the other hand, some few memoirs submitted to me for critical examination, demanded a good deal of attention.

Of the many calculations made during the year the most noteworthy is that undertaken for Prof. F. W. Clarke, chief of the Division of Chemistry. His least-square adjustment of the ratios of the atomic weights of the chemical elements requires the solution of thirty simultaneous equations. This work has been carried on by Mr. B. C. Washington, jr., when not occupied by other duties, since April last.

Owing to engrossing occupation with the field and other work mentioned above, but little progress was made with the special questions in physical geology, to which allusion has been made in previous reports.

I was assisted throughout the year by Mr. Washington, who made most of the computations and performed all of the clerical duties required in the work of the division. During the months of February and March, 1890, Mr. S. S. Gannett was assigned to the division and made most of the calculations required by my astronomical work of the previous year. In field work I had the assistance of Mr. H. L. Baldwin, jr., at Speareville, Kansas; of Mr. W. T. Griswold at Boisé City, Idaho; of Mr. R. U. Goode at Cisco, Texas; and of Mr. A. P. Davis at Sierra Blanca, Texas.

Very respectfully, your obedient servant,

R. S. WOODWARD,
Chief Geographer.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF DR. DAVID T. DAY.

DIVISION OF MINING STATISTICS AND TECHNOLOGY,
Washington, D. C., June 30, 1890.

SIR: I have the honor to present the following administrative report of the operations of the Division of Mining Statistics and Technology for the fiscal year 1890. At the beginning of the year the force under my charge was occupied in preparing a report called "Mineral Resources of the United States, 1888," covering the statistics of production for the previous calendar year. This work has been carried on during the entire year and the completed manuscript was presented to you for publication on March 29. The revision of the proof was completed May 26, and the preparation of a complete index of this and the preceding volumes of the series is now going forward. In addition to the preparation of these statistics a large amount of general correspondence has been carried on in response to requests for statistical and technical information relative to the mineral resources of the United States.

On June 24 I received instructions from you to take up in behalf of the Geological Survey the collection of the mineral statistics of the United States for the Eleventh Census, and to carry this on in conjunction with the work of preparing a volume entitled "Mineral Resources of the United States, 1889." Under a commission from the Superintendent of Census bearing date of July 18 this work has been actively prosecuted. A general plan for collecting these statistics was formulated and approved by the Superintendent of Census, and during the months of August, September, and October the work of carrying out this mineral census was subdivided among preeminent experts throughout the United States. After formulating proper schedules the active prosecution of collecting this information, designed primarily for the Census Bureau, was actively commenced at the beginning of the calendar year 1890, and at this date the inquiry is well advanced. By arrangement with the Superintendent of Census the data thus collected for the Census Bureau will be accessible for use in publishing a volume to be called "Mineral Resources of the United States, 1889" as soon as preliminary publication is given to the material by census bulletins.

On August 2 Mr. Jefferson Middleton, clerk U. S. Geological Survey and one of my staff, was transferred to a similar position in the Census Office and in that Bureau has continued to act as the principal secretary in carrying on this work. The other regular member of my staff is Mr. William A. Raborg. The work of both of these gentlemen has been eminently satisfactory. Mr. Raborg was, on April 19, detailed as a special agent without compensation on the census force and directed to assist in the collection of the mineral statistics at Denver, Colorado, where he is still employed at the close of the fiscal year.

Mr. Albert Williams, jr., who holds an appointment as geologist, U. S. Geological Survey, has been occasionally employed.

Respectfully submitted.

DAVID T. DAY,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF MR. W. A. CROFFUT.

EDITORIAL DIVISION,
Washington, D. C., June 30, 1890.

SIR: The manuscripts which the Director has accepted and concluded to publish as annual reports, papers, bulletins, and monographs, and the proofs from the Government Printing Office, have occupied the attention of this division during the fiscal year. I have pleasure in announcing that, with the cordial cooperation of the Public Printer, the publication of the annual reports of the Survey has been brought up to date, and almost all of the bulletins and monographs have been put in type. The amount of editorial work involved is not adequately indicated by the accompanying tabular statement, which may be regarded only as a measure of progress made.

Manuscripts read.	Proofs read.	Published.
Tenth annual. Eleventh annual. Monograph XVII. Bulletins 60, 61, 62, 63, 64, 65, 66, 67, 68, 69. Mineral Resources, sixth volume.	Ninth annual. Tenth annual. Monographs I, XV, XVI. Bulletins 54, 55, 56, 57, 58, 59, 60, 61, 63, 64, 66. Mineral Resources, sixth volume.	Eighth annual. Monographs XV, XVI. Bulletins 53, 54, 55, 56, 57, 59, 60. Mineral Resources, sixth volume.

The following are the monographs and bulletins thus designated:

MONOGRAPHS.

I. Lake Bonneville, by Grove Karl Gilbert.
XV. The Potomac or Younger Mesozoic Flora, by William Morris Fontaine.
XVI. The Paleozoic Fishes of North America, by John Strong Newberry.
XVII. The Penokee Iron-bearing Series of Northern Wisconsin and Michigan, by Roland D. Irving and C. R. Van Hise.

BULLETINS.

53. The Geology of Nantucket, by Nathaniel Southgate Shaler.

54. On the Thermo-electric Measurement of High Temperatures, by Carl Barus.

55. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1886-'87, by Frank Wigglesworth Clarke, Chief Chemist, with papers by R. B. Riggs, W. F. Hillebrand, H. S. Washington, J. E. Whitfield, and William Hallock.

56. Fossil Wood and Lignite of the Potomac Formation, by Frank Hall Knowlton.

57. A Geological Reconnaissance in Southwestern Kansas, by Robert Hay.

58. The Glacial Boundary in Western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, by George Frederick Wright, with an introduction by Thomas Chrowder Chamberlin.

59. The Gabbros and Associated Rocks in Delaware, by Frederick D. Chester.

60. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1887-'88, by F. W. Clarke, Chief Chemist, papers by T. M. Chatard, J. E. Whitfield, L. G. Eakins, R. B. Warder, Carl Barus, and William Hallock.

61. Contributions to the Mineralogy of the Pacific Coast, by William Harlow Melville and Waldemar Lindgren.

62. The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan; a contribution to the subject of dynamic metamorphism in eruptive rocks, by George Huntington Williams, with an introduction by R. D. Irving.

63. A Bibliography of Paleozoic Crustacea from 1698 to 1889, including a list of North American Species and a Systematic Arrangement of Genera, by Anthony W. Vogdes.

64. A report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1888-'89, by F. W. Clarke, Chief Chemist, with papers by Charles Catlett, W. F. Hillebrand, J. E. Whitfield, J. S. Diller, and William Hallock.

65. Comparative Stratigraphy of the Bituminous Coal Rocks of the northern half of the Appalachian field, by I. C. White.

66. On a Group of Volcanic Rocks from the Tewan Mountains, New Mexico, and on the occurrence of primary quartz in certain basalts, by Joseph Paxson Iddings.

67. Relations of the Traps of the Newark System in the New Jersey region, by Nelson H. Darton.

68. Earthquakes in California in 1889, by J. E. Keeler.

69. A Classed and Annotated Bibliography of Fossil Insects, by Samuel Hubbard Scudder.

Besides the work thus outlined this division has during the year read in copy and proof volume 13 of Hayden's Survey and several thousand pages of the publications of the Bureau of Enthology.

Respectfully,

W. A. Croffut,
Executive Officer in Charge.

Hon. J. W. Powell,
Director U. S. Geological Survey.

REPORT OF MR. DE LANCEY W. GILL.

DIVISION OF ILLUSTRATIONS,
Washington, D. C., June 30, 1890.

SIR: I have the honor to submit the following statement of the work done in the division under my charge during the fiscal year ending to-day.

Since assuming charge of this division I have classified the work of the various draughtsmen in such a way as to obtain the best results as to quality, together with the largest possible output. The work I have classified approximately as follows:

(1) Topographic and geologic map drawing. The preparation of geologic sections and diagrams, lettering, etc.

(2) Paleontologic drawing.

(3) The drawing of geologic landscapes and specimens.

At the beginning of the present fiscal year the work of the division had increased to such an extent that it became necessary to employ three additional draughtsmen. These men were selected with special reference to their knowledge and skill in scientific drawing. Their work for the year shows a thoroughly satisfactory result. This increase in the personnel of the division enables us to show greater uniformity of work and a much less cost of production than formerly.

The personnel of the division is as follows: John L. Ridgway, Daniel W. Cronin, H. Hobart Nichols, H. A. C. Hunter, F. W. von Dachenhausen, Charles R. Keys. Mr. Ridgway has been engaged for the last year principally in completing a series of drawings of Cambrian fossils for Mr. C. D. Walcott; Mr. Cronin in miscellaneous map and geologic diagram work and lettering; Mr. Nichols in geologic landscape drawing; Mr. Hunter in miscellaneous specimens and diagrams; Mr. von Dachenhausen in paleontologic drawing for Prof. Lester F. Ward; Mr. Keys, whose services date from May 17, 1890, on a series of drawings of crinoids for and under the supervision of Prof. William B. Clark.

Nine hundred and sixty drawings have been produced by the draughtsmen of this division since the beginning of the fiscal year, viz:

Paleontologic	500
Geologic sections and diagrams	377
Landscapes	38
Maps	23
Objects	22

One annual report, one monograph, and eight bulletins have been transmitted through this division within the fiscal year. The illustrations for these publications were classified for engraving as follows:

Chromo-lithography	30
Wood engraving	29
Half tone	72
Heliotype	11
Photo-engraving	369

On account of the great press of work in the office no field work was done this year.

The photographic work of the Survey has been conducted as in previous years under the able management of Mr. J. K. Hillers. No field work has been undertaken by him or his assistants this year.

The following is a statement of work done in the photographic laboratory during the fiscal year ending June 30, 1890.

Negatives.		Prints.		Transparencies.	
Size.	Number.	Size.	Number.	Size.	Number.
28 by 34	175	28 by 34	1,043	28 by 34	19
22 by 28	44	22 by 28	164	20 by 24	15
20 by 24	399	20 by 24	2,656	....	....
14 by 17	124	14 by 17	423	....	....
11 by 14	261	11 by 14	2,385	....	....
8 by 10	292	8 by 10	927	....	....
6¼ by 8½	110	6½ by 8½	333	....	....
5 by 8	398	5 by 8	1,209	....	....

Very respectfully, your obedient servant,

De Lancey W. Gill,
In charge of Division of Illustrations.

To Hon. J. W. Powell,
Director U. S. Geological Survey.

REPORT OF MR. S. J. KÜBEL.

Engraving Division,
Washington, D. C., June 30, 1890.

Sir: I have the honor to submit the following report upon the operations of the Engraving Division from the date of its beginning up to and including June 30, 1890:

On February 15, 1890, I entered upon my duties and began the work of organization. It became necessary to arrange for the purchase of the plant for the engraving and printing rooms, and for the engagement of the force of employés. Orders for office furniture, instruments, and material were placed with various dealers; some purchases were made in open market, and more important ones subjected to bids. Correspondence and conference were had with a number of engravers and printers with a view to their engagement. In late February and early March I visited Philadelphia, New York, and Boston, to inquire into the most approved methods followed in the larger engraving and printing houses, to procure a force of engravers and printers, and to arrange for the purchase of a plant. Conferences were had with some of the leading Northern firms of lithographers and engravers, and through their courtesy inspection was made of their methods, processes, and operations.

In the selection of engravers special stress was laid upon their capabilities for performing the various classes of work of engraving entering into the composition of the atlas sheets. Engravers generally are specialists—known as letterers, topographical engravers, etc., from the fact of having devoted themselves more especially to one or the other of various branches of engraving. In the economical production of original engraved map work, the preferable method of operating would be the classification and distribution of the work among the engravers with regard to the special efficiencies of the individuals employed. On the other hand, in the rapid and accurate performance of work of revision, particularly where the publishing of maps in colors necessitates the consideration of several plates in connection with such revision, the above method of specializing would not, in most cases, give the best results. Accordingly, as much of the work to be performed by this division is of the nature of revision, it was deemed advisable to select a force of employés with especial adaptability for this work.

Careful attention was also given to the selection of a printer, as the duties are varied and delicate. He is required to make proofs of the engraved plates by direct lithographic and zincographic methods, and also to aid in experimental work for the development of economic processes.

On the recommendation of the Director the following persons were appointed by the Secretary of the Interior:

Name.	Residence.	Date of appointment.	Designation.
W. D. Evans	Baltimore, Maryland	Mar. 15, 1890	Engraver.
H. T. Knight	Washington, District of Columbia	Mar. 20, 1890	Do.
O. J. Stuart	New York, New York	Apr. 1, 1890	Do.
E. H. Daniel	Washington, District of Columbia	Apr. 1, 1890	Do.
D. Barr	New York, New York	Apr. 7, 1890	Printer.

The work of engraving and printing was begun immediately upon the installation of the plant.

Up to the date of this report revision and correction of different kinds have been made on sixty different atlas sheets, including the entire set of Rhode Island sheets, which received final revision.

Four new sheets have been taken up for original engraving, viz: Tipton sheet, Iowa; Durant sheet, Iowa; Larned sheet, Kansas; Cheney sheet, Kansas. Of this number the Durant and Tipton sheets have been finished, and a proof edition of the latter has been printed.

Preliminary studies bearing upon the engraving of a set of standard plates for geologic color-printing have been begun and are still in progress. Various methods for their execution have been discussed, trials made, and proofs submitted.

The printer has been occupied with preparing stones, proving work for the use of engravers and for purposes of revision, transferring from plate to stone, and printing office editions of revised atlas sheets, as well as of newly engraved plates. Practical test was made of a sample of native lithographic stone from Texas.

In the prosecution of the work of the division that of revision is primarily considered. When a supply of proofs is required, the plates to be printed are taken up and revised to the latest data, and an edition, usually of two hundred and fifty copies, is printed. In most cases fifty copies of these are printed on Linaura fabric for field use; the remaining copies are on paper.

The engraving of new matter alternates with the work of revision, precedence being given the latter.

The division is also charged with the care and handling of the copper plates for purposes of transportation and the general supervision of plates as received from contractors.

Records are kept of the time consumed in the work and the cost of the same, so that accurate account may be had of the cost of each separate piece of work.

The plant of the division consists of two Parke lithographic presses, a full supply of lithographic stones, inks, colors, paper, etc.; engraving desks, and instruments, etc., and arrangements have been made for the purchase of a stone-grinding machine, a routing machine, a plate press, and a motor.

Very respectfully,

S. J. KÜBEL,
Chief Engraver.

HON. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF MR. CHARLES C. DARWIN.

Division of Library and Documents,
Washington, D. C., July 1, 1890.

Sir: I have the honor to submit the annual report of work done during the fiscal year just closed in the division of library and documents by its three branches of library, documents, and correspondence.

LIBRARY.

The library needs, more than any other part of the Survey, a permanent and appropriate abiding place. Confined in quarters ill suited for library conveniences and intended only for business purposes, it has overflowed into rooms in the cellars and upon the second, fourth, and fifth stories, until the labor of administering it is doubled by the difficulties of its environment. No confusion has yet resulted from this condition, and the current work has been kept well up to date. The books acquired during the year are all catalogued, and but two or three hundred pamphlets are yet to be attended to. The volumes in the duplicate room have been arranged, numbered, and so catalogued that they are readily accessible. I greatly desire during the coming year to print and distribute this card catalogue, confident that there would result exchanges between this and other libraries which would benefit all parties. The books and pamphlets now in the library number 65,472.

Contents of the library June 30, 1890.

BOOKS.			
On hand June 30, 1889:			
Received by exchange	17,953		
Received by purchase	6,347		
		24,300	
Received during the last year:			
By exchange	1,290		
By purchase	1,925		
		3,215	
			27,515
PAMPHLETS.			
On hand June 30, 1889:			
Received by exchange	30,850		
Received by purchase	3,250		
		34,100	
Received during the last year:			
By exchange	2,730		
By purchase	1,127		
		3,857	
			37,957
Total number of books and pamphlets			65,472

The average of circulation remains at about a thousand volumes per month.

Five hundred and forty-five books have been received from the Government Bindery of those sent to it last year, and a new lot of five hundred volumes was recently sent for binding.

PUBLICATIONS.

Monographs XV and XVI and Bulletins 53, 54, 55, 56, 57, 59, and 60 have been published during the year. The list of publications of the Survey corrected to June 30, 1890, is given in the advertisement prefixed to this volume.

Exchange.—Four thousand and twenty books and pamphlets have been received during the year by exchange; the Eighth Annual Report has been distributed to all correspondents, and Bulletins 48 to 57 and Monographs XIII to XVI have been sent to all entitled to complete exchange.

This distribution is as follows:

Exchange distribution.

	Copies.		Copies
Monograph XIII (2 vols.)	747	Bulletin 53	747
Monograph XIV	747	Bulletin 54	746
Monograph XV (2 vols.)	746	Bulletin 55	746
Monograph XVI	746	Bulletin 56	746
Bulletin 48	747	Bulletin 57	746
Bulletin 49	747	Eighth Annual (2 vols.)	1,532
Bulletin 50	747		
Bulletin 51	747	Total	11,984
Bulletin 52	747		

(In 15,009 volumes.)

Sales.—The table below shows in detail the sale account for 1889–'90:

Title of work.	Price.	No. sold.	Amount.	Title of work.	Price.	No. sold.	Amount.
Monograph II	$10.12	4	$40.48	Bulletin 3	.05	20	$1.00
Monograph III	11.00	1	11.00	Bulletin 4	.05	32	1.60
Monograph IV	1.50	5	7.50	Bulletin 5	.20	68	13.60
Monograph V	1.85	19	35.15	Bulletin 6	.05	28	1.40
Monograph VI	1.05	4	4.20	Bulletin 7	.10	31	3.10
Monograph VII	1.20	9	10.80	Bulletin 8	.10	21	2.10
Monograph VIII	1.10	4	4.40	Bulletin 9	.05	31	1.55
Monograph IX	1.15	7	8.05	Bulletin 10	.05	35	1.75
Monograph X	2.70	5	13.50	Bulletin 11	.05	27	1.35
Monograph XI	1.75	5	8.75	Bulletin 12	.05	13	.65
Monograph XII	8.40	8	67.20	Bulletin 13	.10	51	5.10
Monograph XIII	2.00	80	160.00	Bulletin 14	.15	31	4.65
Monograph XIV	1.00	36	36.00	Bulletin 15	.05	21	1.05
Monograph XV	2.50	1	2.50	Bulletin 16	.05	27	1.35
Bulletin 1	.10	23	2.30	Bulletin 17	.05	21	1.05
Bulletin 2	.05	28	1.40	Bulletin 18	.05	25	1.25

Sales—Continued.

Title of work.	Price.	No. sold.	Amount.	Title of work.	Price.	No. sold.	Amount.
Bulletin 19	$0.05	21	$1.05	Bulletin 43	$0.15	42	$6.30
Bulletin 20	.10	28	2.80	Bulletin 44	.05	37	1.85
Bulletin 21	.05	30	1.50	Bulletin 45	.10	49	4.90
Bulletin 22	.05	28	1.40	Bulletin 46	.15	149	22.35
Bulletin 23	.15	22	3.30	Bulletin 47	.10	85	8.50
Bulletin 24	.25	21	5.25	Bulletin 48	.10	53	5.30
Bulletin 25	.10	34	3.40	Bulletin 49	.15	40	6.00
Bulletin 26	.10	97	9.70	Bulletin 50	.15	69	10.35
Bulletin 27	.10	31	$3.10	Bulletin 51	.15	48	7.20
Bulletin 28	.10	32	3.20	Bulletin 52	.10	83	8.30
Bulletin 29	.05	27	1.35	Bulletin 53	.10	49	4.90
Bulletin 30	.25	26	6.50	Bulletin 54	.25	65	16.25
Bulletin 31	.15	29	4.35	Bulletin 55	.10	10	1.00
Bulletin 32	.20	73	14.60	Bulletin 56	.10	55	5.50
Bulletin 33	.05	29	1.45	Bulletin 57	.05	2	.10
Bulletin 34	.10	20	2.00	Bulletin 59	.10	2	.20
Bulletin 35	.10	28	2.80	Mineral Resources, 1882	.50	70	35.00
Bulletin 36	.10	32	3.20	Mineral Resources, 1883–'84	.60	86	51.60
Bulletin 37	.25	25	6.25				
Bulletin 38	.05	25	1.25	Mineral Resources, 1885	.40	74	29.60
Bulletin 39	.10	28	2.80	Mineral Resources, 1886	.50	87	43.50
Bulletin 40	.05	33	1.65	Mineral Resources, 1887	.50	246	123.00
Bulletin 41	.15	43	6.45	Total		2,931	943.88
Bulletin 42	.15	47	7.05				

Free distribution.—The popular demand for the Survey publications which can be distributed gratuitously has been met by a supply of 28,897 volumes. This includes 125 of the 800 complete sets of Monographs II–XII, Bulletins 1–40, and Mineral Resources first to fourth, furnished to the Department of the Interior for distribution to libraries under the "joint resolution to distribute copies of special memoirs and reports of the United States Geological Survey."

The work done in the document branch of the division for the year is shown in the following table:

Publications distributed in 1889–'90.

Publications sent out in exchange	15,009
Publications sold	2,931
Publications distributed gratuitously	28,897
Proofs of atlas sheets	2,451
Total number of books and maps distributed	49,288

CORRESPONDENCE.

The correspondence of the division, which includes all papers relating to the exchange, sale, and distribution of publications, and to the purchases and circulation of library books, has amounted to 12,469 letters sent and 18,153 letters received, a daily average of over forty letters sent and over fifty-nine letters received. The files and indexes of letters and indexes of publications distributed are kept fully up to date.

I am, sir, very respectfully,

CHAS. C. DARWIN,
Librarian.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

REPORT OF MR. JNO. D. McCHESNEY.

DIVISION OF ACCOUNTS,
Washington, D. C., October 3, 1890.

SIR: I have the honor to transmit herewith a detailed statement of expenditures from the appropriation for the U. S. Geological Survey (exclusive of item of $250,000 for Irrigation Survey—see Part II) for the fiscal year ending June 30, 1890, amounting to $494,657.15.

I am, with respect, your obedient servant,

JNO. D. McCHESNEY,
Chief Disbursing Clerk.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

ANALYSIS OF DISBURSEMENTS.

Under the following heads appear the total expenditures under the various appropriations for the U. S. Geological Survey:

1. Salaries, office of the Director	$35,047.27
2. Salaries of scientific assistants	67,145.58
3. Skilled laborers and various temporary employés	14,986.15
4. Topography	192,283.73
5. Geology	90,786.65
6. Paleontology	39,294.75
7. Chemical and physical researches	16,522.75
8. Preparation of illustrations	11,841.75
9. Mineral Resources of the United States	6,803.77
10. Books for library	4,230.03
11. Engraving geological maps of the United States	15,714.72
Total	494,657.15

RECAPITULATION.

	Geological Survey.	Salaries, office of Geological Survey.	Geological maps of the United States.	Total appropriation.
Appropriation, fiscal year ending June 30, 1890 (act approved March 2, 1889)	$470,700.00	$35,540.00	$45,000.00	$551,240.00
Expended as per detailed statement herewith	443,895.16	35,047.27	15,714.72	494,657.15
Balance on hand, July 1, 1890	26,804.84	492.75	29,285.28	56,582.85

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the first quarter of 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 17	1	Charles H. Cherry	Pay. July 1 to 17, 1889	$38.00
24	2	Albert Williams, jr	Traveling expenses	21.15
24	3	...do	Services, July 20 to 23, 1889	15.00
31	4	George W. Shutt	Services, July, 1889	252.70
31	5	O. C. Marsh	...do	337.00
31	6	W. M. Fontaine	...do	168.50
31	7	J. Henry Blake	...do	151.60
31	8	Alpheus Hyatt	Services, July 19 to 31, 1889	104.83
31	9	Leo Lesquereux	Services, July, 1889	75.00
31	10	Charles D. Walcott	...do	202.20
31	11	Pay-roll of employés	...do	421.20
31	12	...do	...do	1,223.80
31	13	...do	...do	890.80
31	14	...do	...do	988.70
31	15	...do	...do	596.05
31	16	...do	...do	436.23
31	18	C. E. Furley	Services, July 13 to 31, 1889	30.65
31	19	Frank T. Smart	Services, July, 1889	101.10
Aug. 1	21	Charles H. Cherry	Services, July 18 to August 1, 1889	60.00
1	22	F. Berger	Services, July, 1889	80.00
1	23	L. P. Bush	...do	50.00
1	24	H. Gibb	...do	70.00
1	25	G. Baur	...do	150.00
1	26	T. W. Stanton	...do	75.80
1	27	New York Central and Hudson River R. R. Co.	Transportation of assistants	63.00
3	28	Samuel H. Scudder	Services, July, 1889	210.60
3	29	Washington Gas Light Co	Laboratory supplies	56.39
3	30	Ira Sayles	Traveling expenses	14.45
6	31	J. S. Topham	Material	12.00
6	32	W. P. Rust	Services, July, 1889	81.00
7	33	Gottlieb Spitzer	Geologic supplies, etc	3.00
7	34	Paul J. Dashiell	Services, July 8 to 31, 1889	40.00
8	35	William C. Day	Services, July, 1889	135.00
8	36	C. D. White	...do	115.21
10	37	Chicago, Burlington and Quincy R. R.	Transportation of assistants	67.50
20	38	F. H. Knowlton	Services, July, 1889	117.90
21	39	Pennsylvania R. R. Co	Transportation of assistants	295.25
21	40	O. C. Chadwick	Hire of horses	24.00
21	41	Joseph F. James	Services, July, 1889	101.10
21	42	A. C. Gill	Services, July 8 to 31, 1889	30.00
21	43	New York Central and Hudson River R. R. Co.	Transportation of assistants	31.50
22	44	E. E. Jackson & Co	Material	43.10
22	45	Quartermaster's Department, U. S. A.	Topographic and geologic material	225.06
23	46	Keuffel & Esser	Laboratory material	8.50
23	47	Hume & Co	Supplies	.40
24	48	Z. D. Gilman	...do	89.55
26	49	St. Paul, Minneapolis and Manitoba R. R.	Transportation of assistants	97.20
26	50	The American Tool and Machine Co.	Material, etc	15.80
26	51	A. M. Gibson	Services, July 1 to 20, 1889	54.00
26	52	J. K. Hillers	Traveling expenses	39.75
27	53	J. Bishop & Co	Laboratory material	17.85
27	54	William C. Day	Services (job)	25.00
28	55	B. F. Norton	Field expenses	15.00
28	56	C. D. White	Traveling expenses	118.42
31	57	O. C. Marsh	Services, August, 1889	337.00
31	58	W. H. Melville	...do	168.50
31	59	T. W. Stanton	...do	75.80
31	60	Alpheus Hyatt	...do	250.00
31	61	J. Henry Blake	...do	150.00
31	62	J. T. Moore	...do	30.00
31	63	F. H. Knowlton	...do	117.90
31	65	J. S. Newberry	Services, July and August, 1889	606.60
31	66	Leo Lesquereux	Services, August, 1889	75.00
31	67	Pay-roll of employés	...do	421.20
31	68	...do	...do	1,233.10
31	69	...do	...do	973.27
31	70	...do	...do	981.16
31	71	...do	...do	648.00
31	72	...do	...do	420.60
31	74	Frank T. Smart	...do	101.10
31	75	George M. Wood	...do	100.00
31	76	William M. Fontaine	...do	168.50

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, etc.—Continued.

Date.	Voucher.	To whom paid	For what paid	Amount.
Sept. 9	77	C. A. White	Traveling expenses	$334.75
10	78	E. J. Pullman	Paleontologic material	4.35
10	79	Melville Lindsay	Laboratory supplies	23.47
10	80	Washington Gas Light Co	do	53.14
10	81	L. H. Schneider's Son	do	3.52
11	82	T. W. Stanton	Traveling expenses	127.52
12	83	Ohio and Mississippi Ry. Co	Freight	3.93
12	84	William P. Rust	Services, August, 1889	87.75
12	85	Perfect Hand Fire Extinguisher Co.	Supplies	24.00
12	88	Charles H. Kraft	Chemical supplies	25.15
12	89	Emil Greiner	Laboratory supplies	87.70
12	90	Northern Pacific R. R	Transportation of assistants	181.15
12	91	G. Baur	Services, August, 1889	150.00
12	92	L. P. Bush	do	50.00
12	93	H. Gibb	do	70.00
13	94	Baltimore and Ohio R. R	Transportation of assistants	85.70
13	95	Texas and Pacific Ry. Co	do	113.10
13	96	F. W. Clarke	Traveling expenses	71.21
14	97	Lester F. Ward	do	119.40
14	98	Joseph F. James	Services, August. 1889	101.10
14	99	Charles S. Cudlip	Supplies for illustrations	339.43
16	100	Charles D. Walcott	Services, August, 1889	202.20
16	101	Z. D. Gilman	Supplies	49.34
19	102	do	do	126.54
24	103	Sam. H. Scudder	Services, August, 1889	210.60
26	104	do	Traveling expenses	116.27
26	105	William C. Day	do	14.43
26	106	Pennsylvania R. R. Co	Freight	1.11
26	107	Northern Pacific R. R	Transportation of assistants	44.25
30	108	Chicago, Santa Fé and California R. R.	do	21.10
30	109	Burlington and Missouri River R. R.	do	30.65
30	110	Pennsylvania R. R	do	33 31
30	111	Washington Gas Light Co	Laboratory supplies	49.63
30	112	Robert F. Miller	Material	42.00
30	114	W. H. Melville	Pay, September, 1889	163.00
30	115	Sam. H. Scudder	do	203.80
30	116	Charles D. Walcott	do	195.60
30	117	Alpheus Hyatt	do	250.00
30	118	Harriett Biddle	Pay, July, August, and September, 1889.	30.00
30	120	F. H. Knowlton	Pay, September, 1889	114.20
30	121	Pay-roll of employés	do	1,219.30
30	122	do	do	907.80
30	123	do	do	920.60
30	124	do	do	629.00
30	125	do	do	397.13
30	126	do	do	407.60
30	128	George M. Wood	do	100 00
30	129	Frank T. Smart	do	97.80
30	130	George W. Shutt	Pay. August, 1889	252.70
30	131	do	Pay, September, 1889	244.60
30	132	Leo Lesquereux	do	75.00
30	133	T. W. Stanton	do	73.40
30	134	William P. Rust	do	81.25
30	136	William M. Fontaine	Services, September, 1889	163.00
30	137	Carl Barus	Traveling expenses	31.68
30	138	Idaho Central R. R	Freight	2.96
30	139	J. Henry Blake	Services, September, 1889	146.80
30	140	Joseph F. James	do	97.80
30	141	O. C. Marsh	do	326.00
		Total		25,675.99

SALARIES, OFFICE GEOLOGICAL SURVEY.

July 31	1	Pay-roll of employés	Services, July, 1889	2,919.41
Aug. 31	2	do	Services, August, 1889	2,775.32
31	3	John R. Walsh	do	75.80
Sept. 30	4	do	Services, September, 1889	73.40
30	5	Pay-roll of employés	do	2,670.84
30	6	J. L. McCord	Services, August and September, 1889	119.40
		Total		8,634.17

Abstract of disbursements made by Anton Karl, special disbursing agent U. S. Geological Survey, during the first quarter of 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 13	1	Charles M. Yeates	Field expenses	$42.20
13	2	Lewis J. Battle	Traveling expenses	16.00
13	3	do	Field expenses	3.80
13	4	James E. Shelley	Traveling expenses	25.25
13	5	Spark Bros	Transportation	1,000.00
17	6	J. Beers & Co	Maps	10.00
18	7	Lincoln Martin	Field expenses	5.75
18	8	do	Traveling expenses	18.50
18	9	A. E. Murlin	do	3.25
17	10	do	Field expenses	121.41
19	11	L. N. Lockhart	Transportation	5.00
19	12	do	do	310.00
19	13	Edmund S. Parker	Traveling expenses	1.50
19	14	Moses Spurlock	do	6.35
19	15	Samuel Dibble, jr	do	10.40
19	16	E. M. Hasbrouck	do	9.10
19	17	Charles M. Yeates	Field expenses	40.67
19	18	do	Traveling expenses	10.30
19	19	H. L. Baldwin, jr	do	23.34
20	20	do	Field expenses	125.81
20	21	H. S. Wallace	do	73.07
22	22	L. Withers	Services	35.87
22	23	J. H. Davies	Office furniture	29.00
22	24	Lewis Nell	Field expenses	145.75
22	25	H. L. Baldwin, jr	do	207.25
22	26	M. Hackett	do	157.96
23	27	William J. Peters	do	39.50
23	28	do	do	45.85
23	29	do	do	27.97
23	30	L. C. Fletcher	do	117.84
23	31	do	do	119.50
23	32	George T. Hawkins	do	132.50
23	33	A. P. Luckett	Subsistence	53.80
23	34	W. J. O'Connell	Field expenses	17.70
34	35	Lewis J. Battle	Traveling expenses	5.45
24	36	D. C. Harrison	do	74.50
24	37	F. D. Haile	Field expenses	24.80
24	38	C. M. Gordon	do	24.25
24	39	H. S. Wallace	do	65.80
24	40	Ellis & Kellner	do	34.00
26	41	R. M. Towson	do	109.87
26	42	J. O. Nye	Transportation	150.00
26	43	Fred J. Knight	Field expenses	157.90
26	44	Henry Gannett	Traveling expenses	20.25
27	45	William H. Herron	Field expenses	141.38
29	46	Lucius McPherson	Transportation	150.00
29	47	Charles H. Ketchum	Field supplies	150.00
29	48	H. B. Blair	Field expenses	253.25
29	49	Charles F. Urquhart	do	148.50
27	50	S. S. Gannett	Subsistence	12.00
29	51	do	Field expenses	73.10
29	52	A. B. Searle	Services, July	75.80
31	53	Marcus Baker	do	252.70
31	54	Gilbert Thompson	do	210.60
31	55	P. C. Warman	do	151.60
31	56	Harry V. Wurdemann	do	64.67
31	57	Howard A. Graham	do	70.80
31	58	John H. Renshawe	do	210.60
Aug. 1	59	James G. Bowen	Transportation	6.00
1	60	Pay-roll (Karl)		2,783.38
1	61	F. H. Ellsworth	Transportation	150.00
1	62	R. U Goode	Services, July	210.60
1	63	James E. Shelley	do	60.00
1	64	Pay-roll (Hackett)	July	484.80
3	65	Marcus Baker	Traveling expenses	28.59
3	66	Louis Nell	Services, July	168.50
3	67	Charles B. Green	do	33.87
3	68	Pay-roll (Nell)	July	274.20
3	69	W. E. Horton	Services, July	60.00
3	70	J. J. Fawbush	do	7.00
3	71	Pay-roll (Baldwin)	July	758.64
3	72	Van H. Manning, jr	Field expenses	122.00
3	73	do	Services, July	101.10
3	74	Pay-roll (Barnard)	July	612.47
3	75	Pay-roll (Wallace)	do	635.10
3	76	Pay-roll (Blair)	do	443.78
3	77	Pay-roll (Hawkins)	do	231.10
3	78	Pay-roll (Fletcher)	do	611.90
3	79	Bushrod C. Washington	Services, July	101.10
5	80	James Longstreet, jr	do	60.60

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher	To whom paid.	For what paid.	Amount.
1889.				
Aug. 3	81	E. W. F. Natter	Services, July	$134.80
3	82	Frank Sutton	..do	117.90
3	83	Lewis J. Battle	...do	60.00
5	84	William Kramer	...do	101.10
5	85	S. S. Gannett	...do	168.50
5	86	W. H. Lovell	...do	134.80
5	87	G. E. Hyde	...do	75.80
5	88	S. Sidney Bradford	...do	50.00
5	89	Charles M. Yeates	...do	151.60
5	90	E. B. Clark	..do	117.90
5	91	J. W. Thom	...do	50.00
9	92	Lincoln Martin	...do	60.00
9	93	Charles M. Yeates	Field expenses	78.27
9	94	Gore, Janney & Co.	Office furniture	85.00
9	95	Glenn S. Smith	Services, July	50.00
9	96	W. R. Atkinson	...do	101.10
9	97	L. D. Brent	...do	75.80
9	98	D. C. Harrison	Field expenses	102.35
9	99	...do	Services, July	117.90
9	100	Ambrose F. Dudley	... do	55.00
9	101	Charles Bogan	...do	50.50
9	102	W. U. Simons	... do	30.00
9	103	E. L. Chipman	...do	50.00
9	104	H. L. Manley	...do	50.00
9	105	Henry Ulke, jr.	...do	50.00
9	106	Nannie M. Peyton	...do	25.00
9	107	C. W. Wreshall	...do	20.96
9	108	E. M. Huguely	...do	25.00
9	109	Pay-roll (Murlin)	...do	358.70
9	110	J. H. Jennings	...do	134.80
9	111	Marcus B. Lambert	...do	75.80
9	112	R. Lee Longstreet	...do	101.10
9	113	G. L. Johnson	...do	60.00
9	114	Robert D. Cummin	...do	134.80
9	115	H. L. Smyth	...do	101.10
9	116	C. J. Akin	...do	60.00
9	117	J. H. Wheat	...do	75.80
9	118	F. P. Gulliver	...do	101.10
9	119	Alfred H. Brooks	...do	60.00
10	120	H. L. Baldwin, jr	Field expenses	235.64
10	121	...do	...do	64.00
10	122	Louis Nell	...do	170.13
10	123	W. H. Lovell	...do	127.25
10	124	... do	...do	87.24
12	125	Fred J. Knight	Services, July	151.60
12	126	H. S. Manley	Traveling expenses	11.05
12	127	Robert D. Cummin	...do	3.33
12	128	Wesley Pratt	...do	7.90
12	129	D. A. Crider	... do	14.95
12	130	William Kramer	... do	7.62
12	131	Charles Bogan	...do	9.07
12	132	Henry Crider	... do	14.95
12	133	L. D. Brent	...do	17.75
12	134	John Marks, jr	Field material	30.47
12	135	G. E. Hyde	Field expenses	109.24
12	136	W. T. Quillin	Traveling expenses	7.90
12	137	H. S. Wallace	Field expenses	62.75
12	138	William H. Herron	...do	28.55
12	139	Frank Sutton	...do	181.70
12	140	...do	...do	55.62
12	141	W. E. Horton	Traveling expenses	44.68
12	142	R. M. Towson	Field expenses	55.65
12	143	G. S. Smith	...do	126.70
12	144	E. C. Barnard	... do	167.50
12	145	William J. Peters.	...do	108.75
12	146	...do	...do	51.20
12	147	...do	...do	60.00
12	148	Van H. Manning, jr	...do	54.87
12	149	F. P. Gulliver	...do	197.28
12	150	...do	Traveling expenses	14.68
12	151	Walter N. Beecher	Transportation	306.25
12	152	Spark Bros	...do	300.00
12	153	J. R. Holliday	Subsistence	135.17
13	154	George Ryneal, jr.	Office material	1.60
13	155	William D. Clark & Co	Field material	4.96
13	156	W. B. Moses & Son	Office furniture	105.00
13	157	Fred A. Schmidt	Drawing paper	22.80
13	158	R. Lee Longstreet	Field expenses	109.25
13	159	John H. Renshawe	Traveling expenses	67.30
13	160	J. G. Reaves	Pasturage	3.61

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Aug. 13	161	Robert D. Cuinmin	Field expenses	$213.03
13	162	William Kramer	do	134.40
13	163	John W. Price	Pasturage	16.93
13	164	Gilbert Thompson	Traveling expenses	53.37
14	165	L. C. Fletcher	Field expenses	119.40
14	166	do	do	127.00
14	167	do	do	82.93
14	168	C. M. Gordon	do	24.25
14	169	Charles M. Yeates	do	111.79
14	170	A. E. Murlin	do	140.96
15	171	Charles S. Platt	Laboratory material	16.85
15	172	M. Hackett	Field expenses	248.50
15	173	G. O. Morgan	Transportation	165.00
17	174	R. J. Moore	Services, July	16.10
17	175	C. M. Gordon	do	40.00
17	176	E. C. Barnard	Field expenses	128.48
17	177	J. H. Chapman	Subsistence	19.50
17	178	Charles B. Green	Traveling expenses	24.75
17	179	G. E. Hyde	do	9.76
20	180	E. E. Jackson & Co	Field material	28.25
20	181	Wyckoff, Seamans & Benedict	Repairs of typewriter	3.50
21	182	Louis Nell	Field expenses	159.76
22	183	Fauth & Co	Instruments	450.00
22	184	L. C. Fletcher	Field expenses	85.79
22	185	do	do	117.50
22	186	do	do	70.00
22	187	do	do	43.20
22	188	do	do	151.63
23	189	R. Lee Longstreet	do	67.45
23	190	Fred J. Knight	do	117.70
23	191	H. S. Wallace	do	38.10
23	192	Van H. Manning, jr	do	89.25
23	193	W. H. Lovell	do	51.35
23	194	H. L. Baldwin, jr	do	88.98
23	195	Pay-roll (Wallace)	August	678.80
26	196	W. A. Maddox	Pasturage	24.00
26	197	W. F. Fling	do	8.38
27	198	M. Hackett	Field expenses	245.80
27	199	J. W. McPherson	Transportation	137.50
27	200	A. E. Murlin	Field expenses	82.46
28	201	S. Sydney Bradford	Services	50.00
28	202	Charles M. Yeates	do	151.60
28	203	Gottlieb Spitzer	Office material	1.50
30	204	Easton & Rupp	do	1.50
30	205	J. W. Thom	Services, August	50.00
30	206	Fred J. Knight	do	151.60
30	207	George T. Hawkins	Field expenses	352.86
30	208	F. P. Gulliver	Services, August	101.10
30	209	James W. Queen & Co	Instruments	210.60
30	210	H. L. Manley	Services, August	50.00
30	211	William J. Peters	Field expenses	153.03
30	212	R. U. Goode	Traveling expenses	87.45
30	213	Charles R. Grandy	Services, August	50.00
30	214	Charles A. Burnett	do	117.90
30	215	Thomas S. Clarke	Traveling expenses	12.25
30	216	J. H. Wheat	Services, August	75.80
30	217	L. M. Hoskins	do	60.00
30	218	C. T. Reid	do	70.80
30	219	James Longstreet, jr	do	60.60
30	220	Alfred H. Brooks	do	60.00
30	221	William J. Peters	do	134.80
30	222	Pay-roll (Blair)	do	461.40
30	223	W. U. Simons	do	30.00
30	224	Pay-roll (Goode)	do	441.70
30	225	Pay-roll (Hackett)	do	484.80
30	226	Pay-roll (Murlin)	do	429.50
30	227	Pay-roll (Barnard)	do	612.40
30	228	James E Shelley	do	60.00
30	229	Gilbert Thompson	Traveling expenses	56.90
30	230	do	Services, August	210.60
30	231	R. M. Towson	Field expenses	116.71
30	232	Louis Nell	Services, August	168.50
30	233	Pay-roll (Nell)	do	374.20
30	234	Fielding Burnes	do	151.60
30	235	R. Lee Longstreet	do	101.10
30	236	Pay-roll (Baldwin)	do	880.60
30	237	P. C. Warman	do	151.60
31	238	S. S. Gannett	do	168.50
31	239	M. W. Luster	Transportation	260.00
31	240	B. C. Washington, jr	Services, August	101.10

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Aug. 31	241	Harry King	Services, August	$151.60
31	242	Edith V. Mullen	...do	60.60
31	243	John H. Renshawe	...do	210.60
Sept. 3	244	Henry Gannett	...do	303.30
3	845	Lewis J. Battle	do	60.00
3	246	L. C. Fletcher	Field expenses	356.68
3	247	William Kramer	Services, August	101.10
3	248	Charles Bogan	...do	50.50
3	249	Henry Ulke, jr	...do	50.00
3	250	H. L. Baldwin, jr	Field expenses	33.28
3	251	W. H. Lovell	Services, August	134.80
3	252	William M. Beaman	...do	21.52
3	253	G. L. Johnson	...do	60.00
3	254	John H. Renshawe	Traveling expenses	79.43
3	255	Keuffel and Esser Co	Instruments	9.00
3	256	G. L. Smith	Field expenses	6.02
3	257	...do	...do	103.52
3	258	G. E. Hyde	...do	212.09
3	259	R. Lee Longstreet	...do	69.63
3	260	Robert D. Cummin	..do	252.05
3	261	William H. Herron	Services, August	84.43
5	262	Lincoln Martin	Supplies	60.00
5	263	Melville Lindsay	...do	1.80
5	264	Pay-roll (Karl)	Services	2,076.39
5	265	John Kirchoff	...do	30.00
4	266	C. J. Akin	Services, August	60.00
4	267	William Kramer	Traveling expenses	20.80
4	268	...do	Field expenses	146.84
4	269	Frank Sutton	Traveling expenses	40.15
4	270	...do	Field expenses	142.23
4	271	W. E. Horton	Traveling expenses	40.30
4	272	J. G. Reaves	Storage	2.00
4	273	Louis Nell	Field expenses	48.20
4	274	...do	...do	117.61
5	275	F. P. Gulliver	Traveling expenses	17.01
5	276	W. H. Lovell	Field expenses	211.06
5	277	L. C. Fletcher	...do	79.18
6	278	Charles M. Yates	...do	120.63
6	279	G. W. Lewellen	Transportation	100.00
6	280	E. B. Clark	Services, August	117.90
7	281	J. H. Jennings	...do	134.80
7	282	Robert D. Cummin	...do	134.80
7	283	Edwin A. Greenough & Co	...do	252.51
7	284	A. B. Searle	...do	75.80
7	285	H. B. Blair	Field expenses	223.60
9	286	F. A. Lewellen	Transportation	100.00
9	287	E. M. Walker	...do	192.00
9	288	E. W. F. Natter	Services, August	134.80
9	289	W. E. Horton	...do	60.00
9	290	F. P. Gulliver	Field expenses	48.69
9	291	...do	...do	178.43
9	292	H. S. Wallace	...do	49.80
9	293	D. C. Harrison	...do	99.80
9	294	L. C. Fletcher	...do	109.08
9	295	E. M. Huguely	Services, August	25.00
9	296	E. C. Barnard	Field expenses	224.19
9	297	H. L. Smyth	Services, August	101.10
12	298	Marcus Baker	Traveling expenses	100.27
9	299	H. L. Baldwin, jr	Field expenses	22.63
9	300	...do	...do	104.60
13	301	Melville Lindsay	Supplies	7.15
13	302	Robert Leitch & Sons	...do	11.00
13	303	W. D. Clark & Co.	...do	5.04
13	304	R. A. Bandy	Field material	33.25
13	305	Van H. Manning, jr.	Field expenses	99.45
13	306	W. F. Fling	Pasturage	8.00
13	307	E. C. Barnard	Field expenses	349.50
13	308	Nannie M. Peyton	Services. August	25.00
13	309	William J. Peters	Field expenses	53.70
13	310	R. O. Gordon	Traveling expenses	52.10
13	311	L. C. Fletcher	Field expenses	65.10
13	312	...do	...do	62.17
13	313	G. E. Hyde	Services, August	75.80
13	314	James McCormick	...do	21.52
13	315	W. R. Atkinson	...do	101.10
13	316	Frank Sutton	...do	117.90
13	317	M. B. Lambert	...do	75.80
13	318	W. F. Lake	Field material	36.05
13	319	Want & Co	...do	76.75
13	320	Ellis & Kellner	...do	120.20

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Sept. 13	321	J. C. Walker	Field expenses	$93.20
13	322	E. H. Carter	Subsistence	288.20
13	323	W. H. Herron	Field expenses	37.65
13	324	G. S. Smith	Services, August	50.00
13	325	D. C. Harrison	...do	117.90
13	326	L. D. Brent	...do	75.80
13	327	William Kramer	Transportation	16.00
13	328	John W. Price	Pasturage	17.03
14	329	W. D. Clark	Supplies	37.20
14	330	E. McL. Long	Traveling expenses	60.60
16	331	E. E. Jackson & Co	Field material	10.00
16	332	George H. Walker & Co	Maps	12.00
17	333	Melville Lindsay	Office supplies	3.50
17	334	C. T. Reid	Services, July	70.80
17	335	William J. Peters	...do	134.80
17	336	L. M. Hoskins	...do	60.00
17	337	...do	Traveling expenses	21.21
17	338	Van H. Manning, jr	Services, July	101.10
17	339	E. L. Chipman	...do	50.00
17	340	Pay-roll (Fletcher)	August (G. Thompson)	611.90
17	341	William H. Herron	Field expenses	30.59
17	342	James G. Bowen	Transportation	4.00
18	343	Fred J. Knight	Transportation and subsistence	141.50
18	344	Joseph N. Austin	Services, September	16.00
19	345	L. C. Fletcher	Field expenses	89.26
20	346	W. & L. E. Gurley	Instruments	8.00
20	347	William J. Peters	Field expenses	112.37
20	348	Samuel Dibble, jr	Services, September	16.66
20	349	...do	Traveling expenses	8.52
21	350	Gilbert Thompson	...do	51.35
21	351	W. H. Lovell	Field expenses	56.48
23	352	H. S. Wallace	...do	64.10
23	353	A. E. Murlin	...do	130.42
23	354	M. Hackett	...do	279.11
23	355	R. O. Gordon	...do	61.87
23	356	W. E. Lackland	Traveling expenses	11.60
24	357	Ambrose F. Dudley	Services, August	55.00
24	358	H. L. Manley	Services, September	25.00
24	359	J. J. Lincoln	Traveling expenses	17.00
24	360	John D. Black	...do	54.15
25	361	Louis Nell	Field expenses	53.75
25	362	...do	...do	59.04
25	363	...do	...do	94.60
25	364	Graphic Publishing Co	Supplies	85.00
25	365	L. C. Fletcher	Field expenses	131.92
25	366	L. H. Schneider's Son	Office material	14.90
25	367	Edward Kubel	...do	31.58
25	368	Charles M. Yeates	Field expenses	122.55
25	369	Wesley Pratt	Traveling expenses	8.15
25	370	D. A. Crider	...do	15.25
25	371	J. N. Crider	...do	15.25
25	372	Henry Gannett	...do	152.51
27	373	J. H. Jennings	Services, September	130.40
27	374	J. H. Chapman	Subsistence	61.50
27	375	Fred Knight	Field expenses	72.00
27	376	Henry J. Green	Repairs	6.78
27	377	R. Lee Longstreet	Field expenses	61.95
27	378	H. L. Manley	Traveling expenses	10.20
27	379	Van H. Manning, jr	Field expenses	81.60
27	380	William H. Herron	...do	97.19
27	381	S. S. Gannett	Services, September	163.00
27	382	H. S. Wallace	Pay-roll, September	331.47
27	383	Louis Nell	...do	363.26
27	384	...do	Services, September	163.00
28	385	L. C. Woodbury	...do	16.00
28	386	H. L. Baldwin, jr	Pay-roll, September	847.13
28	387	L. C. Fletcher	...do	596.20
28	388	H. B. Blair	...do	452.20
28	389	M. Hackett	...do	381.73
28	390	A. E. Murlin	...do	352.60
28	391	R. O. Gordon	...do	351.40
28	392	J. J. Lincoln	Services, August	1.96
28	393	Charles F. Urquhart	Pay-roll, September	259.46
28	394	E. B. Clark	Services, September	11 .20
28	395	F. P. Gulliver	...do	97.80
28	396	G. E. Hyde	...do	73.40
28	397	J. H. Wheat	...do	73.40
28	398	L. M. Hoskins	...do	4.00
28	399	Ambrose F. Dudley	...do	55.00
28	400	J. W. Thom	...do	50.00

Abstract of disbursements made by Anton Karl, etc —Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Sept. 28	401	W. U. Simons	Services, September	$30.00
28	402	Charles R. Grandy	...do	50.00
28	403	A. B. Searle	...do	73.40
28	404	M. H. Elliott	Services, August	2.25
28	405	S. Sydney Bradford	Services, September	25.00
28	406	Thomas C. Nelson	...do	10.50
28	407	...do	...do	20.00
28	408	Charles M. Yeates	...do	146.80
28	409	Van H. Manning, jr	...do	97.80
28	410	E. L. Chipman	...do	50.00
28	411	Fred J. Knight	...do	146.80
28	412	W. H. Lovell	...do	130.40
28	413	James McCormick	...do	58.80
28	414	Lewis J. Battle	...do	60.00
28	415	R. U. Goode	...do	203.80
28	416	John H. Renshawe	...do	203.80
28	417	Harry King	...do	146.80
28	418	Lucas Harvey	Services, August	54.78
28	419	H. A. Graham	Services, September	68.40
28	420	Gilbert Thompson	...do	203.80
28	421	Pay-roll (Karl)	September	2,766.46
28	422	G. E. Hyde	Field expenses	253.50
28	423	Robert D. Cummin	...do	207.70
28	424	...do	Traveling expenses	4.35
28	425	W. H. Lovell	Field expenses	90.53
28	426	Frank Sutton	Services, September	114.20
28	427	W. J. Richardson	Traveling expenses	4.85
28	428	...do	Field expenses	65.88
28	429	M. B. Lambert	Services, September	73.40
28	430	Lincoln Martin	...do	60.00
28	431	E. W. F. Natter	...do	130.40
28	432	James Longstreet, jr	...do	58.80
28	433	James E. Shelley	...do	60.00
28	434	William Kramer	...do	97.80
28	435	R. Lee Longstreet	...do	97.80
28	436	Charles Bogan	...do	49.00
28	437	C. J. Akin	...do	60.00
28	438	John H. Renshawe	Traveling expenses	93.40
28	439	D. C. Harrison	Services, September	114.20
28	440	L. D. Brent	...do	73.40
28	441	William J. O'Connell	...do	51.63
28	442	W. O. Beall	...do	60.00
		Total		57,190.44

Abstract of disbursements made by Mark B. Kerr, Disbursing Agent, U. S. Geological Survey, during the first quarter of 1890.

1889.				
July 15	1	A. C. Peale	Traveling expenses	$74.95
15	2	George P. Merrill	...do	23.80
15	3	Arthur Keith	Field expenses	100.69
15	4	Bailey Willis	Traveling expenses	39.74
15	5	L. G. Thompson	One horse	200.00
20	6	Gore, Janney & Co.	Office furniture	85.00
20	7	J. S. Diller	Traveling expenses	46.60
24	8	Nelson H. Darton	...do	80.45
25	9	Cone & Kimball Company	Field subsistence	78.33
25	10	A. Lamme & Co	...do	70.43
25	11	...do	Field supplies	38.82
25	12	J. M. Safford	Field expenses	16.62
31	13	G. F. Becker	Services, July, 1889	337.00
31	14	W. H. Melville	...do	168.50
31	15	Pay-roll	...do	344.60
31	16	F. C. Boyce	...do	60.00
31	17	Frank Rader	...do	40.00
31	18	J. S. Diller	...do	168.50
31	19	Pay-roll	...do	105.80
31	20	A. C. Peale	...do	168.50
27	21	...do	Field expenses	71.81
27	22	C. Willard Hayes	...do	86.88
27	23	Pay-roll	Services, July, 1889	727.10
27	24	...do	...do	212.20
27	25	...do	...do	772.40
27	26	...do	...do	378.60
27	27	...do	...do	621.70
27	28	...do	...do	480.10

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 31	29	Bailey Willis	Field expenses	$58.90
Aug. 1	30	C. R. Van Hise	Services, July, 1889	337.00
1	31	Pay-roll	...do	472.55
1	32	I. C. Russell	...do	202.20
1	33	J. Stanley-Brown	...do	101.10
1	34	Pay-roll	...do	231.10
1	35	...do	...do	227.87
1	36	Arthur Keith	Field expenses	17.10
1	37	Alexander Davis	...do	2.53
1	38	Frank W. Geiger	Traveling expenses	18.50
1	39	W. B. Smith	Services, July, 1889	75.00
July 31	40	Holbrook, Merrill & Stetson	Field supplies	16.64
31	41	E. A. Learned	...do	9.00
Aug. 5	42	J. S. Diller	Field expenses	108.40
5	43	C. Willard Hayes	...do	43.80
6	44	Collier Cobb	Services, July, 1889	50.00
6	45	H. R. Geiger	Traveling expenses	87.88
6	46	Arthur Keith	Field expenses	103.83
6	47	J. Stanley Brown	Traveling expenses	65.00
6	48	J. M. Safford	Field expenses	31.40
6	49	...do	Services, July, 1889	141.85
6	50	W. T. Lander	...do	75.00
6	51	Aug. F. Foerste	...do	50.00
6	52	J. B. Woodworth	...do	50.00
6	53	George H. Williams	...do	80.00
July 2	54	C. T. Garrett	One horse	165.00
Aug. 9	55	C. Willard Hayes	Field expenses	52.19
9	56	James G. Bowen	Forage, etc	75.00
9	57	N. S. Shaler	Services, July, 1889	270.00
9	58	J. M. Safford	Traveling expenses	6.75
9	59	John C. Parker	Office supplies	10.00
9	60	G. K. Gilbert	Traveling expenses	59.50
12	61	C. R. Van Hise	Field expenses	116.66
14	63	L. T. Thompson	Forage	11.41
15	64	Lawrence C. Johnson	Field expenses	48.34
15	65	Richard E. Edes	Traveling expenses	18.65
16	66	W. Lindgren	Field expenses	89.65
16	67	R. S. Tarr	...do	49.45
16	68	...do	Services, July, 1889	19.36
19	69	A. C. Peale	Field expenses	29.50
22	70	C. W. Coman	...do	38.48
27	71	J. B. Smith	Field subsistence	42.46
27	72	Isaiah Rendell	...do	33.55
27	73	Main & Winchester	Field supplies	7.95
27	74	Goldberg, Bowen & Co	Field subsistence	48.25
27	75	Pay-roll	Services, August, 1889	344.60
27	76	...do	...do	772.40
27	77	...do	...do	212.20
27	78	...do	...do	657.10
31	69	A. C. Peale	...do	168.50
31	80	J. S. Diller	...do	168.50
31	81	G. F. Becker	...do	337.00
31	82	F. C. Boyce	...do	60.00
31	83	Frank Rader	...do	40.00
31	84	George L. Cannon, jr	Services, July, 1889	135.00
31	85	...do	Services, August, 1889	135.00
31	86	C. W. Hayes	Field expenses	53.24
31	87	H. R. Geiger	...do	61.91
31	88	I. C. Russell	Services, August, 1889	202.20
31	89	J. Stanley-Brown	...do	101.10
31	90	G. W. Granniss	Rent rooms, July and August, 1889	110.00
31	91	W. J. McGee	Traveling expenses	12.85
31	92	Pay-roll	Services, August, 1889	130.00
31	93	...do	...do	231.10
31	94	J. S. Diller	Field expenses	175.82
31	95	C. W. Coman	Services, July and August, 1889	59.68
31	96	...do	Services, August, 1889	40.32
31	97	Aug. F. Foerste	Traveling expenses	52.84
31	98	Nelson H. Darton	Field expenses	139.29
31	99	Pay-roll	Services, August, 1889	621.70
31	100	...do	...do	480.10
31	101	...do	...do	231.10
31	102	...do	...do	378.60
Sept. 5	103	W. S. Bayley	Field expenses	101.21
5	104	Lawrence C. Johnson	...do	62.22
5	105	Arthur Keith	...do	75.87
6	106	William B. Clark	Services, July, 1889	135.00
6	107	...do	Services, August, 1889	130.00
9	108	Robert T. Hill	...do	140.00
9	109	N. S. Shaler	...do	270.00
9	110	Collier Cobb	...do	50.00

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Sept. 5	111	J. M. Safford	Field expenses	$56.68
Aug. 31	112	...do	Services, August, 1889	141.85
Sept. 15	113	Baker & Hamilton	Field material	77.55
15	114	Main & Winchester	...do	52.50
15	115	A. Lietz & Co	Field repairs	6.00
15	116	Goldberg, Bowen & Co	Field subsistence	52.99
15	117	H. W. Turner	Field expenses	40.42
10	118	Aug. F. Foerste	Services, August, 1889	50.00
10	119	J. B. Woodworth	...do	50.00
10	120	R. S. Tarr	...do	50.00
12	121	A. C. Peale	Field expenses	53.65
13	122	William B. Clark	...do	330.30
13	123	C. R. Van Hise	Services, August, 1889	337.00
13	124	Pay-roll	...do	446.10
14	125	L. G. Thompson	Forage	24.00
14	126	G. K. Gilbert	Traveling expenses	59.00
14	127	C. W. Hayes	Field expenses	59.70
16	128	Watersmeet Lumber Co	Subsistence, etc	23.31
16	129	James G. Bowen	Forage	45.00
16	130	Kenneth C. Kerr	Field expenses	7.75
20	131	United States Express Co	Field material	5.25
20	132	W. J. McGee	Traveling expenses	28.60
20	133	John B. Bean	Services, etc., July to September	358.00
20	134	James Forristell	...do	240.00
20	135	James Gittings	...do	140.56
20	136	Noah R. King	...do	126.85
23	137	W. T. Lauder	Services, August, 1889	75.00
23	138	J. B. Smith	Field subsistence	43.84
23	139	John T. Sparks	One horse	150.00
23	140	H. R. Geiger	Field expenses	81.03
23	141	C. W. Hayes	...do	51.94
30	142	J. S. Diller	Services, September, 1889	163.00
30	143	G. F. Becker	Traveling expenses	95.83
30	144	Pay-roll	Services, September, 1889	126.67
30	145	...do	...do	335.80
30	146	G. F. Becker	...do	326.00
30	147	C. D. Vay	Services, July and August	200.00
25	148	Gottlieb Spitzer	Field material	4.50
25	149	E. E. Jackson & Co	Office material	19.74
25	150	Belt & Dyer	...do	136.00
21	151	H. Rosendale	...do	3.65
25	152	E. Morrison	...do	3.75
25	153	Wm. D. Clark & Co	Field material	1.80
25	154	Melville Lindsay	...do	.53
25	155	Barber & Ross	...do	7.60
25	156	Newman & Son	Office material	.80
25	157	Shepherd & Hurley	Repairs, etc	34.80
28	158	Henry B. Hitz	Services August and September, 1889.	105.50
28	159	Pay-roll	Services September, 1889	464.80
28	160	...do	...do	205.60
30	161	A. C. Peale	...do	163.00
30	162	Pay-roll	...do	606.60
30	163	...do	...do	367.80
		Total		23,163.02

Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent, U. S. Geological Survey, during the first quarter of 1890.

1889.				
July 20	1	T. Nelson Dale	Traveling expenses	$25.24
20	2	Lewis Brown, postmaster	Post-office box rent	5.00
25	3	H. L. Smyth	Field expenses	30.13
26	4	...do	...do	17.17
27	5	T. Nelson Dale	Traveling expenses	16.66
29	6	William H. Hobbs	...do	15.15
29	7	E. D. Keyes & Co	Supplies	7.74
30	8	H. L. Smyth	Field expenses	7.76
31	9	Raphael Pumpelly	Pay for July, 1889	337.00
31	10	T. Nelson Dale	...do	150.00
31	11	A. O. D. Taylor, jr	...do	101.10
31	12	A. Prescott Baker	Rent for July, 1889	50.00
Aug. 1	13	Richard Bliss	Bibliographical work	22.50
1	14	Ben K. Emerson	Pay for July, 1889	101.10
5	15	T. Nelson Dale	Traveling expenses	22.61
5	16	William H. Hobbs	Pay for July, 1889	40.97
6	17	H. L. Smyth	Field expenses	9.98

Abstract of disbursements made by A. O. D. Taylor, jr., etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Aug. 6	18	H. A. Craigin	Traveling expenses	$13.40
6	19	Z. W. Bliss	...do	7.60
8	20	Algernon B. Corbin	Stationery supplies	9.10
9	21	Ben K. Emerson	Traveling expenses	84.74
9	22	Edward Stabe	Pay for July, 1889	55.00
10	23	Henry J. Green	One aneroid barometer	23.25
16	24	T. Nelson Dale	Traveling expenses	21.76
18	25	Charles S. Merrick	Pay to July 31, 1889	5.86
20	26	H. A. Craigin	...do	70.84
20	27	Z. W. Bliss	...do	19.20
20	28	C. L. Whittle	Pay for July, 1889	100.00
31	29	H. L. Smyth	Field expenses	15.33
31	30	L. J. Carmalt	Pay for July, 1889	30.00
31	31	R. P. Loder	Traveling expenses	4.85
31	32	William H. Hobbs	...do	45.84
31	33	Joseph H. Perry	Pay to July 31, 1889	13.44
31	34	H. L. Smyth	Field supplies and expenses	268.20
31	35	Raphael Pumpelly	Pay for August, 1889	337.00
31	36	T. Nelson Dale	...do	150.00
31	37	A. O. D. Taylor, jr	...do	101.10
31	38	Richard Bliss	Bibliographical work	27.90
Sept. 2	39	A. Prescott Baker	Rent for August, 1889	50.00
2	40	Ben K. Emerson	Pay for August, 1889	101.10
3	41	Adams Express Co	Express charges	2.65
4	42	C. L. Whittle	Pay for August, 1889	100.00
4	43	Henry J. Green	Aneroid barometer	24.25
4	44	Raphael Pumpelly	Office expenses	45.32
4	45	Charles S. Merrick	Pay for August, 1889	30.00
4	46	T. Nelson Dale	Traveling expenses	32.16
4	47	A. O. D. Taylor, jr	...do	13.40
5	48	William H. Hobbs	Pay for August, 1889	75.00
6	49	Pay-roll	August, 1889	241.02
6	50	Eastman Dry Plate & Film Co	One Kodak camera	25.00
7	51	Whitney & Son	Photographic supplies	14.15
11	52	J. Steining & Son	Hardware supplies	14.50
12	53	H. L. Smyth	Field supplies and expenses	30.00
13	54	Nathan Barker	Carpentry work	21.90
17	55	H. L. Smyth	Field expenses	53.37
18	56	Raoul P. Loder	Pay to September 11, 1889	11.00
18	57	...do	Traveling expenses	10.70
18	58	Joseph H. Perry	...do	33.08
19	59	S. S. Pierce	Supplies	3.20
19	60	Keuffel & Esser	Drawing material	7.00
20	61	H. L. Smyth	Field supplies and expenses	95.63
20	62	...do	Traveling expenses	7.20
20	63	T. J. Eaves	One wagon	50.00
20	64	E. D. Keyes & Co	Supplies	10.10
21	65	Joseph H. Perry	Incidental expenses	4.65
21	66	H. A. Craigin	Traveling expenses	9.45
21	67	Z. W. Bliss	...do	9.45
26	68	T. Nelson Dale	...do	22.86
26	69	William H. Hobbs	...do	34.54
27	70	H. A. Craigin	Pay to September 19, 1889	63.27
28	71	Z. W. Bliss	...do	19.00
30	72	T. Nelson Dale	Pay for September, 1889	150.00
30	73	A. O. D. Taylor, jr	...do	97.80
30	74	William H. Hobbs	...do	75.00
		Total		3,952.27

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during the first quarter of 1890.

1889.				
July 31	1	Pay-roll of employés	Salaries, July, 1889	$1,180.80
Sept. 5	2	J. R. Biering	Pasturage	17.50
19	3	A. Lamme & Co	Field subsistence	153.69
19	4	J. E. Wolff	Traveling expenses	46.15
19	5	Pay-roll of employés	Salaries, August, 1889	1,222.10
19	6	Arnold Hague	Traveling expenses	53.95
19	7	E. H. Shuster	...do	25.45
30	8	Pay-roll of employés	Salaries, September, 1889	1,200.80
		Total		3,900.44

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during the first quarter of 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Aug. 4	1	Eric M. Noble	Services (job)	$128.00
4	2	John R. Proctor	Services, July 1 to August 4, 1889	210.00
		Total		338.00

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during October and November, 1889.

1889.				
Oct. 10	1	De Lancey W. Gill	Traveling expenses	$18.02
10	2	Charles C. Darwin	....do	37.15
10	3	William H. Dall	....do	40.77
11	4	Charles D. Walcott	....do	232.04
12	5	Eugene Leamy	Services, September 9 to 27, 1889	50.00
14	6	Thomas M. Chatard	Services, July 1 to 21, 1889	102.72
16	8	E. B. Wilson	Services, August and September, 1889.	110.00
16	9	A. Hermann	Services, July, August, and September, 1889.	250.00
16	10	H. Gibb	Services, September, 1889	70.00
16	11	T. A. Bostwick	Services, July, August, and September; 1889.	250.00
16	12	F. Berger	Services, August and September, 1889.	160.00
16	13	G. Baur	Services, September, 1889	150.00
16	14	O. A. Peterson	Services, August and September. 1889.	110.00
16	15	J. B. Hatcher	... do	400.00
16	16	L. P. Bush	Services, September, 1889	50.00
16	17	Eric M. Noble	Services, September 2 to 30, 1889	65.00
23	18	Eimer & Amend	Laboratory material, etc	139.03
23	19	James W. Queen & Co	....do	60.32
23	21	Ira Sayles	Traveling expenses	15.48
24	24	Chicago, Milwaukee and Saint Paul R. R.	Transportation of assistants	12.20
24	25	Baltimore and Potomac R. R. Co.	....do	10.00
24	26	Burlington and Missouri River R. R.	....do	45.90
24	27	Denver and Rio Grande R. R.	....do	35.00
24	28	Baltimore and Ohio R. R	....do	55.00
24	29	Northern Pacific R. R	....do	55.70
24	30	Chicago and Northwestern R. R.	....do	20.20
24	31	Aaron Veeder	Three negatives (paleontologic)	10.00
24	32	William Carlton Regand	Publications	4.25
24	33	Bangs & Co	....do	180.15
24	34	David G. Francis	....do	35.50
24	35	Romyn Hitchcock	....do	36.50
25	36	Joseph F. James	Traveling expenses	239.65
25	37	Richmond and Danville R. R	Transportation of assistants	138.15
30	39	John C. Parker	Publications	135.25
30	40	O. C. Marsh	Services, October, 1889	337.00
30	41	J. B. Hatcher	....do	200.00
30	42	H. Gibb	....do	70.00
30	43	G. Bauer	....do	150.00
30	44	L. P. Bush	....do	50.00
30	45	Sam. H. Scudder	....do	210.00
30	46	William M. Fontaine	....do	168.50
30	47	Ira Sayles	....do	117.90
30	48	T. W. Stanton	....do	75.30
30	49	Alpheus Hyatt	....do	250.00
30	50	W. H. Melville	....do	168.50
30	51	O. W. Tefft	Services, October 1 to 12, 1889	22.00
30	52	William F. Finch	Services, July 22 to 24, 1889	5.00
30	53	Eugene Leamy	Services, October 1 to 25, 1889	60.00
30	54	Pay-roll of employés	Services, October, 1889	421.20
30	55	....do	....do	1,209.42
30	56	....do	....do	1,178.80
30	57	....do	....do	1,037.74
30	59	....do	....do	418.99
30	61	....do	....do	633.48
31	62	Frank T. Smart	....do	101.10
Nov. 2	64	J. Henry Blake	....do	151.60
2	65	W. P. Rust	....do	87.75
2	66	O. A. Peterson	....do	55.00
2	67	E. B. Wilson	....do	55.00
2	68	W. H. Burwell	Services, September and October, 1889.	82.50

Abstract of disbursements made by J. D. McChesney, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Nov. 2	69	Joseph McDonough	Publications	$24.00
2	70	Henry I. Richmond	Traveling expenses	28.13
2	71	J. B. Beers & Co	Publications	22.00
2	72	Washington Gas-light Co.	Laboratory supplies	44.64
2	73	Milwaukee and Northern R. R.	Transportation of assistants	20.20
2	75	P. J. Cronan	Paleontologic supplies	66.75
2	76	Charles S. Cudlip	Supplies for illustrations	92.45
2	77	Adams Express Co	Freight charges, July, 1889	144.35
4	78	Z. D. Gilman	Laboratory supplies	37.87
4	79	...do	Supplies	167.90
6	80	Sam. H. Scudder	Traveling expenses	267.83
6	81	...do	...do	379.35
8	86	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	37.60
8	89	S. H. Zahn & Co	Publications	1.90
8	90	J. F. Manning	Laboratory supplies	12.50
8	91	H. S. Williams	Services, July 1 to October 31, 1889	501.40
11	92	W. B. Sanders	Publications	38.00
11	93	G. W. Shutt	Pay for October, 1889	252.70
11	94	Adams Express Co	Freight charges	49.05
11	95	Chicago, Burlington and Quincy R. R.	Transportation of assistants	12.50
11	96	George E. Littlefield	Publications	2.50
11	97	Tice & Lynch	Storage, etc	8.80
12	98	Henry Buford	Services, July 8 to 16, 1889	15.00
14	99	Leo Lesquereux, jr	Services, October 1 to 25, 1889	60.48
14	101	Quartermaster's Department, U. S. Army.	Field material	25.49
15	102	F. H Knowlton	Traveling expenses	278.27
15	103			
15	104	W. F. Hillebrand	Traveling expenses	352.45
15	105	Frank T. Smart	...do	11.50
16	106	...do	...do	75.50
19	107	Baltimore and Ohio R. R.	Transportation of assistants	81.50
19	108	Chicago and Northwestern R. R.	...do	10.10
19	109	T. H. Gardner	Publications	11.00
22	110	Dietrick W. Kolbe	Services, July 8 to 11, 1889	8.75
22	111	Wood & Forsyth	Supplies for illustrations	4.00
22	112	T. W. Stanton	Traveling expenses	113.55
22	113	George E. Littlefield	Publications	5.85
30	114	J. H. Danaghy	Services, July 1 to August 20, 1889	51.00
30	115	John F. Stephenson	Freight, August, September, and October, 1889.	2.06
30	116	Alpheus Hyatt	Services, November, 1889	250.00
30	117	Ira Sayles	...do	114.20
30	118	J. Henry Blake	...do	146.80
30	119	Sam. H. Scudder	...do	203.80
30	120	O. C. Marsh	...do	326.00
30	121	L. P. Bush	...do	50.00
30	122	H. Gibb	...do	70.00
30	123	G. Bauer	...do	150.00
30	125	W. H. Melville	...do	163.00
30	126	Frank Burns	...do	50.00
30	127	Pay-roll of employés	...do	407.60
30	128	...do	...do	1,140.06
30	129	...do	...do	1,165.80
30	130	...do	...do	358.80
30	131	...do	...do	676.80
		Total		19,233.64

SALARIES, OFFICE GEOLOGICAL SURVEY.

Oct. 31	1	Pay-roll of employés	Services, October, 1889	$2,952.48
Nov. 30	2	...do	Services, November, 1889	2,874.06
		Total		5,826.54

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during December, 1889.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Dec. 7	1	Pay-roll of employés	Services, November, 1889	$969.60
7	3	George W. Shutt	...do	244.60
7	4	George Ryneal, jr	Supplies	157.18
7	5	...do	Laboratory supplies	4.00
10	6	David G. Francis	Publications	9.25
10	7	Edward Willis	Services, October 10 and 11, 1889	5.00
10	8	William P. Rust	Services, November, 1889	84.50
10	9	William M. Fontaine	...do	163.00
10	10	Moss Engraving Co	Making geologic section	9.00
10	11	Missouri Pacific Ry. Co	Transportation of assistants	4.80
10	12	Rio Grande Western Ry. Co	...do	25.00
10	13	Atlantic and Pacific Ry. Co	...do	25.70
10	14	Northern Pacific R. R. Co	...do	261.60
10	15	Houghton, Mifflin & Co	Publications	6.50
10	16	Pennsylvania R. R. Co	Freight	3.33
11	17	Washington Gas-light Co	Laboratory supplies	47.51
11	19	Charles S. Prosser	Traveling expenses	102.21
11	20	J. W. Powell	...do	25.50
10	21	A. O. Peterson	Services, November 1 to December 15, 1889.	178.06
17	22	E. B. Willson	...do	98.92
14	23	Pennsylvania R. R	Transportation of assistants	40.50
14	24	Jos. D. Weeks	Services, August 1 to 31, 1889	150.00
16	27	E. Morrisson	Supplies for illustrations	65.00
17	28	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	75.05
17	29	Denver and Rio Grande R. R	...do	17.80
17	30	Chicago and Northwestern R. R	...do	35.40
18	31	Felix L. Dames	Publications	408.65
18	32	F. A. Brockhaus	...do	214.12
18	33	Citizens' National Bank	Bills of exchange	5.23
19	34	Isaac Newton	Services, December 1 to 15, 1889	6.45
19	35	The Wabash R. R	Transportation of assistants	27.75
18	36	Ellen L. Cudlip and Fillmore Beall.	Supplies for illustrations	106.75
18	37	H. N. Stokes	Services, November 1 to 9, 1889	29.35
20	39	Gottlieb Spitzer	Paleontologic supplies	5.85
23	40	Adams Express Co	Freight charges, September, 1889	38.05
23	41	George W. Knox	Freight, July, August, and September, 1889.	112.35
23	42	Whitall, Tatum & Co	Chemical supplies	21.92
23	43	Northern Distilling Co	Geological supplies	21.39
23	44	Chicago, Milwaukee and St. Paul R. R.	Transportation of assistants	31.50
23	45	Chicago, Burlington and Northern R. R.	...do	26.55
23	46	Atchison, Topeka and Santa Fé R. R.	...do	28.40
23	48	Pennsylvania Company	...do	17.50
27	49	St. Paul, Minnesota and Manitoba Ry.	...do	48.90
27	50	John C. Parker	Publications	57.50
24	51	L. H. Schneider's Sons	Supplies	80.94
27	52	De Lancey W. Gill	Traveling expenses	36.00
28	53	Z. D. Gilman	Laboratory supplies	4.13
28	54	...do	Supplies	182.96
30	55	Easton & Rupp	Library supplies	6.50
31	56	W. H. Melville	Services, December, 1889	168.50
31	57	Harriet Biddle	Services, October, November, and December, 1889.	30.00
31	58	Sam. H. Scudder	Services, December, 1889	210.60
31	59	Frank Burns	...do	50.00
31	60	Ira Sayles	...do	117.90
31	61	National Press Intelligence Co	Newspaper clippings	19.80
31	62	John S. Leng's Son & Co	Laboratory supplies	16.39
31	63	Edward J. Hannan	Repairs to laboratory	14.10
31	64	William D. Clark & Co	Supplies	.70
31	65	...do	...do	10.70
31	66	Edward J. Hannan	Services	3.50
31	67	Pay-roll of employés	Services, December, 1889	421.20
31	68	...do	...do	1,123.47
31	69	...do	...do	1,204.60
31	70	...do	...do	1,049.11
31	71	...do	...do	699.10
31	72	...do	...do	370.60
31	74	O. C. Marsh	...do	337.00
31	75	G. Craven	Services, September and October, 1889.	250.00
31	76	A. Hermann	Services, October 1 to December 31, 1889.	250.00

Abstract of disbursements made by J. D. McChesney, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889. Dec. 31	77	T. A. Bostwick	Services, October 1 to December 31, 1889.	$250.00
31	78	F. Berger	...do	240.00
31	79	J. B. Hatcher	Services, December, 1889	200.00
31	80	G. Baur	... do	150.00
31	81	H. Gibb	...do	70.00
31	82	L. P. Bush	...do	50.00
31	83	J. Henry Blake	...do	151.60
31	84	William M. Fontaine	...do	168.50
31	85	Alpheus Hyatt	...do	250.00
31	86	Washington Gas-light Co.	Laboratory material	47.88
31	87	Hume & Co.	Suppiies	2.65
31	91	Baltimore and Ohio R. R	Transportation of assistants	47.25
31	92	William P. Rust	Services, December, 1889	65.00
		Total		12,357.90

SALARIES, OFFICE GEOLOGICAL SURVEY.

Dec. 31	1	Pay roll of employés	Services, December. 1889	2,942.70

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during the second quarter of 1890.

1889. Oct. 7	1	W. E. Horton	Services, September	$60.00
7	2	H. L. Smyth	..do	97.80
7	3	Robert D. Cummin	...do	130.40
7	4	A. G. Stanley	Transportation	30.45
7	5	Nannie M. Peyton	Services, September	25.00
7	6	William Kramer	Traveling expenses	14.57
7	7	...do	Field expenses	127.05
7	8	H. L. Baldwin, jr	...do	106.24
7	9	R. U. Goode	Traveling expenses	91.93
7	10	George T. Hawkins	Pay-roll, September	227.80
7	11	E. C. Barnard	...do	540.20
7	12	W. R. Atkinson	Services, September	97.80
9	13	W. H. Lovell	Field expenses	202.72
9	14	G. S. Smith	...do	124.00
9	15	...do	Traveling expenses	4.58
9	16	James W. Queen & Co	Instruments	216.00
9	17	Thomas S. Clark	Traveling expenses	50.40
9	18	Benjamin D. Carpenter	Services	192.00
9	19	Glenn S. Smith	Services, September	50.00
9	20	Henry Ulke, jr	...do	50.00
9	21	Robert F. McMillan	Traveling expenses	4.35
9	22	William H. Herron	Subsistence	32.95
9	23	L. H. Schneider's Son	Supplies	4.48
9	24	L. M. Hoskins	Traveling expenses	5.43
9	25	William M. Beaman	Services, September	58.80
9	26	Charles F. Urquhart	Field expenses	118.45
9	27	D. C. Harrison	...do	107.00
9	28	F. P. Gulliver	Traveling expenses	10.96
9	29	...do	Field expenses	69.49
9	30	C. K. Judson	Office furniture	125.00
9	31	F. P. Gulliver	Field expenses	45.42
9	32	...do	...do	200.71
9	33	G. L. Johnson	Services, September	60.00
9	34	L. C. Fletcher	Field expenses	116.97
9	35	Charles S. Weed	Services, September	87.50
9	36	William J. Peters	...do	130.40
9	37	C. T. Reid	...do	68.40
9	38	R. O. Gordon	Field expenses	67.40
9	39	M. Hackett	...do	138.72
9	40	William H. Herron	...do	36.90
9	41	William J. Peters	...do	205.06
9	42	...do	...do	180.15
10	43	E. M. Huguely	Services, September	25.00
10	44	H. S. Wallace	Field expenses	61.40
11	45	Edwin A. Greenough & Co	Services, September	277.63
11	46	W. F. Fling	Pasturage	6.00
11	47	Keuffel & Esser Co.	Office furniture	43.95
12	48	R. M. Towson	Field expenses	197.07
14	49	John W. Price	Pasturage and storage	15.60

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Oct. 14	50	Henkel & Corpening	Storage	$6.00
14	51	Van H. Manning, jr	Field expenses	94.40
14	52	J. F. Smith & Co	Pasturage	9.00
14	53	Thos. Sinclair & Son	Publication	87.50
15	54	Chas. M. Yeates	Field expenses	163.48
15	55	James W. Queen & Co	Instruments	90.00
18	56	S. S. Gannett	Field expenses	73.15
18	57	G. L. Johnson	do	22.57
18	58	William M. Beaman	do	18.41
18	59	E. C. Barnard	do	121.40
18	60	Louis Nell	do	75.15
18	61	do	do	144.64
18	62	do	do	92.88
18	63	J. L. Smith	Map	12.00
18	64	L. C. Fletcher	Field expenses	107.61
18	65	Thomas Somerville & Sons	Repairs	1.10
23	66	L. C. Fletcher	Field expenses	124.63
23	67	C. M. Flora	Traveling expenses	21.80
23	68	E. C. Barnard	Field expenses	273.43
23	69	H. S. Wallace	do	97.35
23	70	Glenn S. Smith	do	63.25
25	71	H. B. Blair	do	223.12
25	72	R. Lee Longstreet	do	55.95
25	73	A. E. Murlin	do	164.87
25	74	John H. Renshawe	Traveling expenses	107.51
25	75	William H. Herron	do	61.42
28	76	Fred. J. Knight	Field expenses	102.00
28	77	E. C. Barnard	do	133.30
28	78	M. Hackett	do	349.22
28	79	Marcus Baker	Traveling expenses	50.26
31	80	J. H. Jennings	Services, October	134.80
31	81	E. B. Clark	do	117.90
31	82	Charles R. Grandy	do	50.00
31	83	F. P. Gulliver	do	101.10
31	84	G. E. Hyde	do	75.80
31	85	Lincoln Martin	do	60.00
31	86	W. H. Lovell	do	134.80
31	87	do	Field expenses	60.06
31	88	William M. Beaman	do	38.83
31	89	do	Services, October	60.60
31	90	Lewis J. Battle	do	60.00
31	91	E. W. F. Natter	do	134.80
31	92	William Kramer	do	101.10
31	93	C. J. Akin	do	60.00
31	94	G. L. Johnson	do	60.00
31	95	James McCormick	do	60.60
31	96	H. S. Wallace	Pay-roll, October	365.40
31	97	Louis Nell	Services, October	168.50
31	98	do	Pay-roll, October	374.20
31	99	R. U. Goode	Services, October	210.60
31	100	R. S. Woodward	do	227.40
31	101	Gilbert Thompson	do	210.60
31	102	Charles Bogan	do	50.50
31	103	L. C. Fletcher	Field expenses	138.81
31	104	Pay-roll (Karl)		2,863.53
31	105	J. W. Thom	Services, October	50.00
31	106	E. L. Chipman	do	50.00
31	107	Henry Ulke, jr	do	50.00
31	108	C. T. Reid	do	70.80
31	109	Frank Sutton	do	117.90
31	110	Thomas C. Nelson	do	40.00
31	111	S. G. Abbott	do	14.19
31	112	J. F. Johnson	do	14.19
31	113	C. Martin	Services	14.19
31	114	Claude Petty	do	14.19
31	115	John H. Renshawe	do	210.60
31	116	Charles M. Yeates	do	151.60
31	117	J. B. Beers & Co	Maps	12.00
Nov. 7	118	S. S. Gannett	Services	168.50
7	119	Fred. J. Knight	do	151.60
7	120	H. L. Smyth	do	101.10
7	121	Charles S. Weed	do	45.00
7	122	L. D. Brent	do	75.80
7	123	William J. Peters	do	134.80
7	124	Ambrose F. Dudley	do	55.00
7	125	Robert D. Cummin	do	134.80
7	126	Pay-roll (Hawkins)	do	239.78
7	127	J. H. Wheat	do	75.80
7	128	W. E. Horton	do	60.00
7	129	W. R. Atkinson	do	101.10
7	130	W. U. Simons	do	30.00

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Nov. 7	131	Pay-roll (Barnard)	Services	$612.40
7	132	James E. Shelley	do	60.00
7	133	Glenn S. Smith	do	50.00
7	134	Pay-roll (Baldwin)	do	809.29
7	135	O. W. Hanson	do	20.32
7	136	Pay-roll (Gordon)	do	329.30
7	137	Pay-roll (Blair)	do	461.40
7	138	Pay-roll (Urquhart)	do	226.10
7	139	Pay-roll (Fletcher)	do	611.90
7	140	Pay-roll (Murlin)	do	505.30
7	141	Edward Kahler	Supplies	15.75
7	142	Pay-roll (Hackett)	Services	434.86
8	143	Robert Leitch & Sons	Supplies	13.10
8	144	S. S. Gannett	Traveling expenses	58.26
8	145	do	Field expenses	91.95
8	146	S. J. Haislett	Supplies	28.50
8	147	M. B. Lambert	Services	75.80
8	148	Charles F. Urquhart	Field expenses	123.10
8	149	Nannie M. Peyton	Services	25.00
9	150	H. L. Baldwin, jr	Field expenses	112.67
9	151	George T. Hawkins	do	331.98
9	152	G. E. Hyde	do	48.72
9	153	Robert D. Cummin	do	202.74
9	154	R. U. Goode	Traveling expenses	131.03
9	155	D. C. Harrison	Subsistence and transportation	128.25
9	156	R. O. Gordon	Field expenses	122.65
9	157	W. H. Lovell	do	57.08
9	158	do	Traveling expenses	30.77
9	159	William J. Peters	Field expenses	247.75
9	160	do	do	56.47
9	161	do	do	120.62
9	162	William Kramer	do	116.57
9	163	do	Traveling expenses	22.18
9	164	Van H. Manning, jr	Field expenses	80.11
9	165	H. S. Wallace	do	43.80
9	166	F. P. Gulliver	do	137.03
9	167	do	do	127.00
9	168	do	do	52.00
9	169	do	do	55.57
9	170	do	Traveling expenses	23.13
9	171	G. E. Hyde	Field expenses	315.58
9	172	R. S. Woodward	Traveling expenses	38.62
9	173	Glenn S. Smith	Field expenses	66.60
9	174	S. B. Cox	Subsistence and transportation	97.00
9	175	L. C. Fletcher	Field expenses	92.75
9	176	W. J. Richardson	do	109.75
9	177	do	Traveling expenses	3.70
11	178	John C. Parker	Typewriter and cabinet	100.00
12	179	Charles M. Yeates	Field expenses	155.75
12	180	James Longstreet, jr	Services	60.60
12	181	Hersey Munroe	Traveling expenses	33.26
12	182	John H. Renshawe	do	112.18
19	183	E. L. Chipman	do	5.02
19	184	do	do	15.36
19	185	Howard A. Graham	do	8.00
19	186	J. S. Topham	Supplies	12.50
19	187	Thos. Sinclair & Son	Publication	35.00
20	188	D. C. Harrison	Services, October	117.90
21	189	Gottlieb Spitzer	Stamp	1.50
21	190	Hume & Co	Material for mounting maps	2.00
30	191	L. C. Fletcher	Field expenses	241.08
30	192	do	do	131.10
30	193	E. C. Barnard	do	226.71
30	194	Robert D, Cummin	do	75.90
30	195	E. W. F. Natter	Services, November	130.40
30	196	James E. Shelley	do	60.00
30	197	Charles R. Grandy	do	50.00
30	198	E. B. Clark	do	114.20
30	199	R. U. Goode	do	203.80
30	200	A. E. Murlin	Pay-roll, November	470.39
30	201	L. C. Fletcher	do	567.86
30	202	Charles M. Yeates	do	346.80
30	203	F. P. Gulliver	Services, November	97.80
30	204	Louis Nell	do	163.00
30	205	Robert D. Cummin	do	130.40
30	206	L. C. Fletcher	Traveling expenses	109.50
30	207	W. L. Miller	do	19.20
30	208	Henry Ulke, jr	do	13.46
30	209	Henry W. Carpenter	do	10.20
30	210	A. E. Murlin	do	16.40
30	211	Harrison E. Crooke	do	11.80

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Nov. 30	212	Robert D. Cummin	Traveling expenses	$43.25
30	213	A. B. Searle	...do	13.87
30	214	...do	...do	9.20
30	215	...do	...do	7.12
30	216	Nat. Tyler, jr	...do	88.45
30	217	Gilbert Thompson	do	109.10
30	218	Anton Karl (pay-roll)	November	3,392.06
30	219	M. Hackett (pay-roll)	...do	424.40
Dec. 4	220	H. L. Smyth	Services, November	97.80
4	221	James Longstreet, jr	...do	58.80
3	222	Fred J. Knight	...do	146.80
3	223	M. B. Lambert	...do	73.40
3	224	G. L. Johnson	...do	60.00
3	225	W. H. Lovell	...do	130.40
3	226	W. E. Horton	...do	60.00
3	227	Frank Sutton	...do	114.20
3	228	J. W. Thom	...do	50.00
3	229	William Kramer	...do	97.80
3	230	W. M. Beaman	...do	58.80
3	231	R. S. Woodward	...do	220.20
3	232	R. Lee Longstreet	...do	97.80
3	233	...do	...do	101.10
3	234	W. U. Simons	...do	30.00
3	235	C. W. Wrenshall	...do	16.67
3	236	Fanny S. Barnett	...do	25.00
3	237	...do	...do	19.17
3	238	E. C. Barnard	Pay-roll, November	600.20
3	239	Charles F. Urquhart	...do	199.96
3	240	Pay-roll (Wallace)	...do	364.20
3	241	H. B. Blair	...do	452.20
3	242	George T. Hawkins	...do	244.20
3	243	R. O. Gordon	...do	361.40
3	244	Glenn S. Smith	Traveling expenses	12.99
3	245	W. J. Richardson	...do	7.64
3	246	R. U. Goode	...do	118.51
3	247	Edward Patterson	...do	25.00
3	248	Edmund S. Parker	...do	9.70
3	249	Louis Nell	Field expenses	69.61
3	250	H. S. Wallace	...do	112.54
3	251	John H. Renshawe	...do	5.29
3	252	W. M. Beaman	...do	61.50
3	253	...do	...do	22.60
3	254	R. O. Gordon	...do	194.20
3	255	W. J. Richardson	...do	56.52
3	256	W. H. Lovell	...do	85.40
3	257	H. S. Wallace	...do	53.85
3	258	Fred. J. Knight	...do	101.45
3	259	William H. Herron	...do	119.96
2	260	Julius Bien & Co	Publication	72.80
2	261	...do	...do	108.70
2	262	E. E. Jackson & Co	Lumber	51.00
2	263	Clifford Arrick	Subsistence	6.00
2	264	T. H. Gardner	Atlas	11.00
4	265	George S. Harris	Publications	105.00
4	266	Henry J. Green	Instruments	12.25
4	267	James W. Queen & Co	...do	8.25
4	268	M. Hackett	Field expenses	302.78
4	269	W. F. Fling	Pasturage	6.00
4	270	J. L. Smith	Atlas	12.00
4	271	E. E. Jackson & Co	Field material	11.00
3	272	John W. Price	Pasturage	6.00
4	273	Louis Nell	Traveling expenses	60.85
4	274	Fred. J. Knight	...do	56.96
4	275	William J. Peters	Field expenses	165.65
4	276	...do	...do	46.75
4	277	...do	...do	53.40
5	278	H. L. Baldwin, jr	...do	86.27
5	279	Charles M. Yeates	...do	131.69
5	280	G. E. Hyde	Services, November	73.40
5	281	L. D. Brent	...do	73.40
5	282	Lincoln Martin	...do	60.00
5	283	J. H. Jennings	...do	130.40
5	284	James McCormick	...do	58.80
5	285	H. L. Baldwin, jr	Traveling expenses	38.52
5	286	D. A. Creder	...do	14.35
5	287	J. M. Gibson	Pasturage	14.67
5	288	William D. Clark & Co	Office material	75.60
6	289	Charles Bogan	Services, November	49.00
6	290	...do	Traveling expenses	9.18
6	291	Judson D. Lincoln	Services	11.61
6	292	Shack Smith	...do	7.74

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889. Dec. 7	293	Charles M. Yeates	Field expenses	$130.50
7	294	...do	Traveling expenses	8.10
7	295	D. C. Harrison	Field expenses	144.50
7	296	...do	Services, November	114.20
7	297	H. L. Baldwin, jr	Pay roll	727.47
7	298	Louis Nell	...do	321.60
7	299	F. P. Gulliver	Field expenses	135.25
7	800	...do	...do	56.87
7	301	Ambrose F. Dudley	Services	55.00
7	302	Henry Ulke, jr	Services, November	26.67
7	303	C. J. Akin	...do	60.00
7	304	John D. Black	Traveling expenses	12.78
7	305	Glenn S. Smith	Services	50.00
7	306	T. Howard Seeley	Traveling expenses	24.11
7	307	Darling, Brown & Sharpe	Office material	10.50
7	308	C. T. Reid	Services, November	68.40
7	309	Lewis J. Battle	...do	60.00
9	310	W. R. Atkinson	...do	97.80
9	311	R. Lee Longstreet	Field expenses	57.19
9	312	Nezzer Neal	Services	30.00
9	313	G. S. Smith	Field expenses	18.87
10	314	G. E. Hyde	...do	245.85
10	315	E. C. Barnard	Traveling expenses	47.75
10	316	H. L. Baldwin, jr	...do	14.20
10	317	B. P. Legare	...do	15.50
10	318	A. B. Searle	Field expenses	2.50
10	319	G. S. Smith	Traveling expenses	10.83
10	320	Nannie M. Peyton	Services	12.50
10	321	James McCormick	Traveling expenses	19.10
10	322	Louis Nell	Field expenses	17.25
10	323	...do	...do	90.26
10	324	John W. Price	Pasturage	30.50
10	325	Edward Kubel	Office supplies	26.61
10	326	William Kramer	Field expenses	68.00
10	327	...do	Traveling expenses	25.81
10	328	C. J. Akin	...do	15.18
10	329	Moses Bittner	Transportation	77.50
10	330	S. B. Cox	Subsistence	133.50
10	331	Edwin A. Greenough & Co	Services	320.13
10	332	W. J. Richardson	Traveling expenses	8.43
10	333	...do	Field expenses	55.25
10	334	E. C. Barnard	Traveling expenses	33.25
10	335	...do	Field expenses	265.18
10	336	A. E. Murlin	...do	233.18
10	337	S. Chester Reid	Traveling expenses	46.10
13	338	Van H. Manning, jr	Services, October	101.10
13	339	...do	Services, November	97.80
13	340	A. E. Wilson	Traveling expenses	45.85
14	341	H. T. Irwin	...do	23.95
14	342	R. M. Towson	...do	45.44
20	343	Louis Nell	Field expenses	415.28
20	344	Van H. Manning, jr	Traveling expenses	76.19
20	345	Charles M. Yeates	...do	53.90
20	346	...do	Field expenses	55.08
20	347	Charles B. Green	Traveling expenses	34.75
20	348	John H. Renshawe	Pasturage	32.67
20	349	Judson D. Lincoln	Traveling expenses	44.50
20	350	H. S. Wallace	...do	54.95
20	351	J. H. Wheat	Services, November	73.40
24	352	W. H. Lovell	Traveling expenses	24.10
24	353	Castle & Henshawe	Supplies	.25
24	354	William D. Clark & Co	Material for mounting maps	36.53
24	355	Hume & Co	...do	2.00
24	356	L. H. Schneider's Son	Supplies	34.65
24	357	Lewis J. Battle	Traveling expenses	11.35
24	358	M. W. Beveridge	Office supplies	.75
20	359	Basil Duke	Traveling expenses	42.80
20	360	James G. Bowen	Transportation	16.50
20	361	George G. Hawkins	Traveling expenses	42.30
20	362	H. S. Wallace	Field expenses	61.70
20	363	G. E. Hyde	Traveling expenses	31.20
20	364	W. H. Lovell	Field expenses	34.15
20	365	H. L. Baldwin, jr	...do	3.57
20	366	Lincoln Martin	Traveling expenses	33.33
20	367	C. T. Reid	...do	34.27
20	368	L. D. Brent	...do	26.45
20	369	J. H. Wheat	...do	7.15
20	370	George H. Lamar	...do	43.45
20	371	F. P. Gulliver	...do	27.01
20	372	...do	Field expenses	30.89
20	373	Thomas C. Nelson	Services, December	9.03

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Dec. 20	374	William H. Griffin	Traveling expenses	$46.35
20	375	D. C. Harrison	...do	147.75
20	376	William H. Herron	...do	46.60
20	377	...do	Field expenses	69.58
20	378	William J. Peters	Services, November	130.40
20	379	...do	Services, December	134.80
20	380	E. C. Barnard	Field expenses	495.85
20	381	R. M. Towson	...do	450.97
20	382	George T. Hawkins	...do	223.23
20	383	H. B. Blair	...do	245.80
27	384	F. P. Metzger	Traveling expenses	49.25
27	385	R. U. Goode	...do	125.16
27	386	G. L. Johnson	Field expenses	126.25
27	387	R. M. Towson	...do	7.60
28	388	R. S. Woodward	Traveling expenses	84.35
28	389	M. R. Avery	...do	43.20
28	390	H. B. Blair	...do	42.80
31	391	J. W. Williams	Services, December	19.19
31	392	S. E. Cook	...do	30.48
31	393	O. W. Hanson	...do	21.93
31	394	G. Unsell	...do	25.80
31	395	J. H. Hagerty	...do	33.54
31	396	C. M. Flora	...do	30.64
31	397	G. L. Johnson	...do	60.00
31	398	W. M. Beaman	...do	60.60
31	399	R. B. Cameron	...do	70.80
31	400	Ernest Buttery	...do	6.77
31	401	C. M. Gordon	...do	45.00
31	402	J. H. Gray	...do	27.09
31	403	W. U. Simons	...do	12.58
31	404	J. J. Fawbush	...do	6.77
31	405	Pay-roll (Wallace)	...do	237.86
31	406	Pay-roll (Urquhart)	...do	216.10
31	407	Robert Boyd	Supplies	.35
31	408	N. B. Dunn	Pasturage	17.40
31	409	W. F. Fling	...do	20.00
31	410	I. M. Buell	Field expenses	39.00
31	411	Ira M. Buell	...do	27.00
31	412	R. O. Gordon	...do	187.05
31	413	...do	Traveling expenses	57.45
31	414	Joseph N. Austin	...do	20.42
31	415	W. E. Lackland	...do	48.30
31	416	R. B. Cameron	...do	57.45
31	417	E. McL. Long	...do	41.34
31	418	C. T. Reid	...do	19.27
31	419	Thomas Sinclair & Son	Publications	70.00
31	420	George Morgan	Services, December	6.00
31	421	J. M. Couch	Storage	2.79
31	422	Henkle, Craig & Co	...do	6.00
31	423	W. G. Chapman	...do	2.48
31	424	Morris Franklin	...do	5.07
31	425	Elias Foglesong	Pasturage	7.00
31	426	James W. Queen & Co	Instruments	8.16
31	427	E. G. Kennedy	Traveling expenses	14.90
31	428	R. Lee Longstreet	Field expenses	33.50
31	429	R. O. Gordon	...do	24.70
31	430	M. Hackett	Traveling expenses	74.46
31	431	J. J. Lincoln	...do	58.10
31	432	James E. Shelley	Services, December	60.00
31	433	H. L. Smyth	...do	101.10
31	434	E. E. Jackson & Co	Office material	6.00
31	435	Pay-roll (Goode & Renshawe)	December	2,297.40
31	436	Pay-roll (Gilbert Thompson)	...do	2,509.30
31	437	Pay-roll (Henry Gannett)	...do	2,817.66
31	438	Pay-roll (Marcus Baker)	...do	2,284.60
31	439	E. W. F. Natter	Services, December	134.80
31	440	C. M. Flora	Traveling expenses	14.70
		Total		58,354.39

Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the second quarter of 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Oct. 7	1	Pay-roll	Services, September, 1889	$747.70
7	2	...do	...do	635.80
7	3	W. P. Jenney	...do	179.40
7	4	Collier Cobb	...do	50.00
7	5	J. B. Woodworth	...do	50.00
7	6	R. S. Tarr	...do	50.00
7	7	Frank Leverett	Services, July and August, 1889	240.00
7	8	R. D Salisbury	...do	245.00
7	9	I. C. Russell	Services, September, 1889	195.60
7	10	J. Stanley Brown	...do	97.80
7	11	George H. Williams	...do	65.00
7	12	Pay-roll	...do	227.80
7	13	C. R. Van Hise	...do	326.00
7	14	George E. Luther	...do	97.80
7	15	...do	Traveling expenses	78.71
7	16	H. W. Turner	...do	41.44
7	17	R. S. Tarr	...do	71.95
7	18	...do	...do	27.25
7	19	Arthur Keith	Field expenses	88.16
7	20	S. S. Mallory	Geological prints	5.00
7	21	Wyckoff, Seamans & Benedict	Repairs	1.15
7	22	Eastman Dry Plate and Film Co.	Photo material	45.25
7	23	A. Lamme & Co	Field supplies	63.10
7	24	James G. Bowen	Forage, etc	69.15
7	25	Aug. F. Foerste	Field expenses	83.29
7	26	Sam. P. Barbee	Storage	37.50
7	27	C. R. Van Hise	Traveling expenses	469.47
7	28	Watersmeet Lumber Co	Subsistence	34.01
7	29	W. B. Clark	Services, September, 1889	100.00
7	30	C. W. Coman	...do	50.00
7	31	F. C. Boyce	...do	60.00
7	32	Frank Rader	...do	40.00
7	33	N. S. Shaler	...do	250.00
7	34	C. W. Hayes	Field expenses	43.48
7	35	Pay-roll	Services, September, 1889	227.80
11	36	G. K. Gilbert	Traveling expenses	41.01
11	37	Western Union Telegraph Co	Telegrams	5.00
11	38	...do	...do	1.61
11	39	Pay-roll	Services, September, 1889	132.00
11	40	R. S. Tarr	Traveling expenses	51.78
11	41	C. W. Coman	...do	28.72
11	42	J. S. Diller	...do	89.20
11	43	H. R. Geiger	Field expenses	77.87
14	44	Lawrence C. Johnson	Traveling expenses	54.00
14	45	Nelson H. Darton	...do	26.20
15	46	...do	...do	129.48
16	47	J. S. Diller	Field expenses	233.02
16	48	Aug. F. Foerste	Traveling expenses	26.56
16	49	...do	Services, September, 1889	50.00
16	50	Robert T. Hill	...do	40.00
16	51	W. S. Bayley	...do	120.00
16	52	Abner Doble	Field material	5.00
16	53	G. F. Becker	Field expenses	44.25
17	54	W. Lindgren	...do	102.95
17	55	H. W. Turner	...do	78.71
18	56	Bailey Willis	...do	139.41
18	57	...do	...do	6.00
22	58	J. Stanley-Brown	Traveling expenses	117.00
22	59	A. C. Peale	...do	126.30
19	60	W. S. Bayley	...do	246.00
22	61	C. R. Van Hise	Field expenses	4.10
22	62	William J. Park & Sons	Stationery	7.20
24	63	J. B. Woodworth	Field expenses	65.22
24	64	George H. Barton	Services, July, 1889	50.00
24	65	J. M. Safford	Services, September, 1889	19.57
31	67	G. F. Becker	Services, October, 1889	337.00
31	68	Pay-roll	...do	344.60
31	69	G. W. Granniss	Rent, laboratory rooms	110.00
28	70	Charles P. Sinnot	Services, July, 1889	50.00
28	71	...do	Field expenses	29.15
28	72	Eastman Dry Plate Co	Developing, etc	19.13
28	73	R. D. Salisbury	Traveling expenses	345.42
28	74	John R. Proctor	Services, August and September, 1889.	50.00
29	75	A. C. Peale	Field expenses	57.21
31	76	Pay-roll	Services, October, 1889	631.70
31	77	...do	...do	657.10
31	78	...do	...do	481.80
31	79	...do	...do	219.00
31	80	...do	...do	570.30

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Oct. 31	81	Pay-roll	Services, October, 1889	$621.70
31	82	do	do	378.60
31	83	I. C. Russell	do	202.20
31	84	W. P. Jenney	do	185.30
31	85	H. W. Turner	Field expenses	47.71
31	86	J. M. Safford	do	30.00
Nov. 1	87	C. R. Van Hise	Services, October, 1889	337.00
1	88	George E. Luther	do	101.10
1	89	Charles D. Walcott	Traveling expenses	45.25
2	90	Lena P. Thompson	Forage	43.25
2	91	Pay-roll	Services, October, 1889	370.00
4	92	I. C. Russell	Field expenses	141.25
4	93	do	Traveling expenses	190.25
5	94	C. W. Hayes	Field expenses	106.00
5	95	William B. Clark	Services, October, 1889	130.00
5	96	C. D. Voy	Services, collector	200.00
5	97	C. D. Voy (voucher canceled)	do	
6	98	F. C. Boyce	Services, October, 1889	60.00
7	99	Frank Rader	do	40.00
6	100	Bailey Willis	Traveling expenses	122.10
8	101	Warren Upham	Services, July-October, 1889	401.10
8	102	James G. Bowen	Pasture, etc	85.54
8	103	Bailey Willis	Field expenses	169.56
9	104	Nelson H. Darton	do	65.16
11	105	James Storrs	Services, October to November, 1889	75.13
11	106	Carrick, Williams & Wright	Field supplies	33.00
11	107	Kenneth O. Kerr	Field expenses	20.98
12	108	Richard E. Edes	Traveling expenses	20.10
12	109	Pay-roll	Services, October, 1889	260.13
13	110	Arthur Keith	Field expenses	133.56
13	111	A. T. Kyle, jr	Pasture, July to October, 1889	25.73
14	112	Wilh. P. Stender	Glass slides	62.00
14	113	Crane, Parris & Co	Exchange	1.82
14	114	W. S. Bayley	Services, October, 1889	57.00
14	115	N. S. Shaler	Traveling expenses	162.07
14	116	G. H. Williams	Services, October, 1889	95.00
15	117	W. Lindgren	Field expenses	84.50
15	118	Lawrence C. Johnson	do	52.90
16	119	James S. Topham	Saddlery	35.05
16	120	E. E. Jackson & Co	Lumber	5.75
14	121	Arthur Bibbins	Traveling expenses	21.45
16	122	Robert T. Hill	Services, October, 1889	60.00
16	123	H. R. Geiger	Traveling expenses	95.04
16	124	Mark B. Kerr	Field and office expenses	34.78
18	125	J. A. Holmes	Services, July to November, 1889	145.00
18	126	Union Stone Co	Material for grinding	15.00
21	127	C. W. Hayes	Field expenses	110.00
21	128	do	do	7.95
26	129	Frank W. Geiger	Traveling expenses	24.15
30	130	C. W. Coman	do	45.90
30	131	do	do	24.91
30	132	C. W. Hayes	Services, October, 1889	101.10
30	133	Warren Upham	Traveling expenses	369.47
30	134	Pay-roll	Services, November, 1889	293.40
30	135	do	do	551.90
30	136	do	do	635.80
30	137	do	do	517.40
30	138	do	do	466.40
30	139	do	do	212.00
30	140	do	do	611.60
30	141	I. C. Russell	do	195.60
30	142	G. F. Becker	do	326.00
30	143	Pay-roll	do	310.80
30	144	Lawrence C. Johnson	do	114.20
30	145	J. B. Hatcher	do	225.00
Dec. 3	146	E. and H. T. Anthony & Co	Packing public property	167.50
3	147	W. J. McGee	Traveling expenses	215.55
3	148	Nelson H. Darton	do	73.35
5	149	James G. Bowen	Pasturage	100.75
4	150	Lena P. Thompson	do	25.00
5	151	Abner Doble	Field material	9.50
6	152	Martin Petterson	Plumbing	5.00
6	153	Warren Upham	Services, November, 1889	97.80
6	154	G. R. Hargadine	Services, July to October, 1889	79.03
6	155	George H. Williams	Services, November, 1889	85.00
6	156	W. S. Bayley	do	72.50
6	157	C. W. Coman	do	50.00
6	158	Pay-roll	do	310.00
Nov. 15	159	H. A. Messenger	Pasturage	10.00
Dec. 6	160	C. R. Van Hise	Services, November, 1889	326.00
6	161	George E. Luther	do	97.80

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Dec. 6	162	H. R. Geiger	Services, November, 1889	$122.20
6	163	William B. Clark	... do	125.00
9	164	Charles W. Richmond	Services, December, 1889	9.78
9	165	H. Davis	Cartage, etc	65.00
9	166	Esther De Puy	One typewriter	85.00
12	167	John Milan	Services, November, 1889	25.00
12	168	T. K. Bolton	Forage	15.00
12	169	A. T. Kyle, jr	Pasturage	14.00
12	170	Frank W. Geiger	Services, November, 1889	50.00
15	171	G. W. Granniss	Rent of rooms, November, 1889	55.00
15	172	Pay-roll	Services, November, 1889	147.80
13	173	Lutz & Bros	Saddlery	61.75
13	174	W. H. Melville	Traveling expenses	37.75
18	175	Arthur Keith	....do	62.67
18	176	....do	....do	56.10
21	177	Kenneth C. Kerr	Field expenses	19.35
21	178	Gottlieb Spitzer	Repairs	2.25
23	179	Frank Leverett	Services, August to December, 1889	475.00
23	180	Z. D. Gilman	Chemical supplies	13.15
23	181	J. A. Holmes	Services	125.00
23	182	W. P. Jenney	Services, November, 1889	179.40
23	183	Gore, Janney & Co	File boxes	16.50
23	184	E. E. Jackson & Co	Lumber	5.50
31	185	Pay-roll	Services, December, 1889	115.62
31	186	Sam P. Barbee	Storage	37.50
31	187	G. R. Hargadine	Services, October to December, 1889	85.16
31	188	....do	Field expenses	1.95
31	189	O. Ganiard	Storage, July to December	30.00
31	190	Pay-roll	Services, December, 1889	319.60
31	191	...do	....do	2,485.20
31	192	....do	....do	1,808.90
31	193	Mark B. Kerr	Telegrams	5.17
31	194	Lawrence C. Johnson	Services, December, 1889	117.90
		Total		30,327.80

Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent, U. S. Geological Survey, during the second quarter of 1890.

1889.				
Oct. 1	1	Joseph H. Perry	Traveling expenses	$15.90
2	2	Ben. K. Emerson	.....do	187.39
2	3	....do	Pay for September, 1889	97.80
2	4	Raphael Pumpelly	.....do	326.00
2	5	C. L. Whittle	.....do	100.00
3	6	....do	Field expenses	18.75
3	7	Joseph H. Perry	Pay to September 7, 1889	37.00
4	8	William H. Hobbs	Field expenses	4.79
5	9	...do	Traveling expenses	27.98
5	10	L. J. Carmalt	Pay to September 20, 1889	26.60
5	11	....do	Traveling expenses	7.05
5	12	A. Prescott Baker	Rent for September, 1889	50.00
7	13	T. Nelson Dale	Traveling expenses	21.76
7	14	Charles S. Merrick	.....do	72.18
14	15	H. L. Smyth	Field expenses	71.10
15	16	T. Nelson Dale	Traveling expenses	19.95
16	17	C. A. Claghorn	Team hire	87.00
17	18	G. F. Gilmore	Camera case, etc	7.00
19	19	T. Nelson Dale	Traveling expenses	14.62
22	20	H. L. Smyth	Field expenses	20.75
28	21	Edward Stabe	Pay for September, 1889	55.00
29	22	J. Eliot Wolff	Incidental expenses	4.73
30	23	J. F. Kemp	Services	50.00
30	24	Richard Bliss	Bibliographical work	38.10
31	25	Raphael Pumpelly	Pay for October, 1889	337.00
31	26	T. Nelson Dale	....do	150.00
31	27	A. O. D. Taylor, jr	....do	101.10
31	28	A. Prescott Baker	Rent for October, 1889	50.00
Nov. 7	29	Edward Stabe	Pay for October, 1889	55.00
8	30	H. L. Smyth	Traveling expenses	19.45
8	31	....do	Field expenses	35.19
9	32	Raphael Pumpelly	Traveling expenses	61.49
18	33	Adams Express Co	Express charges	2.30
19	34	C. L. Whittle	Pay for October, 1889	100.00
20	35	Raphael Pumpelly	Office expenses, etc	48.45
20	36	E. D. Keyes & Co.	Supplies	3.98
22	37	H. L. Smyth	Field expenses	145.41

Abstract of disbursements made by A. O. D. Taylor, jr., etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1889.				
Nov. 27	38	Western Union Telegraph Co	Telegrams	$2.98
30	39	S. S. Pierce & Co	Supplies	7.07
Dec. 2	40	Richard Bliss	Bibliographical work	24.60
9	41	Raphael Pumpelly	Traveling expenses	84.80
9	42	do	Pay for November, 1889	326.00
9	43	T. Nelson Dale	do	150.00
9	44	A. O. D. Taylor, jr	do	97.80
9	45	A. Prescott Baker	Rent for November, 1889	50.00
11	46	C. L. Whittle	Pay for November, 1889	100.00
16	47	Edward Stabe	do	55.00
16	48	do	Pay to December 14, 1889	24.78
16	49	do	Traveling expenses	9.00
17	50	Adams Express Co	Express charges	26.10
18	51	N. Y. and B. D. Express Co	do	4.45
19	52	Ben. K. Emerson	Traveling expenses	106.75
19	53	do	Incidental expenses	5.10
26	54	H. L. Smyth	Traveling expenses	35.45
26	55	do	Field expenses	34.39
		Total		3,610.09

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during the second quarter of 1890.

1889.				
Oct. 21	1	Yellowstone Park Association	Field subsistence	$35.87
21	2	do	Field expenses	17.90
21	3	do	Subsistence	52.00
21	4	George W. Wakefield	Field expenses	16.00
22	5	R. T. Smith	Field subsistence	93.44
22	6	J. C. McCartney	Field expenses	70.64
25	7	Louis V. Pirsson	Traveling expenses	28.20
28	8	A. Lamme & Co	Field subsistence	202.54
28	9	J. D. Bolin	Pasturage and forage	26.85
31	10	Pay-roll of employés	Services, October, 1889	432.39
31	11	do	do	732.10
Nov. 27	12	E. H. Shuster	Traveling expenses	31.45
29	13	Jos. P. Iddings	do	58.20
29	14	J. E. Wolff	do	56.50
30	15	Louis V. Pirsson	do	31.80
30	16	Pay-roll of employés	Services, November, 1889	710.80
Dec. 2	17	Arnold Hague	Traveling expenses	54.80
3	18	Walter H. Weed	do	63.20
4	19	David B. May	Fresh meat	84.75
5	20	Frederick Koch	Services	16.67
9	21	John B. Bean	Field expenses	385.00
9	22	William C. Howard	Services, July, 1889	38.70
9	23	do	Services, August, 1889	50.00
9	24	Ed. Hibbard	Services, July, 1889	38.70
9	25	do	Services, August, 1889	50.00
9	26	J. E. Wolff	Field expenses	53.85
16	27	E. L. Fridley	do	12.00
31	28	Pay-roll of employés	Services, December, 1889	732.10
31	29	Arnold Hague	Field expenses	77.82
31	30	R. T. Smith	Field supplies	4.36
31	31	Elwood Hofer	Services	90.00
		Total		4,348.63

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during January, 1890.

1890.				
Jan. 11	1	Robert Beall	Publications	$71.75
11	2	Wash. B. Williams	Supplies	160.75
17	3	George W. Shutt	Pay, December, 1889	252.70
17	4	William A. Raborg	Traveling expenses	18.90
17	5	J. Bishop & Co	Repairs to laboratory material	19.60
17	6	Darling, Brown & Sharpe	Topographic supplies	63.00
17	7	Goodnow & Wightman	Laboratory supplies	34.81
17	8	James W. Queen & Co	do	66.68
17	9	John S. Leng's Son & Co	do	2.29

Abstract of disbursements made by J. D. McChesney, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Jan. 17	10	National Press Intelligence Co.	Newspaper clippings	$11.15
17	11	Prescott and Arizona Ry.	Transportation of assistants	22.20
17	12	Pennsylvania Co	...do	17.50
17	14	St. Paul, Minneapolis and Manitoba R. R.	...do	48.90
17	15	Pennsylvania R. R	...do	10.00
17	17	Prescott, Arizona Central R. R.	Freight charges	.45
17	18	Smedley Bros. & Co	...do	7.15
17	19	Ambrose Fitzgerald	...do	2.54
21	20	Emil Greiner	Laboratory material	3.75
21	21	The American Tool Machine Co.	...do	152.25
21	22	E. & H. T. Anthony & Co	Supplies for illustrations	14.58
21	23	Gustav E. Stechert	Publications	172.70
21	24	W. B. Saunders	...do	2.00
21	25	R. R. Bowker	...do	6.00
31	26	Robert Clarke & Co	...do	5.00
21	27	N. D. C. Hodges	...do	7.00
21	28	United States Express Co	Freight	42.75
21	31	J. D. Free, jr	Publications	2.35
21	32	Simon Brentano	...do	4.95
21	33	Boyd's Directory Co	...do	20.00
21	34	Newman & Son	Repairs to typewriter	2.50
21	35	Charles H. Kraft	Laboratory supplies	101.93
21	36	Franklin & Co	Paleontologic supplies	2.50
21	37	E. E. Jackson & Co	Miscellaneous supplies	78.02
23	38	Frank Burnest	Traveling expenses	114.12
25	39	M. M. Sawin	Freight	8.09
25	41	Emil Greiner	Laboratory material	16.30
24	42	Ellen L. Cudlip and Fillmore Beall.	Supplies for illustrations	32.00
27	44	William D. Clark & Co	Laboratory supplies	11.80
27	45	William A. Hedrick	Services, July 1 to August 15, 1890	40.00
27	46	McFadden Company	Laboratory material	21.00
27	47	J. Bishop & Co	Repairs, etc	10.27
27	48	Emil Greiner	Laboratory supplies	4.10
28	49	Columbia Phonograph Co	Paleontologic supplies	30.74
28	50	Inland and Seaboard Coasting Co.	Freight	5.81
28	51	Whitall, Tatum & Co	Laboratory supplies	3.00
29	52	John S. Rick	Publications	75.00
30	53	E. Morrison	...do	105.65
31	54	Chicago and Northwestern Ry	Transportation of assistants	25.00
31	55	George Ryneal, jr	Supplies	228.52
31	57	George W. Shutt	Pay for January, 1890	258.80
31	58	Alpheus Hyatt	...do	137.09
31	59	H. Gibb	...do	70.00
31	60	G. Baur	...do	150.00
31	61	L. P. Bush	...do	50.00
31	62	J. B. Hatcher	...do	200.00
31	63	O. C. Marsh	...do	344.40
31	64	Ira Sayles	...do	120.60
31	65	J. Henry Blake	...do	155.00
31	66	Samuel H. Scudder	...do	215.30
31	67	Pay-roll of employés	...do	602.70
31	68	...do	...do	1,141.22
31	69	...do	...do	1,135.00
31	70	...do	...do	1,281.50
31	71	...do	...do	714.70
31	72	...do	...do	378.90
31	74	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	148.20
31	75	Washington Gas-light Co	Laboratory supplies	53.38
31	76	Eric M. Noble	Services, October 1 to November 30, 1889.	160.00
		Total		9,476.34

SALARIES, OFFICE GEOLOGICAL SURVEY.

1890. Jan. 31	1	Pay roll of employés	Services January, 1890	3,058.60

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during January, 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Jan. 23	1	William J. Peters	Traveling expenses	$54.91
23	2	do	Field expenses	175.65
23	3	do	do	187.90
23	4	do	do	60.65
23	5	Charles S. Weed	Services. November, 1889	45.00
23	6	do	Services, December, 1889	8.70
23	7	M. Hackett	Field expenses	485.66
23	8	R. Lee Longstreet	Traveling expenses	14.55
23	9	Judson D. Lincoln	Field expenses	3.00
23	10	Wyckoff, Seamans & Benedict	Repairs on typewriter	22.00
23	11	J. Karr	Repairs on instruments	50.00
23	12	W. H. Renshaw	Pasturage and storage	81.56
23	13	W. Andrew Boyd	Office supplies	5.00
23	14	G. L. Johnson	Traveling expenses	3.05
23	15	Henry Gannett	do	15.20
23	16	R. S. Woodward	Field expenses	36.83
23	17	H. B. Blair	do	320.85
23	18	W. M. Beaman	Traveling expenses	15.05
23	19	do	Field expenses	35.50
23	20	Fauth & Co	Instruments	493.45
23	21	Julius Bien & Co	Publications	137.50
23	22	Fred. J. Knight	Services, January, 1890	75.00
23	23	Robert Leitch & Sons	Supplies	2.80
25	24	William D. Clark & Co	Material for mounting maps	36.90
25	25	E. Morrison	Supplies	20.00
25	26	Gotlieb Spitzer	do	.35
25	27	Julius Lansburgh	Furniture	4.37
28	28	A. E. Wilson	Traveling expenses	13.00
28	29	Duncan Hannegan	do	13.25
28	30	Lincoln Martin	Services, January, 1890	60.00
28	31	Lewis J. Battle	do	60.00
28	32	do	Traveling expenses	41.00
28	33	H. L. Baldwin, jr	do	13.25
28	34	do	Services, January, 1890	155.00
28	35	Charles R. Grandy	do	50.00
30	36	W. C. Robinson	do	9.68
30	37	Mary C. Whittle	Field expenses	10.00
30	38	John W. Price	Pasturage and storage	77.10
31	39	E. W. F. Natter	Services, January, 1890	137.80
29	40	William H. Herron	Field expenses	5.59
31	41	Charles F. Urquhart	Pay-roll, January, 1890	218.30
31	42	A. H. Chase & Bro	Cleaning carpets	6.40
31	43	Lincoln Martin	Traveling expenses	13.00
31	44	W. O. Beall	do	14.00
31	45	Charles R. Grandy	do	14.00
31	46	A. B. Searle	do	14.00
31	47	W. M. Morton	do	6.05
31	48	Pay-roll (Baker)	Services, January, 1890	2,336.90
31	49	Pay-roll (Gannett)	do	2,865.46
31	50	Pay-roll (Renshaw)	do	1,215.30
31	51	Pay-roll (Goode)	do	1,060.70
31	52	Pay-roll (Thompson)	do	2,595.31
31	53	W. and L. E. Gurley	Repairs on instruments	32.00
31	54	Higgins & Co	Map	8.50
31	55	Royce & Marean	Office supplies	6.60
31	56	J. H. Hagerty	Forace	115.16
31	57	J. T. Wilkes	do	9.00
31	58	Western Union Telegraph Co	Labor	5.00
31	59	H. S. Pritchett	Services, November and December, 1889.	300.00
31	60	do	Field expenses, astronomical work	52.50
31	61	Charles Kiner	Services, January, 1890	9.67
31	62	Henry J. Green	Instruments	36.25
31	63	J. T. Avery, administrator	Services, January, 1890, M. R. Avery, deceased.	57.50
31	64	W. F. Fling	Forage	20.00
31	65	J. M. Gibson	Pasturage	55.00
31	66	Henry Rummel	Storage and forage	75.00
31	67	do	do	75.00
31	68	W. W. Mildrum	Instruments	6.00
31	69	Wilkes & Ganse	Forage	13.50
31	70	W. H. Renshaw	Forage and storage	90.00
31	71	A. P. Anderson	Forage	35.00
31	72	N. B. Dunn	Pasturage	94.65
31	73	H. L. Baldwin, jr	Field expenses	161.00
		Total		14,653.85

Abstract of disbursements made by Mark B. Kerr, disbursing agent U. S. Geological Survey during January, 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Jan. 2	1	James G. Bowen	Forage, etc	$98.40
2	2	A. O'D. Taylor, jr	Services, December, 1889	101.10
2	3	Arthur Keith	Field expenses	70.85
2	4	Alexander Davies	...do	3.15
2	5	Columbus Freeman	...do	20.85
2	6	T. Nelson Dale	Services, December, 1889	150.00
2	7	T. K. Bolton	Forage	162.00
3	8	Raphael Pumpelly	Services, December, 1889	337.00
3	9	Geo. E. Luther	...do	101.10
3	10	Pay-roll	...do	360.00
3	11	J. S. Gage	Services, August, 1889	10.00
3	12	Nelson H. Darton	Traveling expenses	8.90
3	13	A. T. Kyle, jr	Pasture, December, 1889	14.00
3	14	Lena P. Thompson	...do	20.00
9	15	A. O'D. Taylor, jr	Traveling expenses	29.75
9	16	T. T. Pitman	Glass slides	3.50
9	17	Richard Bliss	Typewriting	17.40
9	18	Newport Water Stocks	Rent	9.00
9	19	H. L. Smyth	Field expenses	13.78
9	20	C. L. Whittle	Traveling expenses	258.74
9	21	Lawrence C. Johnson	...do	112.28
9	22	Charles S. Merrick	...do	5.60
9	23	C. R. Van Hise	...do	51.22
9	24	William J. Park & Son	Stationery	25.10
9	25	William B. Clark	Services, December, 1889	105.00
9	26	Warren Upham	...do	101.10
9	27	W. S. Bayley	...do	65.00
9	28	George H. William	...do	75.00
9	29	Raphael Pumpelly	Field expenses	64.59
9	30	Robert T. Hill	Services, November, 1889	80.00
9	31	C. W. Coman	Traveling expenses	36.20
9	32	G. K. Gilbert	...do	49.10
11	33	H. L. Smyth	Field expenses	45.73
11	34	Scovill & Adams Co	Supplies	7.81
14	35	A. Prescott Baker	Rent of rooms	50.00
14	36	E. &. H. T. Anthony & Co	Material	4.70
14	37	Providence Telephone Co	Rent	23.00
14	38	Henry M. Cozzens, jr	Services	36.75
14	39	T. J. Olsson	Typewriting	14.00
14	40	The Scovill and Adams Co	Photo material	2.81
14	41	W. Zinsser & Co	Material	4.10
14	42	Lawrence C. Johnson	Field expenses	61.42
14	43	E. and T. H. Anthony & Co	Packing material	5.00
16	44	W. Lindgren	Field expenses	54.15
17	45	J. A. Holmes	Services, December, 1889	80.00
17	46	A. C. Peale	Field expenses	59.50
17	47	William Beals, jr	Traveling expenses	13.15
17	48	H. W. Turner	...do	72.05
20	49	William B. Clark	Field expenses	15.00
20	50	E. D. Keys & Co	...do	1.30
20	51	W. P. Jenney	Traveling expenses	296.78
21	52	...do	Services, December, 1889	185.30
22	53	Isaiah Rendell	Forage	94.80
21	54	C. H. Hitchcock	Collecting	6.00
22	55	J. M. Safford	Services, December, 1889	14.67
23	56	...do	Field expenses	5.50
20	57	James W. Queen & Co	Field material	9.15
23	58	...do	...do	4.50
25	59	Raphael Pumpelly	Traveling expenses	48.45
28	60	J. E. Wolff	Services, October to December, 1889	76.09
22	61	H. L. Smyth	Field expenses	170.40
31	62	Pay-roll	Services, January, 1890	2,570.64
31	63	...do	...do	1,940.80
31	64	...do	...do	325.60
		Total		8,858.86

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during January, 1890.

1890.				
Jan. 20	1	E. J. Owenhouse	Storage	$30.00
20	2	...do	Field material	8.50
31	3	Pay-roll of employés	Services, January, 1890	749.10
		Total		787.60

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during February, 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Feb. 12	1	Robert Boyd	Supplies	$50.28
12	2	W. H. Lowdermilk & Co	Publications	187.50
12	4	William Ballantyne & Son	...do	2.53
12	5	David T. Day	Field expenses	3.75
12	6	Pennsylvania R. R	Transportation of assistants	16.00
12	7	Eimer & Amend	Laboratory material, etc	264.27
12	8	William P. Rust	Services, January, 1890	67.50
12	9	R. W. Westbrook	Services, July 1, to December 31, 1889	150.00
12	10	W. A. Washburn	...do	150.00
12	11	G. Craven	Services, November, 1889	125.00
12	12	Eric M. Noble	Services, December, 2 to 31, 1889	100.00
12	13	Pennsylvania R. R. Co	Freight	2.09
13	14	M. W. Beveridge	Topographical and geological supplies.	6.31
14	15	Easton & Rupp	Supplies	7.15
17	18	Z. D. Gilman	Laboratory supplies	30.13
17	19	...do	Supplies	215.45
17	21	Dietrick W. Kolbe	Services, Jannary 13 to 24, 1890	22.00
17	22	W. B. Moses & Son	Supplies	413.10
24	23	William Wesley & Son	Publications	309.57
24	24	Ulrich Hoepli	...do	6.56
24	25	Citizens' National Bank	Bills of exchange	2.05
25	26	Adams Express Co	Freight charges	112.35
26	28	George Ryneal, jr	Supplies	377.37
28	30	Pat Graves	Services, September 2 to 7, 1889	6.00
28	31	George W. Knox	Freight charges	116.45
28	33	O. C. Marsh	Services, February, 1890	311.20
28	34	L. P. Bush	...do	50.00
28	35	H. Gibb	...do	70.00
28	36	Ira Sayles	...do	108.80
28	37	Samuel H. Scudder	...do	194.40
28	38	Wash. B. Williams	Supplies	183.83
28	39	Adams Express Co	Freight charges, November, 1889	155.90
28	41	Washington Gas-light Co	Gas	55.88
28	42	G. W. Shutt	Services, February, 1890	233.40
28	43	J. Henry Blake	...do	140.00
28	44	J. B. Hatcher	...do	200.00
28	45	R. C. Jones	Publications	7.00
28	47	George Latimer	Services, February 1 to 13, 1890	23.21
28	48	Pay-roll of employés	Services, February, 1890	544.60
28	49	...do	...do	1,022.12
28	50	...do	...do	1,162.00
28	51	...do	...do	1,064.50
28	52	...do	...do	645.60
28	53	...do	...do	342.20
		Total		9,258.05

SALARIES, OFFICE GEOLOGICAL SURVEY.

1890. Feb. 28	1	Pay-roll of employés	Services, February, 1890	2,764.40

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during February, 1890, *for geological maps of the United States.*

1890.				
Feb. 6	1	Julius Bien & Co	Engraving maps	$3,500.01
6	2	...do	...do	1,460.00
17	3	...do	...do	3,390.00
28	4	Stephen J. Kubel	Services, February 15 to 28, 1890	92.30
		Total		8,442.31

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during February, 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Feb. 11	74	G. L. Johnson	Field expenses	$32.40
12	75	Clifford Arrick	Traveling expenses	15.25
11	76	H. L. Baldwin, jr	Field expenses	94.05
13	77	Julius Bien & Co	Publication	108.70
13	78	George S. Harris	....do	87.50
13	79	James W. Queen & Co	Instruments	13.20
13	80	W. T. Quillin	Services, December, 1889 and January, 1890.	32.90
13	81	J. M. Gibson	Forage	55.00
13	82	Elias Foglesong	....do	10.00
14	83	Robert Leitch & Sons	Repairs for instruments	3.50
15	84	Thomas Sinclair & Son	Publications	157.50
21	85	Julius Bien & Co	....do	131.00
21	86	H. L. Baldwin, jr	Field expenses	9.00
21	87	Clifford Arrick	Traveling expenses	24.15
21	88	John W. Price	Pasturage and transportation	88.00
21	89	William D. Clark & Co	Office supplies	9.30
21	90	W. F. Fling	Forage	20.00
21	91	James W. Queen & Co	Repairs for instruments	18.00
21	92	George S. Harris	Publication	70.00
21	93	Charles F. Urquhart	Traveling expenses	73.00
21	94	....do	Field expenses	472.03
24	95	H. L. Baldwin, jr	....do	100.79
24	96	....do	....do	127.05
24	97	Gilbert Thompson	Traveling expenses	110.55
25	98	P. C. McHenry	Typewriter	70.00
25	99	Julius Bien & Co	Publication	40.00
25	100	James W. Jones	Traveling expenses	6.05
24	101	H. L. Smyth	Services, January, 1890	103.30
24	102	E. E. Jackson & Co	Material	129.12
28	103	Hersey Munroe	Services, February, 1890	77.80
28	104	R. McC. Michler	....do	77.80
28	105	Clifford Arrick	....do	77.80
28	106	H. L. Baldwin, jr	....do	140.00
28	107	Lewis J. Battle	....do	60.00
28	108	A. B. Searle	....do	70.00
28	109	A. E. Wilson	....do	65.40
28	110	Duncan Hannegan	....do	50.00
28	111	W. O. Beall	....do	60.00
28	112	Lincoln Martin	....do	60.00
28	113	Charles R. Grandy	....do	50.00
24	114	John C. Parker	Repairs for typewriter	2.00
28	115	W. H. Renshawe	Forage and storage	90.00
28	116	Thomas H. Robey	Services, (carpenter)	15.00
28	117	J. H. Hagerty	Forage	70.00
28	118	H. L. Baldwin, jr	Field expenses	134.75
28	119	Henry Rummel	Forage and storage	75.00
28	120	Pay-roll (Baker)	Services, February, 1890	2,121.20
28	121	Pay-roll (Gannett)	....do	2,638.06
28	122	Pay-roll (Thompson)	....do	1,880.20
28	123	Pay-roll (Renshawe)	....do	1,109.40
28	124	Pay-roll (Goode)	....do	1,057.00
28	125	E. W. F. Natter	....do	124.40
		Total		12,317.15

Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during February, 1890.

1890.				
Feb. 8	1	Pay-roll	Services, January, 1890	$370.00
8	2	J. M. K. Southwick	Field material	22.49
8	3	Raphael Pumpelly	Services, January, 1890	344.40
8	4	Charles S. Merrick	Services, September to November, 1889.	9.00
8	5	Charles E. Hammett, jr	Stationery	4.97
8	6	Newport Gas-light Co	Gas, November and December, 1889.	7.60
8	7	C. L. Whittle	Services, December, 1889	100.00
8	8	....do	Services, January, 1889	100.00
8	9	C. A. Claghorn	Hire of horses, etc	162.00
28	10	Benjamin K. Emerson	Services, January, 1890	103.30
8	11	A. Prescott Baker	Rent of rooms, January, 1890	50.00
8	12	William A. Foster	Services, January, 1890	10.00
8	13	T. Nelson Dale	....do	150.00
8	14	Michael Bayer	....do	8.00
8	15	J. E. Wolff	Traveling expenses	3.75
8	16	....do	....do	4.00

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Feb. 8	17	James G. Bowen	Forage, January, 1890	$103.35
8	18	Lawrence C. Johnson	Services, January, 1890	120.60
8	19	William B. Clark	....do	80.00
8	20	A. T. Kyle, jr	Pasture, January, 1890	14.00
8	21	Walpole Emery Mills	Emery	14.80
8	22	W. P. Jenney	Field expenses	34.95
8	23	....do	Services, January, 1890	189.40
8	24	C. W. Hall	Traveling expenses	31.81
8	25	....do	....do	53.38
8	26	George E. Luther	....do	30.50
8	27	L. G. Thompson	Forage, January, 1890	34.00
8	28	William J. Swinburne	Fuel	52.05
28	29	William D. Clark	Silesia	1.25
8	30	J. D. Free & Co	Material	2.25
8	31	Mark B. Kerr	Telegrams	.90
8	32	H. W. Turner	Field expenses	92.12
10	33	Richard Bliss	Services, January, 1890	23.70
10	34	C. W. Hall	Services, July to October, 1889	31.50
10	35	W. S. Bayley	Services, January, 1890	62.50
10	36	Robert T. Hill	....do	80.00
10	37	Frank Leverett	Services, December, 1889, and January, 1890.	200.00
10	38	Warren Upham	Services, January, 1890	103.30
12	39	W. Lindgren	Traveling expenses	48.50
14	40	Lawrence C. Johnson	....do	71.66
14	41	T. Nelson Dale	Field expenses	14.36
14	42	Raphael Pumpelly	....do	22.84
15	43	E. J. Pullman	Photo supplies	127.85
18	44	H. L. Smyth	Field expenses	52.50
18	45	C. W. Coman	Traveling expenses	21.62
18	46	Julius Lansburgh	Office supplies	13.11
18	47	George H. Williams	Services, January, 1890	60.00
28	48	Pay-roll	Services, February, 1890	2,041.30
28	49	....do	....do	2,139.20
28	50	T. Nelson Dale	....do	150.00
28	51	Lawrence C. Johnson	....do	108.80
28	52	Pay-roll	....do	298.80
		Total		7,976.41

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during February, 1890.

1890. Feb. 28	4	Pay-roll of employés	Services, February, 1890	$676.80

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during March, 1890.

Mar. 6	1	Bangs & Co	Publications	$229.50
6	2	James D. and E. S. Dana	....do	6.00
6	3	Julius Lansburgh	Supplies	140.65
6	4	J. Blake Kendall	....do	7.50
6	5	Melville Lindsay	....do	4.09
6	6	William P. Rust	Services, February, 1890	60.00
6	7	Chesapeake and Ohio R. R	Transportation of assistants	27.50
7	8	James W. Queen & Co	Laboratory supplies	39.09
7	9	Baker & Adamson	....do	18.52
8	10	L. Moxley	....do	10.00
8	11	Ellen S. Cudlip and Fillmore Beall.	Supplies	43.15
8	12	Baltimore and Ohio R. R	Freight charges	6.23
8	13	Smedley Bros. & Co	....do	20.30
8	14	George Burrill	Services, March 1 to 8, 1890	10.50
11	15	Atlantic and Pacific R. R	Transportation of assistants	22.64
11	18	Hume & Co	Supplies	2.00
11	19	David G. Francis	Publications	38.00
14	21	Pennsylvania R. R. Co	Transportation of assistants	67.95
14	22	Emil Greiner	Laboratory supplies	4.45
14	23	American Tool and Machine Co.	....do	14.50
14	24	Gottlieb Spitzer	Topographic supplies	7.50
14	25	....do	Supplies	.60

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890. Mar. 14	26	J. M. Mixson	Services, February 10 to March 10, 1890.	$50.00
18	27	Scribner & Welford	Publications	112.81
18	28	Charles Scribner	...do	19.37
18	29	E. J. Pullman	Supplies for illustrations	5.20
18	30	Chicago, St. Paul and Pittsburgh R. R.	Transportation of assistants	37.50
18	32	New York, New Haven and Hartford R. R.	...do	3.11
18	33	Boston and Albany R. R.	...do	3.11
18	34	Quartermaster's department, U. S. Army.	Supplies	5.03
20	35	H. W. Johns Manufacturing Co	...do	2.85
20	36	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	19.67
20	37	W. H. Morrison	Supplies	3.00
20	38	M. W. Beveridge	...do	2.94
20	39	L. H. Schneider's Son	...do	30.51
20	41	W. B. Moses & Son	...do	21.40
22	42	Terre Haute and Indianapolis R. R.	Transportation of assistants	20.25
25	44	St. Louis and San Francisco R. R.	...do	13.60
25	45	Bausch & Lomb Optical Co	Supplies	6.56
26	46	Eimer & Amend	Laboratory supplies	77.95
29	47	Julius Lansburgh	Supplies	6.00
29	48	Meadville Vise Co	Laboratory supplies	6.00
29	49	Fremont, Elkhorn and Missouri Valley R. R.	Freight	4.85
29	50	George Ryneal, jr	Supplies	52.29
29	51	Wyckoff, Seamans & Benedict.	Remodeling typewriter	32.00
29	52	Wash. B. Williams	Supplies	40.25
31	53	Sam. H. Scudder	Services, March, 1890	215.30
31	54	Pay-roll of employés	...do	602.70
31	55	...do	...do	1,150.90
31	56	...do	...do	1,281.50
31	57	...do	...do	1,135.00
31	58	...do	...do	776.70
31	59	...do	...do	378.90
31	61	J. Henry Blake	...do	155.00
31	62	Ira Sayles	...do	120.60
31	63	O. C. Marsh	...do	344.40
31	64	L. P. Bush	...do	50.00
31	65	H. Gibb	...do	70.00
31	66	J. B. Hatcher	...do	200.00
31	67	R. W. Westbrook	Services, January 1 to March 31, 1890.	75.00
31	68	F. Berger	Services, January, February, March, 1890.	240.00
31	69	W. A. Washburne	Services, January 1 to March 31, 1890.	90.00
31	70	A. Hermann	...do	250.00
31	71	T. A. Bostwick	...do	250.00
31	72	Eric M. Noble	Services, February 11 to March 31, 1890.	100.00
31	73	Washington Gas-light Co	Laboratory material	53.76
31	77	Sam H. Scudder	Traveling expenses	40.00
31	78	Lake Shore and Michigan Southern Ry. Co.	Freight	.69
31	79	George W. Shutt	Services, March, 1890	258.30
		Total		9,195.67

SALARIES, OFFICE GEOLOGICAL SURVEY.

1890. Mar. 29	1	H. D. Fairly	Services. March 1-7, 1890	14.00
31	2	Pay-roll of employés	Services, March, 1890	2,998.30
		Total		3,012.30

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during March, 1890, *for geological maps of the United States.*

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Mar. 7	Mar. 1	Julius Bien & Co	Engraving maps	$828.00
11	2	S. J. Kübel	Traveling expenses	44.20
19	3	Wash. B. Williams	Engraving supplies	28.00
20	4	M. W. Beveridge	....do	1.53
22	5	Julius Bien & Co	Engraving maps	552.00
25	6	James B. Lambie	Engraving supplies	9.00
26	7	Robert Mayer & Co	....do	194.00
29	8	Wash. B. Williams	Engraver's supplies	146.62
29	9	Wyckoff, Seamans & Benedict.	One typewriter	85.00
29	10	George Ryneal, jr	Engraver's supplies	37.50
29	11	Gore, Janney & Co	Two letter files	1.50
31	12	Pay-roll of employés	Services, March, 1890	326.72
31	13	Fred. A. Schmidt	Engraver's supplies	11.61
		Total		2,265.68

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during March, 1890.

1890.				
Mar. 6	126	Thomas H. Robey	Services, carpenter, March, 1890	$2.50
6	127	Lewis J. Battle	Traveling expenses	16.95
6	128	A. B. Searle	....do	20.80
6	129	Hersey Munroe	Field expenses	44.75
6	130	Rand, McNally & Co	Map	3.00
6	131	C. N. Wood	....do	5.00
7	132	John W. Price	Forage	80.00
7	133	H. L. Smyth	Services, February	93.40
8	134	Wyckoff, Seamans & Benedict.	Repairs on typewriter	22.00
8	135	Hersey Munroe	Field expenses	84.80
12	136	Julius Lansburgh	Office furniture	4.37
12	137	James W. Queen & Co	Repairs for instruments	9.00
12	138	William D. Clark & Co	Material for mounting maps	37.13
12	139	A. H. Chace & Bro	Cleaning carpets	1.80
12	140	Elias Foglesong	Forage	10.00
12	141	W. & L. E. Gurley	Repairs for instruments	35.00
12	142	J. M. Gibson	Forage	55.00
12	143	N. B. Dunn	....do	81.00
13	144	Hersey Munroe	Field expenses	18.07
14	145	Clifford Arrick	Traveling expenses	31.10
17	146	H. L. Baldwin, jr	Field expenses	231.55
20	147	....do	....do	99.65
20	148	James S. Topham	Field supplies	7.60
17	149	H. L. Baldwin, jr	Field expenses	85.05
17	150	A. E. Wilson	Traveling expenses	31.60
20	151	John C. Parker	Railroad guide	.50
27	152	Hersey Munroe	Field expenses	42.05
28	153	H. L. Baldwin, jr	....do	178.73
31	154	Pay-roll (Goode)	Services, March, 1890	1,164.00
31	155	Pay-roll (Renshawe)	....do	1,215.30
31	156	Pay-roll (Thompson)	....do	2,057.40
31	157	Pay-roll (Baker)	....do	2,336.90
31	158	Pay-roll (Gannett)	....do	2,888.60
31	159	Lincoln Martin	....do	60.00
31	160	Lewis J. Battle	....do	60.00
31	161	Charles R. Grandy	....do	50.00
31	162	A. E. Wilson	....do	72.30
31	163	Clifford Arrick	....do	86.10
31	164	Duncan Hannegan	....do	50.00
31	165	W. O. Beall	....do	60.00
31	166	A. B. Searle	....do	77.50
31	167	H. L. Baldwin, jr	....do	155.00
31	168	Hersey Munroe	....do	86.10
31	169	R. McC. Michler	....do	86.10
		Total		11,837.70

Abstract of disbursements made by Mark B. Kerr, special disbursing agent, U. S. Geological Survey, during March, 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Mar. 1	1	James G. Bowen	Forage, February, 1890	$98.00
1	2	W. S. Bayley	Services	91.25
1	3	H. W. Turner	Field expenses	25.55
1	4	C. L. Whittle	Services, February, 1890	100.00
4	5	Lena P. Thompson	Forage, February, 1890	23.00
5	6	A. Hansen	Forage	30.50
5	7	A. Lietz & Co	Repairs	2.75
5	8	A. T. Kyle, jr	Forage, February, 1890	14.00
5	9	Pay-roll	Services, February, 1890	340.00
5	10	Benjamin K. Emerson	...do	93.40
5	11	William B. Clark	...do	120.00
5	12	William A. Foster	...do	10.00
5	13	A. Prescott Baker	...do	50.00
5	14	Michael Boyer	...do	8.00
7	15	G. R. Hargadine	Services, January, 1890	30.00
7	16	...do	Services, February, 1890	30.00
8	17	George H. Williams	...do	80.00
13	18	C. K. Judson	Office furniture	17.50
13	19	W. B. Moses & Sons	...do	21.80
13	20	Barber & Ross	Field material	2.55
13	21	Melville Lindsay	...do	1.50
13	22	E. E. Jackson & Co	...do	33.74
13	23	Warren Upham	Traveling expenses	25.61
13	24	Richard Bliss	Typewriting	24.60
13	25	Raphael Pumpelly	Services, February, 1890	311.20
13	26	H. Rosendale	Field material	8.00
14	27	W. P. Jenney	Services, February, 1890	171.20
15	28	Columbus Freeman	Services, March, 1890	17.25
15	29	Wash. B. Williams	Office furniture	42.00
15	30	Warren Upham	Services, February, 1890	93.40
15	31	N. B. Dunn	Pasturage, January, 1890	81.00
18	32	L. H. Davis	Services, February and March, 1890	5.50
18	33	L. H. Schneider's Son	Supplies	1.05
18	34	E. E. Jackson & Co	Lumber	60.00
18	35	George Ryneal, jr	Supplies	32.20
22	36	J. B. Woodworth	Field expenses	23.31
22	37	T. Nelson Dale	...do	15.52
22	38	Lawrence C. Johnson	...do	64.33
18	39	John C. Parker	Repairs	45.00
31	40	A. T. Kyle, jr	Pasturage, March, 1890	14.00
31	41	L. H. Schneider's Son	Material	1.75
31	42	E. E. Jackson & Co	Repairs	20.30
31	43	W. P. Jenney	Services, March, 1890	189.40
31	44	N. B. Dunn	Forage, January and March, 1890	108.00
31	45	Pay-roll	Services, March, 1890	2,135.40
31	46	...do	...do	2,296.30
31	47	C. A. White	...do	232.50
31	48	Lawrence C. Johnson	...do	120.60
31	49	Pay-roll	...do	298.18
31	50	T. Nelson Dale	...do	150.00
31	51	A. Prescott Baker	Rent for March, 1890	50.00
31	52	William A. Foster	Services, March, 1890	10.00
31	53	Michael Boyer	...do	8.00
		Total		7,879.14

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during March, 1890.

1890.				
Mar. 31	5	Pay-roll of employés	Services, March, 1890	$576.90

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during April, 1890.

1890.				
Apr. 5	1	J. V. Burket & Co	Supplies	$41.81
9	2	E. E. Jackson & Co	...do	139.85
9	3	George Ryneal, jr	...do	50.56
9	4	Robert M. Ashburner	Manuscript	22.50
9	5	A. C. Stocking	Services, March 24 to April 5, 1890	25.00
9	6	National Press Intelligence Co	Newspaper clippings	14.25
9	7	William P. Rust	Services, March, 1890	65.00
9	8	Harriet Biddle	Services, January 1 to March 31, 1890	30.00

Abstract of disbursements made by J. D. McChesney, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890. Apr. 11	9	L. G. Eakins	Traveling expenses	$18.83
11	10	Adams Express Co	Freight, December, 1889	87.75
11	11	....do	Freight, January, 1890	73.25
11	12	....do	Freight, February, 1890	21.55
15	14	Z. D. Gilman	Supplies	220.72
17	15	Samuel H. Scudder	Cash paid for freight	8.15
17	16	De Lancey W. Gill	Traveling expenses	19.90
17	17	Inland & Seaboard Coasting Co	Freight	2.76
17	18	Henry A. Clark & Son	Paleontologic supplies	85.00
17	19	Eimer & Amend	Laboratory material, etc	95.14
17	20	Louisville and Nashville R. R.	Transportation of assistants	27.50
19	21	United States Express Co	Freight, November, 1889, to February 28, 1890.	139.25
19	22	Whitall, Tatum & Co.	Laboratory supplies	9.20
19	23	Ellen S. Cudlip and Fillmore Beall.	Supplies	75.00
22	24	William D. Clark & Co	....do.	.54
22	25	American Tool & Machine Co	Laboratory supplies	63.30
25	26	Eimer & Amend	....do	41.97
25	27	James W. Queen & Co	....do	81.47
25	28	George W. Knox	Freight charges, etc	43.93
25	29	J. B. Hammond	Supplies	499.16
25	30	Smithsonian Institution	Transportation of exchange	878.50
30	31	E. E. Jackson & Co	Supplies	41.67
30	32	Columbia Phonograph Co	Services	63.04
30	34	W. P. Jenney	Cash paid for material	37.12
30	35	Henry S. Williams	Services, November 1, 1889, to March 31, 1890.	623.60
30	36	Ira Sayles	Services, April, 1890	115.40
30	37	Pay-roll of employés	....do	576.85
30	38	....do	... do	1,118.14
30	39	....do	....do	1,292.55
30	40	....do	....do	1,088.40
30	41	....do	....do	743.40
30	42	....do	....do	362.65
30	44	O. C. Marsh	....do	329.70
30	45	J. B. Hatcher	....do	200.00
30	46	E. B. Wilson	...do	65.00
30	47	L. P. Bush	....do	50.00
30	48	H. Gibb	....do	70.00
30	49	T. C. Beecher	Services, March 22 to April 30, 1890.	72.74
30	50	O. A. Peterson	....do	85.97
30	51	Peter Olson	..do	72.74
30	52	Eric M. Noble	Services, April, 1890.	100.00
30	53	John S. Mills	Services, April 14 to 30, 1890	60.00
30	54	Washington Gas-light Company	Laboratory supplies	57.13
30	55	George W. Shutt	Services, April, 1890	247.25
		Total		10,355.19

SALARIES, OFFICE GEOLOGICAL SURVEY.

1890. Apr. 30	1	Pay-roll of employés	Services, April, 1890	2,870.05
30	2	May S. Clark	....do	59.30
		Total		2,929.35

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during April, 1890, *for geological maps of the United States.*

1890. Apr. 17	1	R. A. Whitehand	Engraver's supplies	$3.00
17	2	George Ryneal, jr	....do	20.01
19	3	Ernest Kubel	Services on copper-plates	23.40
21	4	Fred. A. Schmidt	Engraver's supplies	7.56
22	5	William D. Clark & Co	....do	21.43
30	6	Robert Mayer & Co	Engraver's material	93.40
30	7	E. E. Jackson & Co	....do	38.00
30	8	Pay-roll of employés	Services, April, 1890	732.92
30	9	H. Hoffa	Engraver's supplies	303.60
		Total		1,238.32

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during April, 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Apr. 3	1	E. C. Barnard	Expressage	$1.20
16	2	H. L. Baldwin, jr	Field expenses	130.75
16	3	Henry Gannett	Traveling expenses	160.45
16	4	Hersey Munroe	Field expenses	104.00
16	5	A. E. Wilson	Traveling expenses	26.90
17	6	R. U. Goode	...do	160.45
17	7	E. W. F. Natter	Services, March	66.67
17	8	W. F. Fling	Storage	20.00
17	9	W. G. Chapman	...do	10.50
17	10	Morris Franklin	...do	12.00
17	11	Henkel, Craig & Co	...do	9.00
17	12	J. M. Couch	...do	6.00
17	13	J. M. Gibson	Forage	55.00
17	14	N. B. Dunn	...do	81.00
17	15	George Ryneal, jr	Office supplies	70.00
17	16	J. H. Haggerty	Forage	70.00
17	17	W. F. Fling	...do	20.00
17	18	Edwin A. Greenough & Co	Services	96.75
17	19	J. R. Rowe	...do	5.00
17	20	L. H. Schnieder's Son	Supplies	22.98
17	21	John W. Price	Forage	80.00
17	22	Elias Foglesong	...do	10.00
17	23	Henry Rummel	...do	75.00
17	24	W. H. Renshaw	...do	90.00
17	25	J. L. Smith	Maps	30.00
17	26	Lewis J. Battle	Traveling expenses	25.80
18	27	W. & L. E. Gurley	Topographic supplies	48.00
18	28	A. T. Pieratt	Services	8.00
18	29	Hersey Munroe	Field expenses	37.50
19	30	Julius Bien & Co	Publications	90.75
23	31	H. L. Baldwin, jr	Field expenses	186.70
23	32	...do	...do	239.00
29	33	W. O. Beall	Traveling expenses	9.75
30	34	Lewis J. Battle	...do	20.45
30	35	Lincoln Martin	Services, April	60.00
30	36	A. E. Wilson	...do	69.20
30	37	Clifford Arrick	...do	82.40
30	38	Charles R. Grandy	...do	50.00
16	39	H. L. Baldwin, jr	...do	148.30
30	40	Albert M. Walker	...do	60.00
29	41	Charles R. Grandy	Traveling expenses	9.75
16	42	William D. Clark & Co	Material for monthly maps	33.36
16	43	W. S. Jenks & Co	Supplies	1.00
16	44	L. H. Schnieder's Son	...do	8.99
16	45	Pay-roll (Thompson)	Services, April	1,978.40
16	46	Pay-roll (Gannett)	...do	2,827.28
30	47	Duncan Hannegan	...do	50.00
30	48	A. B. Searle	...do	74.20
30	49	Lincoln Martin	Traveling expenses	9.00
30	50	Clifford Arrick	...do	41.85
30	51	G. L. Johnson	...do	7.33
30	52	Duncan Hannegan	...do	8.75
30	53	H. L. Baldwin, jr	...do	54.60
		Total		7,654.01

Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during April, 1890.

1890.				
Apr. 1	1	Columbus Freeman	Services, March, 1890	$21.00
1	2	James G. Bowen	Forage, March, 1890	84.75
5	3	Ben. K. Emerson	Services, March, 1890	103.30
15	4	Raphael Pumpelly	...do	344.40
5	5	C. L. Whittle	...do	100.00
5	6	Pay-roll	...do	360.00
5	7	William B. Clark	...do	105.00
5	8	Richard Bliss	...do	25.80
5	9	J. E. Wolff	Services, January to March, 1890	95.25
5	10	L. G. Thompson	Forage, March, 1890	22.30
5	11	J. U. Burket & Co	Electric plant	56.00
8	12	Frank Leverett	Services, February to March, 1890	155.00
8	13	...do	Services, March, 1890	95.00
8	14	Warren Upham	...do	103.30
8	15	George H. Williams	...do	75.00
8	16	Adams Express Co	Expressage	13.05
8	17	E. E. Jackson & Co	One inkstand	4.50

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Apr. 8	18	James W. Queen & Co	Material	$2.14
8	19	George R. Hargadine	Services, March, 1890	30.00
8	20	Samuel P. Barbee	Storage, January to March, 1890	37.50
16	21	W. P. Jenney	Field expenses	77.05
16	22	...do	...do	304.77
16	23	Lawrence C. Johnson	Traveling expenses	56.00
16	24	C Schneider	Field expenses	.91
16	25	James B. Lambie	Field supplies	.75
16	26	Thomas Bennix	...do	.60
18	27	Nelson H. Darton	Traveling expenses	19.62
18	28	...do	...do	98.40
18	29	G. K. Gilbert	...do	8.02
18	30	Bailey Willis	...do	371.99
19	31	Wyckoff, Seamans & Benedict	Typewriter, etc	87.50
19	32	John C. Parker	Supplies	7.50
19	33	G. E. Culver	Traveling expenses	35.75
19	34	John A. Martin	Services, April, 1890	8.96
19	35	W. S. Bayley	Services, March, 1890	110.00
22	36	George E. Luther	Traveling expenses	30.70
25	37	Wells, Fargo & Co. Express	Expressage	82.90
25	38	Gilbert van Ingen	Traveling expenses	9.18
25	39	Williams, Brown & Earle	Steel boxes	18.00
25	40	I. M. Buell	Field expenses	66.57
25	41	C. W. Coman	...do	15.23
25	42	E. J. Pullman	One Kodak	45.00
30	43	Lawrence C. Johnson	Services, April, 1890	115.40
30	44	Nelson H. Darton	...do	123.60
30	45	Arthur Keith	...do	98.90
30	46	C. W. Hayes	...do	98.90
30	47	C. R. Van Hise	...do	329.70
30	48	George E. Luther	...do	98.90
30	49	Pay-roll	...do	2,041.45
30	50	...do	...do	1,714.30
30	51	Raphael Pumpelly	...do	329.70
30	52	T. Nelson Dale	...do	150.00
30	53	A. Prescott Baker	...do	50.00
30	54	William A. Foster	...do	10.00
30	55	Frederick E. Morris	Services, March to April, 1890	81.70
30	56	Gilbert van Ingen	Services, April, 1890	17.50
30	57	W. P. Jenney	...do	181.30
		Total		8,730.04

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during April, 1890.

1890.				
Apr. 7	1	Wyckoff, Seamans & Benedict	Typewriter repairs	$32.00
14	2	E. J. Owenhouse	Storage	15.00
30	3	Pay-roll of employés	Services, April, 1890	552.20
		Total		599.20

Abstract of disbursements made by C. D. Davis, special disbursing agent. U. S. Geological Survey, during April, 1890.

1890.				
Apr. 30	1	Pay-roll of employés	Services, April, 1890	$1,057.20
30	2	...do	...do	1,168.30
30	3	...do	...do	2,241.25
30	4	W. O. Beall	...do	60.00
30	5	Lewis J. Battle	...do	60.00
		Total		4,586.75

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during May, 1890.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
May 6	1	E. E. Jackson & Co	Supplies	$340.00
6	2	. . do	....do	343.75
8	3	D. B. Fletcher & Co	....do	2.75
8	4	Cromwell Steamship Co	Transportation of assistants	210.00
8	5	Pennsylvania R. R. Co	Freight	2.09
8	6	....do	....do	.84
8	7	Julius Lansburgh	Supplies	4.37
8	8	Samuel H. Scudder	Services, April, 1890	206.00
8	9	J. Henry Blake	....do	148.30
8	10	Wash. B. Williams	Paleontologic supplies	25.00
8	11	Emil Greiner	Laboratory supplies	16.75
8	12	E. J. Pullman	Supplies	89.78
8	13	J. D. Free, jr	Publications	5.84
8	14	George Ryneal, jr	Material and supplies	26.52
8	15	L. H. Schneider's sons	....do	48.57
8	16	Wash. B. Williams	Supplies	18.57
10	17	R. C. Jones	Publications	6.00
10	18	....do	....do	19.00
13	19	Scribner & Welford	....do	20.85
13	20	A. S. Clark	....do	17.55
13	21	W. B. Saunders	....do	1.20
13	22	William P. Rust	Services, April, 1890	65.00
13	23	Pennsylvania R. R. Co	Transportation of assistants	47.50
14	25	W. H. Morrison	Publications	62.85
15	26	R. R. Bowker	....do	3.00
15	27	Robert Clarke & Co	....do	5.00
17	28	Scientific Publishing Co	....do	7.50
17	29	M. W. Beveridge	Supplies	6.60
17	30	Joseph T. Sabin	Publications	4.00
17	31	S. H. Zahn & Co	....do	4.94
17	32	Baltimore and Ohio R. R. Co	Freight	56.68
17	33	....do	....do	11.99
17	34	....do	....do	1.77
19	35	W. H. Dall	Traveling expenses	24.30
20	36	Bertha Zinc Co	Laboratory supplies	10.00
20	37	George Ryneal, jr	Supplies for illustrations	2.42
20	38	E. J. Pullman	....do	8.91
20	39	Eric M. Noble	Services, May 1 to 15, 1890	75.00
20	40	John C. Parker	Repairs	25.00
22	41	F. W. Clarke	Traveling expenses	14.25
26	42	Whital, Tatum & Co	Laboratory supplies	17.51
26	43	E. J. Brooks	Supplies for illustrations	2.45
26	44	Wyckoff, Seamans & Benedict	Repairs, etc	5.00
27	45	W. B. Moses & Son	Supplies	22.50
28	46	L. H. Schneider's Son	....do	36.38
28	47	Melville Lindsay	Paleontologic supplies	3.38
28	49	John S. Mills	Services, May 1 to 24, 1890	100.00
31	50	Henry Bufford	Services, May 1 to 14, 1890	24.00
31	51	J. Henry Blake	Services, May, 1890	153.40
31	52	Samuel H. Scudder	....do	213.00
31	53	Ira Sayles	....do	119.20
31	54	Lewis S. Hayden	Publications	7.65
31	55	O. C. Marsh	Services, May, 1890	340.60
31	56	L. P. Bush	....do	50.00
31	57	O. H. Peterson	....do	65.00
31	58	J. B. Hatcher	....do	200.00
31	59	H. Gibb	....do	70.00
31	60	Peter Olsen	....do	55.00
31	61	Darling, Brown & Sharpe	Laboratory supplies	7.75
31	62	Emil Greiner	....do	15.10
31	63	Pay-roll of employés	Services, May, 1890	596.30
31	64	....do	....do	1,657.10
31	65	....do	....do	111.40
31	66	....do	....do	1,267.60
31	67	....do	....do	1,123.20
31	68	....do	....do	797.87
31	69	....do	....do	374.70
31	71	Columbus Freeman	Services, May 16 to 31, 1890	19.50
31	72	Z. D. Gilman	Topographical supplies, etc	236.99
31	73	....do	Laboratory supplies	29.13
31	75	George W. Shutt	Services, May, 1890	255.50
		Total		9,967.15

SALARIES, OFFICE GEOLOGICAL SURVEY.

31	1	Jules G. Casey	Services, May 1 to 3, 1890	3.96
31	2	Pay-roll of employes	Services, May, 1890	2,924.10
		Total		2,928.06

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey during May, 1890, *for geological maps of the United States.*

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
May 6	1	E. E. Jackson & Co	Engraver's supplies	$98.50
8	2	M. W. Beveridge	...do	1.35
12	3	William H. Arneth	Engraver's material	6.00
15	4	Robert Mayer & Co	Engraver's material, etc	692.40
15	5	...do	...do	24.45
15	6	Wyckoff, Seamans & Benedict	Engraver's supplies	3.00
15	7	Ernest Kubel	Services (job)	117.00
15	8	J. F. Manning	Engraver's material, etc	11.81
17	9	M. W. Beveridge	Engraver's supplies	2.80
20	10	Milton Bradley & Co	...do	3.72
20	11	George Ryneal, jr	...do	5.05
22	12	R. F. Bartle	...do	20.00
22	13	Peter Adams Co	...do	10.20
27	14	Barber & Ross	...do	5.75
28	15	L. H. Schneider's Son	...do	34.27
29	16	J. C. Entwistle	...do	67.50
29	17	J. B. Hammond	...do	34.00
31	18	Pay-roll of employés	Services. May, 1890	784.60
31	19	Z. D. Gilman	Engraver's supplies	47.15
		Total		1,969.55

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during May, 1890.

1890.				
May 3	1	R. McC. Michler	Services, April	$82.40
15	2	S. J. Haislett	Field supplies	32.00
15	3	Hume & Co	Supplies	4.75
15	4	J. L. Smith	Map	10.00
15	5	Edward Kubel	Supplies	17.35
15	6	Julius Bien & Co	Publications	260.00
15	7	W. M. Beaman	Traveling expenses	13.14
15	8	A. E. Wilson	...do	32.85
15	9	A. B. Searle	...do	38.95
15	10	...do	...do	17.35
15	11	...do	...do	9.75
15	12	R. McC. Michler	...do	37.45
15	13	H. L. Baldwin, jr	Field expenses	35.00
15	14	...do	...do	254.20
15	15	...do	Traveling expenses	36.65
15	16	G. L. Johnson	Field expenses	30.69
15	17	Hersey Munroe	...do	65.30
15	18	...do	...do	60.00
15	19	...do	...do	45.23
15	20	...do	Services, April	82.40
15	21	W. T. Quillin	Services, February, March, and April	60.00
15	22	L. C. Fletcher	Field expenses	18.50
15	23	H. L. Smyth	Services, March	103.30
15	24	N. B. Dunn	Forage	81.00
15	25	W. H. Renshaw	...do	90.00
15	26	Elias Foglesong	...do	10.00
15	27	Henry Rummel	...do	75.00
15	28	W. F. Fling	...do	20.00
15	29	John W. Price	...do	86.00
15	30	J. H. Hagerty	...do	70.00
15	31	J. M. Gibson	...do	55.00
15	32	Jasper Gracy	Storage	4.01
15	33	A. P. Anderson	Pasturage	47.55
15	34	...do	Forage	66.15
15	35	W. & L. E. Gurley	Supplies	435.00
16	46	George Ryneal, jr	...do	.45
16	37	The Tucker L. and D. File Co	Furniture	82.00
16	38	A. Annentrout	Transportation	132.50
16	39	Charles F. Urquhart	Traveling expenses	18.25
16	40	...do	Field expenses	79.55
16	41	H. L. Baldwin, jr	...do	30.50
16	42	H. S. Wallan	Traveling expenses	24.95
16	43	R. B. Cameron	...do	18.75
16	44	R. O. Gordon	...do	18.75
16	45	Nat. Tyler, jr	...do	20.00
16	46	Robert D. Cummin	Field supplies	6.00
16	47	Young & Kuhen	Transportation	120.00
23	48	Louis H. Evarts	Maps	5.35
19	49	Wilkes & Gause	Storage	22.50
19	50	Want & Co	Forage	33.36
19	51	J. C. Walker	Field expenses	17.00

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
May 19	52	Ellis & Kellner	Field material	$63.15
19	53	W. F. Lake	do	32.95
19	54	Picnick Hotel	Field expenses	52.50
19	55	B. L. Spencer	Subsistence	94.86
24	56	James McCormick	Traveling expenses	17.60
24	57	H. L. Wallace	Field expenses	73.00
20	58	J. H. Jennings	Traveling expenses	10.82
20	59	C. A. Kimball	Field material	106.60
20	60	W. S. Hutt	do	77.47
20	61	W. K. Finks & Co	Subsistence	58.75
20	62	E. McL. Long	Traveling expenses	66.55
20	63	G. E. Hyde	do	28.05
20	64	Tom. Padgett	Field material	93.20
27	65	F. Howard Seely	Traveling expenses	50.26
20	66	E. F. Reese & Son	Field expenses	44.50
20	67	Horsfull & Cameron	Field material	35.10
27	68	R. M Towson	Traveling expenses	50.26
27	69	George T. Hawkins	do	25.50
27	70	do	Field expenses	80.95
27	71	Young & Kuhen	Transportation	275.00
27	72	J. H. Hagerty	Forage	24.84
27	73	G. L. Johnson	Field expenses	75.17
27	74	L. H. Schneider's Son	Office supplies	5.36
27	75	James W. Queen & Co	Repairs for instruments	8.16
27	76	E. E. Jackson & Co	Supplies	28.94
27	77	William D. Clark & Co	Material for mounting maps	37.74
28	78	E. M. Walker	Transportation	77.10
28	79	Charles R. Grandy	Traveling expenses	17.55
28	80	J. H. Wheat	do	18.05
28	81	F. P. Gulliver	do	17.55
29	82	John Boler	do	4.00
15	83	C. W. Goodlove	Services, May	71.60
19	84	Robert D. Cummin	do	136.20
15	85	F. P. Gulliver	do	102.20
20	86	Van H. Manning, jr	do	102.20
20	87	J. H. Wheat	do	76.60
20	88	Charles R. Grandy	do	50.00
21	89	Glenn S. Smith	do	71.60
21	90	Lincoln Martin	do	60.00
23	91	William J. Peters	do	136.20
23	92	B. Peyton Legare	do	60.00
23	93	J. J. Lincoln	Services, part of April	43.52
23	94	C. T. Reid	Services, May	71.60
23	95	B. C. Washington, jr	do	102.20
31	96	D. C. Harrison	do	119.20
28	97	L. D. Brent	do	76.60
31	98	J. H. Jennings	do	136.20
29	99	R. O. Gordon	do	119.20
31	100	W. R. Atkinson	do	102.20
31	101	Basil Duke	do	71.60
31	102	H. B. Blair	do	136.20
31	103	W. L. Miller	do	71.60
31	104	John J. Lincoln	Services, part of April	15.82
31	105	do	Services, May	61.40
31	106	W. E. Lackland	do	60.00
31	107	William H. Griffin	do	71.60
31	108	Philip Weiss	do	8.71
31	109	John Boler	do	14.67
31	110	W. P. Lawson	Transportation	100.00
31	111	W. H. Lovell	Services, May	136.20
31	112	A. E. Wilson	do	71.60
31	113	William Kramer	Traveling expenses	7.61
31	114	Lincoln Martin	do	7.25
31	115	W. M. Beaman	do	33.21
31	116	W. H. Lovell	do	7.40
31	117	C. W. Goodlove	do	22.60
31	118	B. Peyton Legare	do	23.24
31	119	Van H. Manning, jr	do	45.49
31	120	R. U. Goode	do	92.59
31	121	J. H. Jennings	do	5.98
31	122	Henry Rummel	Forage, May	72.49
31	123	James F. Smyth	Field supplies	33.47
31	124	J. H. Jennings	Field expenses	87.49
31	125	Hersey Munroe	do	84.40
31	126	George W. Stuart	Services, May	40.00
31	127	M. B. Lambert	do	76.60
31	128	W. M. Beaman	do	61.40
31	129	William Kramer	do	102.20
31	130	Lewis J. Battle	do	60.00
31	131	James McCormick	do	61.40
31	132	G. E. Hyde	do	76.60
31	133	G. L. Johnson	do	71.60

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
May 31	134	R. M. Towson	Services, May	$119.20
31	135	Urban Katsik	do	7.74
31	136	J. J. Fawbush	do	16.93
31	137	F. Howard Seely	do	60.00
31	138	George H. Lamar	do	71.60
31	139	William H. Herron	do	102.20
31	140	H. L. Baldwin, jr	do	153.40
31	141	R. U. Goode	do	213.00
31	142	John H. Renshawe	do	213.00
31	143	Pay-roll (Gannett)	do	2,628.60
31	144	Pay-roll (Baker)	do	1,101.50
31	145	Pay-roll (Thompson)	do	2,227.20
31	146	Pay-roll (Urquhart)	do	204.13
31	147	Pay-roll (Gordon)	do	239.17
31	148	Pay-roll (Wallace)	do	367.12
31	149	Pay-roll (Hawkins)	do	224.03
31	150	F. P. Gulliver	Field expenses	84.46
31	151	W. R. Atkinson	do	38.90
31	152	do	Traveling expenses	15.71
31	153	William Kramer	do	7.27
31	154	do	Field expenses	21.03
31	155	S. B. Cox	Subsistence and transportation	43.00
31	156	J. M. Gibson	Forage	55.00
31	157	W. H. Renshaw	do	72.42
31	158	Robert D. Cummin	Field expenses	92.88
31	159	M. B. Lambert	do	36.41
31	160	W. H. Lovell	do	38.31
31	161	C. E. Hyde	do	72.44
31	162	J. B. Hammond	Material	30.00
31	163	William H. Herron	Field expenses	67.90
31	164	R. M. Towson	do	180.80
31	165	A. B. Dickerson	Services	5.00
		Total		17,008.50

Abstract of disbursements made by Mark B. Kerr, special disbursing agent, U. S. Geological Survey, during May, 1890.

1890.				
May 1	58	Arthur Keith	Field expenses	$10.00
12	59	James W. Queen & Co	Petrographic supplies	38.13
12	60	George Ryneal, jr	Field supplies	13.24
12	61	S. J. Meeks	Repairs	10.75
12	62	W. H. Walmesley	Field supplies	.75
12	63	W. & L. E. Gurley	Repairing instruments	37.50
12	64	W. S. Bayley	Traveling expenses	46.50
1	65	Columbus Freeman	Services, April, 1890	30.75
1	66	Pay-roll	do	360.00
5	67	C. A. White	do	140.93
12	68	C. R. Van Hise	Traveling expenses	100.15
12	69	W. S. Bayley	Services, April, 1890	60.00
12	70	Nelson H. Darton	Traveling expenses	160.88
12	71	C. W. Hayes	do	68.51
12	72	Warren Upham	Services, April, 1890	98.90
12	73	C. L. Whittle	do	100.00
12	74	do	Traveling expenses	12.41
12	75	do	do	24.30
12	76	Richard Bliss	Services, April, 1890	24.30
12	77	Frank Leverett	do	130.00
12	78	George H. Williams	do	115.00
12	79	George R. Hargadine	do	30.00
12	80	A. T Kyle, jr	Pasturage	14.00
12	81	W. Lindgren	Traveling expenses	43.05
12	82	James G. Bowen	Forage, April, 1890	89.50
12	83	William B. Clark	Services, April, 1890	120.00
13	84	Lena P. Thompson	Forage, April, 1890	23.00
14	85	Gilbert van Ingen	Traveling expenses	44,80
14	86	Aug. F. Foerste	do	73.98
14	87	Arthur Keith	do	20.65
14	88	do	do	4.90
15	89	Columbus Freeman	Services, May, 1890	19.50
19	90	W. Lindgren	Field expenses	47.00
19	91	J. B. Woodworth	Traveling expenses	44.72
19	92	E. De Puy	Rent of typewriter	25.00
19	93	Charles K. Worthen	Geological specimens	31.50
19	94	T. Nelson Dale	Field expenses	13.15
21	95	W. P. Jenney	do	3.50

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
May 31	96	Pay-roll	Services. May, 1890	$2,001.40
31	97	...do	....do	2,016.00
31	98	W. Lindgren	....do	136.20
31	99	H. W. Turner	....do	136.20
		Total		6,521.05

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during May, 1890.

1890.				
May 7	1	Joseph P. Iddings	Services, March 1 to 25, 1890	$138.89
31	2	Pay-roll of employés	Services, May, 1890	713.53
		Total		852.42

Abstract of disbursements made by J. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during June, 1890.

1890.				
June 3	1	A. B. Hurlbut	Geologic supplies	$2.80
4	2	N. S. Shaler	Services, May, 1890	270.00
6	3	W. P. Jenney	....do	187.40
7	4	George H. Williams	....do	120.00
7	5	Frank Leverett	....do	135.00
7	6	George E. Luther	....do	102.20
7	7	W. S. Bayley	....do	72.50
7	8	C. R. Van Hise	....do	340.60
7	9	T. Nelson Dale	....do	150.00
7	10	M. A. Foster	....do	10.00
7	11	Raphael Pumpelly	....do	340.60
7	12	Bangs & Co.	Publications	71.77
7	14	James G. Bowen	Care and forage of animals	121.00
7	15	Pay roll of employés	Services, May, 1890	257.20
7	16	Lawrence C. Johnson	....do	119.20
7	17	Royce & Marean	Supplies	6.60
7	18	L. G. Thompson	Field expenses	22.00
7	19	Washington Gas-light Co	Laboratory supplies	54.63
9	20	F. H. Knowlton	Traveling expenses	35.38
9	21	Warren Upham	Services, May, 1890	102.20
9	22	J. B. Woodward	....do	50.00
9	23	John R. Proctor	Services, October 1, 1889, to May 31, 1890.	140.00
9	24	Nelson H. Darton	Services, May, 1890	127.80
10	25	C. W. Hayes	Field supplies	151.71
10	26	....do	....do	59.35
10	27	William P. Rust	Services, May, 1890	67.50
10	28	Thomas Parry	Traveling expenses	7.25
10	29	L. C. Johnson	......do	31.50
11	30	Samuel Springmann	Freight and hauling	61.77
11	31	William J. Swinburne	Office fuel	33.20
11	32	Henry Carey Baird & Co	Publications	2.00
11	33	Raphael Pumpelly	Miscellaneous field expenses	19.48
11	34	A. Prescott Baker	Rent, May, 1890	50.00
11	35	Prof. Arthur Lakes	Services, May 11 to June 10, 1890	150.00
11	36	Gilbert van Ingen	Field expenses	1.00
11	37	J. R. Bien	Publications	15.00
11	38	G. K. Gilbert	Traveling expenses	67.24
12	39	Wyckoff, Seamans & Benedict	Repairs	5.15
12	40	E. E. Jackson & Co	Geological supplies	6.80
12	41	E. J. Pullman	Supplies	386.81
13	42	Robert Clarke & Co	Publications	5.00
13	43	W. F. Fling	Services	1.80
13	44	W. H. Walmsley	Supplies	6.75
13	45	Gilbert van Ingen	Field expenses	3.94
13	46	Pennsylvania R. R. Co	Transportation of assistants	263.43
13	47	Gilbert van Ingen	Traveling expenses	38.70
13	48	Gustav E. Stechert	Publications	232.38
17	49	Lutz & Bro.	Supplies	7.00
17	50	Joseph Minic	Services, May 14 to 31, 1890	34.84
17	51	George Terreio	....do	34.84
17	52	Charles Oley	....do	52.26
17	53	W. H. Snyder	Services, May 23 to 31, 1890	12.00

Abstract of disbursements made by J. D. McChesney, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 17	54	George R. Hargadine	Services, May, 1890	$30.00
17	55	C. W. Coman	....do	50.00
17	56	Richmond and Danville R. R	Transportation of assistants	370.10
18	57	Seth H. Chadbourne	Publications	4.50
18	58	Sawin's Express	Freight	4.94
18	59	S. J. Haislett	Geologic field material	20.00
19	61	John C. Parker	One typewriter	80.00
21	62	George Ryneal, jr	Supplies	218.37
21	63	Emil Greiner	Laboratory supplies	21.85
21	64	F. A. Genth	Services	100.00
21	65	C. L. Whittle	....do	10.61
24	66	G. D. Harris	Traveling expenses	29.57
24	67	Ch. Gaulon, sr	Publications	198.14
24	68	Citizens' National Bank	*Bill of exchange*	1.70
25	69	William B. Clark	Services	25.00
25	70	E. G. Paul	....do	12.00
25	71	David G. Francis	Publications	31.95
25	72	....do	....do	2.10
25	73	Seth H. Chadbourne	....do	26.25
25	74	George Ryneal, jr	Supplies	14.60
25	75	E. Morrison	....do	17.20
25	76	W. B. Moses & Sons	....do	13.00
27	77	Baker & Adamson	....do	30.10
27	78	Bangs & Co	Publications	79.37
27	79	Eimer & Amend	Supplies and material	83.11
27	80	E. E. Jackson & Co	Material	1.25
27	81	Burlington and Missouri River R. R.	Transportation of assistants	12.50
30	82	J. S. Diller	Traveling expenses	7.15
30	83	....do	*Field expenses*	24.53
30	84	Gilbert van Ingen	Services, May, 1890	75.00
30	85	....do	Services, June, 1890	75.00
30	86	G. F. Becker	....do	329.70
30	87	Raphael Pumpelly	....do	329.70
30	88	O. C. Marsh	....do	329.70
30	89	A. Hermann	Services, April 1 to June 30, 1890	250.00
30	90	T. H. Bostwick	....do	250.00
30	91	Ira Sayles	Services, June, 1890	115.40
30	92	J. B. Woodworth	....do	50.00
30	93	C. W. Coman	....do	50.00
30	94	T. N. Dale	....do	150.00
30	95	Samuel H. Scudder	....do	206.00
30	96	W. Lindgren	....do	131.90
30	97	H. W. Turner	....do	131.90
30	98	B. B. Bache	....do	50.00
30	99	Walter P. Jenney	....do	181.30
30	100	J. Henry Blake	....do	148.30
30	102	G. K. Gilbert	Traveling expenses	109.27
30	103	N. H. Darton	Services, June, 1890	123.60
30	104	W. J. McGee	....do	247.25
30	105	Pay-roll of employés	....do	576.85
30	106	....do	....do	1,162.05
30	107	....do	....do	1,717.86
30	108	....do	....do	1,703.55
30	109	....do	....do	209.30
30	110	....do	....do	1,104.50
30	111	....do	....do	1,088.40
30	112	....do	....do	783.40
30	113	....do	....do	362.65
30	115	....do	....do	253.90
30	116	....do	....do	178.90
30	117	George E. Luther	....do	98.90
30	118	S. R. Van Hise	....do	329.70
30	119	C. H. Davis	Pasturage	3.00
30	120	James G. Bowen	Care and forage of animals	74.90
30	121	J. S. Topham	Field material	28.20
30	122	Washington Gas-light Co	Gas for June, 1890	44.89
		Total		19,222.44

SALARIES, OFFICE GEOLOGICAL SURVEY.

1890.				
June 9	1	May S. Clark	Services, May, 1890	$61.40
30	2	....do	Services, June, 1890	59.30
30	3	Pay-roll of employés	....do	2,830.45
		Total		2,951.15

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during June, 1890, *for geological maps of the United States.*

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 7	1	Robert Mayer & Co	Supplies	$17.20
13	2	Ernest Kubel	Copperplates	828.26
17	3	E. F. Brooks	Supplies	4.04
18	4	A. G. Elliott & Co	do	10.00
18	5	Wash. B. Williams	do	31.00
21	6	William D. Clark & Co	do	7.65
21	7	George Ryneal, jr	do	35.20
21	8	Peter Adams Co	do	43.92
25	9	E. F. Brooks	Material	5.64
27	10	E. E. Jackson & Co	do	27.50
30	11	Pay-roll of employés	Services, June, 1890	747.70
30	12	J. S. Topham	Engravers' supplies	3.00
30	13	James Lockhead	Engravers' material	37.75
		Total		1,798.86

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during June, 1890.

1890.				
June 6	1	L. C. Fletcher	Field expenses	$17.00
9	2	R. O. Gordon	do	35.00
9	3	H. S. Wallace	do	42.55
9	4	William H. Griffin	Traveling expenses	19.75
9	5	Glenn S. Smith	Field expenses	10.00
9	6	do	Traveling expenses	12.52
9	7	Lewis J. Battle	do	5.75
9	8	John J. Lincoln	do	12.62
9	9	Julien J. Mason	do	4.40
9	10	Ewing J. Speed	do	4.40
9	11	Albert M. Walker	do	4.40
9	12	Robert D. Cummin	do	12.67
9	13	M. B. Lambert	do	12.52
9	14	George H. Lamar	do	13.75
9	15	William H. Herron	do	40.00
9	16	Elias Foglesong	Forage	10.00
9	17	J. M. Pritchett	Field expenses	17.10
12	18	R. S. Woodward	Services, May	230.00
16	19	Edward Kubel	Supplies	5.47
16	20	Edward Kahler	Repairs for instruments	2.00
16	21	Thompson & Co	Supplies	16.50
16	22	F. P. May & Co	do	3.04
16	23	E. E. Jackson & Co	do	7.50
16	24	Fauth & Co	Instruments	350.00
16	25	Hume & Co	Material for mounting maps	2.00
16	26	W. & L. E. Gurley	Supplies	57.00
16	27	do	Instruments	13.00
16	28	do	do	350.00
16	29	James W. Queen & Co	do	216.00
16	30	C. Schneider	Supplies	6.00
16	31	The Norris Peters Co	Publications	74.00
16	32	Emil Jonscher	Supplies	124.25
16	33	John W. Price	Forage	80.00
16	34	N. B. Dunn	do	81.00
16	35	A. E. Wilson	Traveling expenses	19.50
16	36	Hersey Munroe	do	35.45
16	37	C. W. Goodlove	do	79.66
6	38	F. E. Conrad & Co	Subsistence	20.05
6	39	N. H. Burns & Co	Field material	28.07
6	40	Louis Koers	Transportation	90.00
6	41	Charles F. Urquhart	Field expenses	62.46
6	42	The Davis-Reinmann Co	Transportation	130.00
6	43	W. K. Finks & Co	Subsistence	26.84
6	44	do	do	37.85
6	45	George T. Hawkins	Field expenses	117.57
17	46	C. G. Hamilton	Field supplies	23.75
17	47	L. D. Brent	Traveling expenses	26.50
17	48	D. C. Harrison	do	9.50
17	49	C. T. Reid	do	37.87
17	50	William J. Peters	do	57.95
17	51	W. H. Renshaw	Transportation	150.00
17	52	Van H. Manning, jr	Field expenses	94.40
17	53	H. L. Baldwin, jr	do	77.31
17	54	do	do	90.39
17	55	J. E. Van Matre	Pasturage and forage	56.00
17	56	D. McClelland	Supplies	80.00
17	57	Fred A. Schmidt	Paper	122.75
17	58	L. C. Fletcher	Field expenses	35.83
17	59	do	do	344.65

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 17	60	G. L. Johnson	Field expenses	$92.10
17	61	Robert D. Cummin	....do	49.12
16	62	Joseph F. Page	Supplies	3.00
19	63	A. E. Murlin	Field expenses	95.12
19	64	Harrison E. Crook	Traveling expenses	14.50
19	65	Andrew F. Joyce's Sons	Transportation	55.00
19	66	William H. Herron	Field expenses	49.28
19	67	D. C. Harrison	....do	53.00
19	68	M. B. Lambert	....do	75.73
19	69	Ambrose F. Dudley	Traveling expenses	24.10
19	70	E. B. Clark	....do	41.00
19	71	W. S. Hutt	Field expenses	28.75
19	72	J. T. Hannaford	Storage expenses	39.00
19	73	J. L. Smith	Maps	12.00
19	74	J. W. Thorn	Traveling expenses	24.00
19	75	Glenn S. Smith	Field expenses	99.12
21	76	E. C. Barnard	Traveling expenses	52.85
20	77	M. Hackett	Services, June	131.90
23	78	A. E. Murlin	Traveling expenses	77.57
23	79	C. G. Van Hook	Services, June	82.40
26	80	Nat Tyler, jr	Traveling expenses	66.60
27	81	Pay roll (Wilson)	Services, June	141.70
27	82	Pay roll (Fletcher)	....do	421.56
27	83	Pay roll (Baldwin)	....do	832.66
27	84	J. H. Jennings	....do	131.90
27	85	James McCormick	....do	59.30
27	86	Frank Sutton	....do	115.40
27	87	E. B. Clark	....do	115.40
27	88	J. W. Thom	....do	50.00
27	89	Albert M. Walker	....do	60.00
27	90	William Kramer	....do	98.90
27	91	J. H. Wheat	....do	74.20
27	92	M. B. Lambert	....do	74.20
27	93	Charles R. Grandy	....do	50.00
27	94	W. M. Beaman	....do	59.30
27	95	F. P. Gulliver	....do	98.90
27	96	Lincoln Martin	....do	60.00
27	97	Ambrose F. Dudley	....do	55.00
27	98	W. H. Lovell	....do	131.90
27	99	Lewis J. Battle	....do	60.00
27	100	W. R. Atkinson	....do	98.90
27	101	John J. Lincoln	....do	59.30
27	102	Pay-roll (Hawkins)	....do	250.40
27	103	Pay-roll (Wallace)	....do	371.20
27	104	Pay-roll (Gordon)	....do	309.60
27	105	Pay-roll (Blair)	....do	340.92
27	106	L. C. Woodbury	Services, May	24.19
27	107	W. T. Quillin	Traveling expenses	5.00
27	108	Edward Kubel	Repairs on instruments	5.75
27	109	S. J. Haislett	Field expenses	5.00
28	110	John H. Renshawe	Services, June	206.00
28	111	O. L. Meadows	....do	3.00
28	112	John Jennings	....do	6.00
28	113	Pay-roll (Barnard)	....do	334.10
28	114	G. E. Hyde	....do	74.20
28	115	B. Peyton Legare	....do	60.06
28	116	Pay-roll (Cooke)	....do	168.10
28	117	Chas. M Yeates	....do	148.30
28	118	Robert Muldrow	....do	74.20
28	119	C. F. Reid	....do	69.20
28	120	William J. Peters	....do	131.90
28	121	Van H. Manning, jr	....do	98.90
30	122	R. U. Goode	Traveling expenses	157.85
30	123	H. B. Blair	Field expenses	23.90
30	124	...do	Traveling expenses	16.00
30	125	G. L. Johnson	Services, June	69.20
30	126	Glenn S. Smith	....do	69.20
30	127	Julien J. Mason	....do	50.00
30	128	W. W. Maxwell	....do	5.00
30	129	Robt. D. Cummin	....do	131.90
30	130	....do	Field expenses.	47.25
30	131	....do	Traveling expenses	7.31
30	132	John H. Klemroth	Services, June	131.90
30	133	Geo. W. Stuart	....do	49.00
30	134	R. McC. Michler	....do	82.40
30	135	Pay roll (Urquhart)	....do	228.90
10	136	F. P. Metzger	....do	60.00
30	137	Pay-roll (Murlin)	....do	272.92
30	138	John H. Renshawe	Traveling expenses	141.78
30	139	Jas. McCormick	....do	6.43
30	140	....do	Field expenses	109.13
30	141	William J. Peters	....do	144.43
30	142	Nat Tyler, jr	Services, June	60.00

Abstract of disbursements made by Anton Karl, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 30	143	D. C. Harrison	Services, June	$115.40
30	144	L. D. Brent	...do	74.20
30	145	S. B. Cox	Subsistence and transportation	52.00
30	146	Ewing Speed	Services, June	50.00
30	147	Wm. Kramer	Traveling expenses	24.56
30	148	...do	Field expenses	82.44
30	149	Frank Sutton	...do	24.60
30	150	...do	...do	54.06
30	151	...do	Traveling expenses	36.24
30	152	M. B. Lambert	...do	5.60
30	153	...do	Field expenses	255.35
30	154	L. C. Fletcher	...do	146.73
30	155	E. C. Barnard	...do	231.78
30	156	Thos. C. Nelson	Services, June	25.00
30	157	A. A. Curtis	...do	8.75
30	158	William Johnson	...do	15.83
30	159	Mrs. C. S. Smith	...do	11.67
30	160	W. H. Lovell	Traveling expenses	6.30
30	161	Basil Duke	...do	14.75
30	162	S. E. Cooke	...do	16.00
30	163	Robert Muldrow	...do	27.40
30	164	W. E. Lackland	...do	12.25
30	165	Thomas S. Clark	...do	13.25
30	166	W. L. Miller	...do	4.95
30	167	Thos. C. Nelson	...do	16.95
30	168	Chas. M. Yeates	...do	6.75
30	169	Chas. E. Cook	...do	46.15
30	170	L. C. Fletcher	...do	16.75
30	171	G. L. Johnson	do	4.13
30	172	...do	Field expenses	83.44
30	173	Wm. H. Herron	...do	47.44
30	174	H. S. Wallace	...do	30.90
30	175	A. E. Wilson	...do	37.25
30	176	W. L. Wood & Co	Subsistence	75.05
30	177	J. P. Brough	...do	37.15
30	178	J. M. Gibson	Forage	39.23
30	179	Van H. Manning, jr	Field expenses	113.40
30	180	H. L. Baldwin, jr	...do	178.04
30	181	J. M. Couch	Storage	6.00
30	182	Pay-roll (Karl)	Services, June	4,530.15
30	183	Jno. H. Renshawe	Field expenses	40.00
30	184	M. Hackett	...do	235.89
		Total		19,165.50

Abstract of disbursements made by Mark B. Kerr, special disbursing agent, U. S. Geological Survey, during June, 1890.

1890.				
June 19	1	Pacific Coast Steamship Co	One first-class fare	$52.50
19	2	...do	Six second-class fares	192.00
19	3	Mark B. Kerr	Traveling expenses	196.50
19	4	Charles Louch	Field subsistence	318.51
19	5	I. C. Russell	Traveling expenses	222.25
30	6	...do	Services, June, 1890	197.80
30	7	Mark B. Kerr	...do	148.30
30	8	J. H. Christie	...do	18.24
		Total		1,346.10

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during June, 1890.

1890.				
June 2	1	Elwood Hofer	Services as herder, January 1 to March 31, 1890.	$135.00
30	2	Pay-roll of employés	Services, June, 1890	717.00
30	3	Elwood Hofer	Services as herder, April 1 to June 30, 1890.	135.00
		Total		987.00

Total amount expended as per foregoing abstracts		493,704.42
Amount of bonded railroad accounts settled through Treasury Department, viz:		
Freight	$124.92	
Transportation for assistants	827.81	952.73
		494,657.15

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, 1890.

THE PLEISTOCENE HISTORY
OF
NORTHEASTERN IOWA.

BY

W J McGEE.

CONTENTS

ILLUSTRATIONS.

THE PLEISTOCENE HISTORY OF NORTHEASTERN IOWA.

By W J McGee.

PREFATORY NOTE.

The survey recorded in the following pages was begun in Dubuque County, Iowa, during the latter part of 1876; and during the ensuing five years the work was gradually extended over the territory herein described. Preliminary publications were made in the American Journal of Science and the Proceedings of the American Association for the Advancement of Science in 1878, in the Geological Magazine (London) in 1879, and in the same and other journals during subsequent years. The field survey was practically completed in the autumn of 1881, and the greater part of the present report was written during the ensuing winter. The work was done at personal cost in amateur fashion. Circumstances transpiring early in 1882 led to the temporary abandonment of the task and compelled postponement of publication for several years.

Although the survey was at first confined to the glacial deposits alone, it was gradually extended to the forms displayed by these deposits; and the study thus became one of topographic form as well as rock structure. Accordingly, even after opportunity came for completing the discussion of the field results, it was deemed unwise to publish the report without more trustworthy and refined maps than were available at the time of the survey. For this reason the final revision of the report and publication were still further delayed.

In 1887 topographic surveys were commenced, within the territory previously studied, by the Director of the U. S. Geological Survey, and a representative area of about 2,000 square miles was mapped on a scale of a mile to the inch with a contour interval of 20 feet and in a manner well adapted to the illustration of the peculiar topographic forms of the area. During 1888 the territory was revisited by me; a special study was made of the relations between configuration and structure in the area covered by the topographic map; a number of critical points were reinvestigated; a few points inadequately studied during the original survey were examined; and the entire work of the previous decade was reviewed. During subsequent months the original report was revised and the more elaborate illustrations were reconstructed; the recent literature of the subject was examined with a view of bringing the discussion down to date, and the matter was again prepared for the press. Some degree of anachronism is inevitable when so long a period intervenes between investigation and publication, and though efforts have been made to minimize this evil it can hardly be hoped that they have been entirely successful.

Be it recognized that the problem discussed herein is complex; that the relations between certain of the deposits and the water ways, and between both deposits and water ways on the one hand and the general configuration of the surface on the other, are anomalous if not unique. And be it freely granted by the writer and fully recognized by the reader that the hypothesis through which the solution of the problem was effected is far reaching, fine spun, and elaborate. The most startling induction of geology, if not of modern science, is the glacial theory; but in the solution of the problem of these pages it is necessary to do more than assume the existence and action of a great sheet of ice hundreds or thousands of feet in thickness and hundreds or thousands of miles in extent. In order to explain the sum of the phenomena it is necessary to picture the great ice sheet not only in its general form and extent, but in its local features, its thickness, its direction and rate of movement over each square league, the *inclination of its surface* both at *top* and *bottom*, and the relation of these slopes to the subjacent surface of earth and rock; and all this without a single glacial stria or an inch of ice polish, save in one small spot, in the whole tract of 16,500 square miles. It is necessary to conceive not only the mode of melting of the ice at each league of its retreat, but also every considerable brook, every river, and every lake or pond formed by the melting, both at its under surface and on its upper surface; it is necessary to restore not only the margin of the mer de glace under each minute of latitude it occupied, but, as well, the cañons by which it was cleft, the floe-bearing lakes and mud-charged marshes with which it was fringed, each island of ice, and each ice-bound lake formed within its limits. And it is not only necessary to reconstruct the geography of a dozen episodes, as does the anatomist the skeleton from a few bones, but to develop a geography such as civilized eye has never seen, and which could exist only under conditions such as utterly transcend the experience of civilized men. All this has been done. The trail of the ice monster has been traced, his magnitude measured, his form and even his features figured forth, and all from the slime of his body alone, where even his characteristic tracks fail.

He who questions this reading of the riddle of these pages would

Glaciated region.

Pleistocene water bodies

GEOGRAPHIC POSITION OF NORTH-EASTERN IOWA

THE GILES COMPANY LITH. N.Y.

do well to essay it for himself on the ground; for the growing literature of science is already too voluminous to be burdened with the endless records of observation and inference growing out of years of study; and the inalienable prerogative of the original investigator to generalize his own observations and deduce his own inferences has been recognized, and has determined the mode of treatment adopted. But let the skeptic remember that the standards and criteria developed elsewhere may require modification here; and if he would read the record aright let him not confine himself to structure alone, to geographic and hypsographic distribution of the deposits alone, or to external configuration alone; for all of these features, and more besides, must be contemplated at once and explained at the same time.

CHAPTER I.

NORTHEASTERN IOWA.

The vast expanse of prairie land stretching from the shores of Lake Michigan to the foothills of the Rocky Mountains, long known familiarly as "The Plains," is interrupted in its northern part by a tongue of broken, wooded country extending down the Mississippi nearly to the upper rapids of that river at Rock Island. So while the greater part of Iowa is a smooth, monotonous drift plain, dotted with bowlders but bare of trees or only sparsely wooded, the extreme northeastern part of the State (lying within the "driftless area" so well described by Chamberlin) is not only wooded, but deeply cañoned by the Mississippi and its tributaries. The mural precipices, the high, round-topped hills, the shady dells, the picturesque cascades, and the many other scenic features for which the upper Mississippi is famed among tourists, are found in Iowa as well as in contiguous parts of Minnesota and Wisconsin.

The territory to which the designation "Northeastern Iowa" is specifically (but arbitrarily) applied, is an incomplete rectangle about 140 by 150 miles, comprising the northeasternmost twenty-nine counties of the State (including the eastern portions only of Jasper and Marshall). It is represented in the accompanying stereogram (Pl. III) and in the lithographed photograph of a model forming Pl. IV, as well as in the several detailed maps; and a list of the counties, with their areas, and the origin of their names is given in the accompanying table:

Counties of Northeastern Iowa.

No.	Name.	Origin of name.[1]	Area.[2]
			Sq. m.
1	Allamakee	Winnebago pronunciation of name of Alex. McGee, an Indian trader	618
2	Benton	Named in honor of Thos. H. Benton, statesman	720
3	Black Hawk	Anglicized name of the noted Sac chief Múk-a-tah-mish-o-káh-kaik	576
4	Bremer	Named in honor of Frederika Bremer, novelist[3]	432
5	Buchanan	Named in honor of President James Buchanan	576
6	Butler	Named in honor of Gen. William Orlando Butler, soldier and statesman	576
7	Cedar	Named from its principal river, the Cedar (originally the "Red Cedar")	576
8	Chickasaw	Named from the Indian tribe	504
9	Clayton	Named in honor of John Middleton Clayton, jurist and statesman	755
10	Clinton	Named in honor of De Witt Clinton, statesman and savant[4]	689

[1] Taken largely from Iowa Historical Record, 1888, vol. 4. pp. 32–37.
[2] Computed in land survey sections from accompanying base map of Northeastern Iowa, 1889.
[3] A village in the county is named *Frederika*, commonly corrupted to "Frederica."
[4] The third town in the county is *De Witt*.

TOPOGRAPHY OF

NORTH EASTERN IOWA

BY W J M^{c} GEE

Vertical Scale 7,500 Feet-1 inch
Horizontal Scale 1:950,400-15 miles:1 inch

1889.

Reproduced from model by Victor and Cosmos Mindeleff.

THE GILES COMPANY, LITH. N.Y.

Counties of Northeastern Iowa—Continued.

No.	Name.	Origin of name.	Area.
			Sq. m.
11	Delaware	Named after the early home of several pioneer settlers, Delaware County, N. Y.	576
12	Dubuque	Named in honor of the pioneer lead miner, Julien Du Buque[1]	605
13	Fayette	Named in honor of the Marquis de la Fayette	720
14	Floyd	Named in honor of John Buchanan Floyd, statesman	504
15	Grundy	Named in honor of Felix Grundy, statesman	504
16	Howard	Named in honor of Tilghman A. Howard, statesman	480
17	Iowa	Euphonized from the tribal name Aia-ou-ez, or Ioways[2]	576
18	Jackson	Named in honor of President Andrew Jackson[3]	628
19	Jasper	Named in honor of Sergeant Jasper of revolutionary fame[4]	($\frac{2}{5}$) 288
20	Johnson	Named in honor of Col. Richard Mentor ("Dick") Johnson, soldier	620
21	Jones	Named in honor of Gen. George Wallace Jones, a pioneer settler and surveyor-general, etc.[5]	576
22	Linn	Named in honor of Louis F. Linn, statesman[6]	720
23	Marshall	Named in honor of Chief Justice John Marshall	($\frac{1}{2}$) 288
24	Mitchell	Named in honor of John Mitchel, Irish patriot	480
25	Muscatine	Aboriginal name (meaning "fire prairie island") of an island in the Mississippi.	434
26	Poweshiek	Named after the Musquakee or Fox chief, Pow-a-sheek[7]	576
27	Scott	Named in honor of General Winfield Scott	447
28	Tama	Named after the Musquakee brave, Tai-o-mah[8]	720
29	Winneshiek	Named after a Winnebago chief	696
	Total		16,460

[1] A village near Dubuque bears the name *Julien*.

[2] The signification of the aboriginal name (frequently rendered "Beautiful Land," etc.) appears to be *The Sleepy Ones*.—Iowa Historical Record, 1885, vol. 1, p. 23, and elsewhere.

[3] A town in the county is named *Andrew*.

[4] The county seat, *Newton*, bears the name of Jasper's comrade in his most noted exploit.

[5] Vide Iowa Historical Record, 1887, vol. 3, pp. 433–456.

[6] Thos. H. Benton's colleague in the United States Senate.

[7] The name signifies "*To dash the water off.*"—Hist. Indian Tribes, McKenney and Hall, 1858, vol. 2, p. 107.

[8] The name signifies "*The bear whose voice makes the rocks to tremble.*"—Ibid., vol. 3, p. 29.

While the most trenchant and conspicuous natural division of the territory is into drift plain on the southwest and the driftless area on the northeast, he who studies the face of the country with attention, whether he be cartographer or capitalist, tourist or habitant, artist or artisan, finds no lack of lesser but still significant natural divisions. To see all of these in their several aspects, the entire territory must be traversed in various directions, and every landscape scanned. But the tourist who would avoid the labor of this may intrust himself to a trained pilot who can, in three short journeys across it, introduce him to every type of surface, every group of rocks, every important water-way, every class of soil and product, every phase of culture, within Northeastern Iowa.

Let us follow a tourist in the hands of such a pilot.

The tourist should commence his journey in the extreme north eastern corner of the State. There he will find the broad "Father of

Waters" meandering through a densely wooded flood plain four or five miles wide, now in a single mile-wide channel; again in a main channel and a half dozen subordinate courses locally known as "sloughs;" and yet again in two or three channels and twice as many sloughs, together cutting the river bottom into a labyrinth of land and water, island and lake, sandbar and marsh, tangled brake and boiling chute, which he could scarce traverse either afoot or afloat without a guide. Anon he would catch glimpses through the glades of 500-foot bluffs frowning darkly upon the river from either side; and at morn or even, he might, despite the width of the valley, see the glint of sunlight on the rounded summits of the opposite hills while the shadows of night yet played about him. And over much of the annually flooded bottom land he may even at this end of the nineteenth century wander for a week without finding trace of human occupancy, unless, perchance, he meet with squalid hunter or toiling fisherman; yet, wherever he might turn, the hoarse scream of the passing packet or the shrill whistle of the locomotive on one side of the river or the other, is hourly borne to his ears upon the river fog.

Should he seek to journey westward upon a road passable for vehicles, he must enter the natural gateway through which the Oneota[1] embouches into the greater river—a gateway a mile wide between the 500-foot salient of sandstone and limestone on the north (the "Minnesota Bluff" of the whites and the "Oneota" of the poor remnant of the Winnebago Indian tribe still lingering about its base) and the scarcely lower Iowa Bluff on the south. Ascending Oneota River he finds himself within a cañon 250 to 500 feet deep, with outer bluffs rising still higher for 25 miles, but gradually diminishing in width from a mile and a half to half a mile; he finds the cañon walls jutting salients, or towering crags, or mural precipices cleft by sharp-cut gorges, interspersed with rounded but rugged and steep forest-clad bluffs; he finds the spring-fed stream diminishing rapidly in volume and flowing briskly in a tortuous channel, cut sometimes in the hard rocks but often in its own sandy flood plain; he finds terraces and indefinite remnants of old flood plains of sand and glacial gravel flanking the bases of the bluffs, sometimes 100 or 150 feet above the present channel. And, with all these, he finds few fine and many poor farms, and sees occasional churches and schoolhouses interspersed with the habitations of thriftless descendents of these ill advised pioneers who dared not settle on the fertile plains once

---

[1] The "Iowa" or "upper Iowa" of most maps. The Indians about its mouth call the bluff flanking it on the north "Oneota," and recognize the river under the same name. The signification of the term as used by the Winnebagoes is obscure. It signifies in the Mohawk dialect "the people who have sprung from a rock." (Schoolcraft; Oneota, or Characteristics of the Red Race of America, 1845, p. v.)

supposed to be barren; and he may now and then stumble upon the ruins of smelting works and iron furnaces, erected in the palmy days when geology was unknown, for the treatment of ores of which heartless science has shown the hills to be barren. (Pl. v.)

When the tourist turns aside from the river into the cañon of a tributary on either hand, he finds the lesser cañon to rise with a strong gradient and gradually contract in width; he finds it walled in by bluffs of horizontally bedded buff magnesian limestone to an ever diminishing height; he finds the stream meandering here and there, with a tributary ravine or cañon at every bend, and anon bifurcating in equal branches, and he passes by niches and alcoves in the walls of the gorge from which burst perennial springs by which the stream is fed; and finally, after leaving the last of the springs behind, when 3, 10, or 20 miles from the river and 300 to 500 feet above it, he finds himself in the midst of a maze of rounded hills divided by a labyrinth of wide branching and meandering ravines. Then if he climbs to the nearest commanding summit he finds that the maze of hills and the labyrinth of ravines blend into a strongly undulating plain, inclining gently, though wrinkling deeply, toward the Oneota and Mississippi, and culminating in rounded domes of gentle slope on the principal divides; his eye falls on occasional ledges and knobs of buff magnesian limestone or gray (or perchance, snow white) sandstone peeping through a scant subsoil of reddish brown loam; and over the uplands he sees wagon roads wandering here and there along the divides between wooden fences, as they wander along the streams between natural cyclopean walls at lower levels—and on them comfortable farm houses, commodious barns, ample schoolhouses, churches at every angle, with the indigenous forest of hard woods and conifers replaced by cultivated fields. If he happens upon a cross-country road he may find it smooth, direct, and well beaten for a mile or two, only to descend with many an undulation and curve over and around the bounding hills into a ravine, and then over rocks into the bed of the stream; or it may become a narrow shelf skirting the face of the bluff and swerving here and there for three miles of length for each mile of advance into the cañon of some insignificant stream, only to rise circuitously and painfully to the divide beyond. But in his wanderings he finds no stone save the buff magnesian limestone, or the gray and white sandstone, no superficial deposits except the loam derived from decomposition of these rocks (and occasional patches of glacial sand or gravel along the Oneota), no land that was not forest clad until stripped by the settler, and no topographic forms other than water-carved slopes, gentle and smooth at high levels, yet steep and rugged along the water ways. (Pls. VI, VII, VIII.)

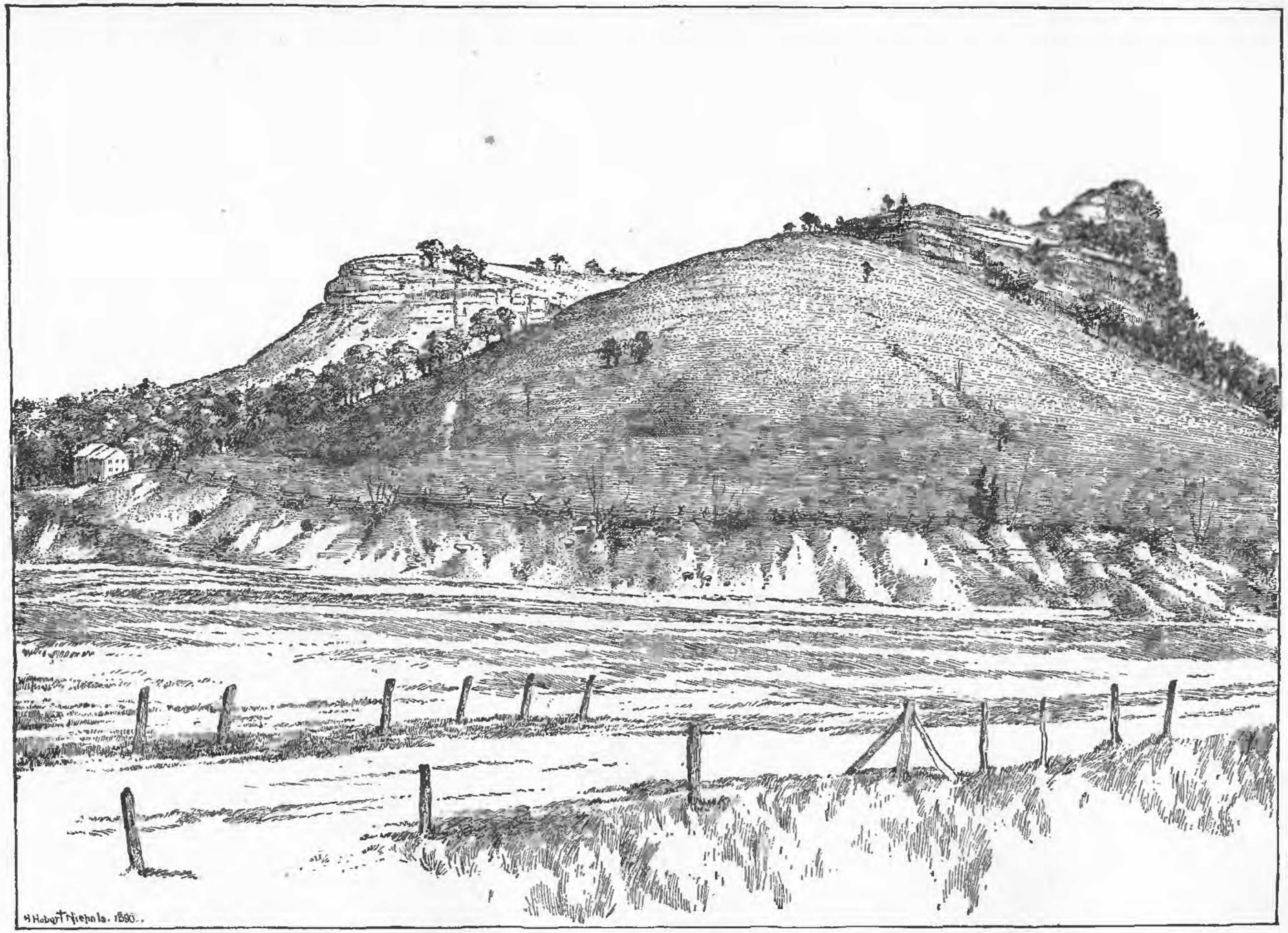
Such is most of Allamakee County, together with portions of Winnesheik and Clayton.

Let the tourist now return to the Oneota midway between its mouth and its great bend at Decorah, and continue his ascent of the stream. He soon observes a change in the configuration of the cañon walls: The higher bluffs, at first round topped, steepest and even precipitous at midheight and talus-burdened at base, are occasionally crowned by knobs and minor ridges which rise sharply from the gentler slopes below and in their steep scarps expose crags, pinnacles, and cliffs of gray, blue, or buff limestone; a few miles farther up stream he sees the same limestone in the summits of the lower as well as the higher bluffs; yet a few miles and he finds the cañon narrowed to a gloomy gorge overshadowed save at midday by cedar-clad limestone cliffs, with the larger tributaries occupying narrow U-shaped troughs—miniature copies of the greater cañon—and the smaller tributary ravines reduced to shadowy glens. When he ascends over the steep scarps to the upland he observes that it is smoother than the country to the eastward, with broader divides and flatter hilltops, with narrower and steeper ravines, and with frequent "sinks"—the earth basins that betray limestone caverns beneath; and about him he sees a rich, brown sand-free soil, and finds himself in a land of fine farms, great barns, strong fences of posts and rails or boards, blooded stock, the apple and the vine, belfried schoolhouses and high-spired churches, perhaps lace-curtained windows and flowered parterres, and other eloquent witnesses of fertility—handicapped albeit by hilly and circuitous market roads; but looking down the divides he finds the transition from the one type of country to the other much less sharply marked upon the uplands than in the cañon walls.

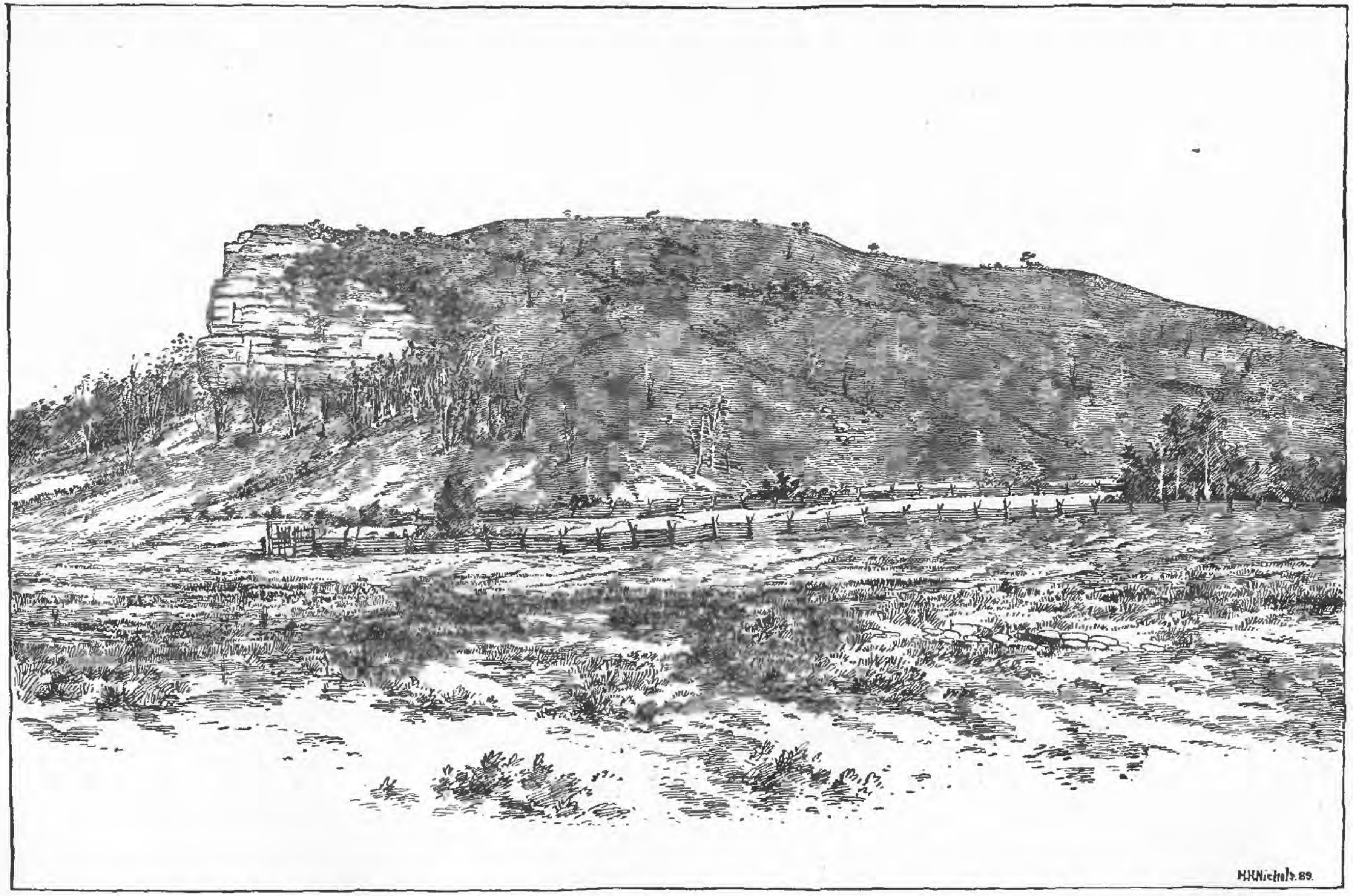
This is the land of the Trenton limestone, which includes much of Winneshiek and Clayton, and parts of Howard and Allamakee Counties.

At Decorah the traveler finds the valley of the Oneota reduced to perhaps 200 feet in depth, and no longer a sharp cut cañon, but a broad valley bounded by gently swelling bluffs, with few precipitous cliffs (and these Trenton limestone) exposed between river channel and hilltop; and ascending to the upland he finds himself on an undulating plain once wooded but now under plow except in the steepest slopes; and over the rich, brown residuary clay into which the limestone passes he might now and then discover a mantle of yellowish buff loam with scattered pebbles, or perchance a bowlder bed at its base—the marginal portion of the loess which elsewhere records with marvelous accuracy the track of the ice monster and the way of his ending. (Pl. IX.)

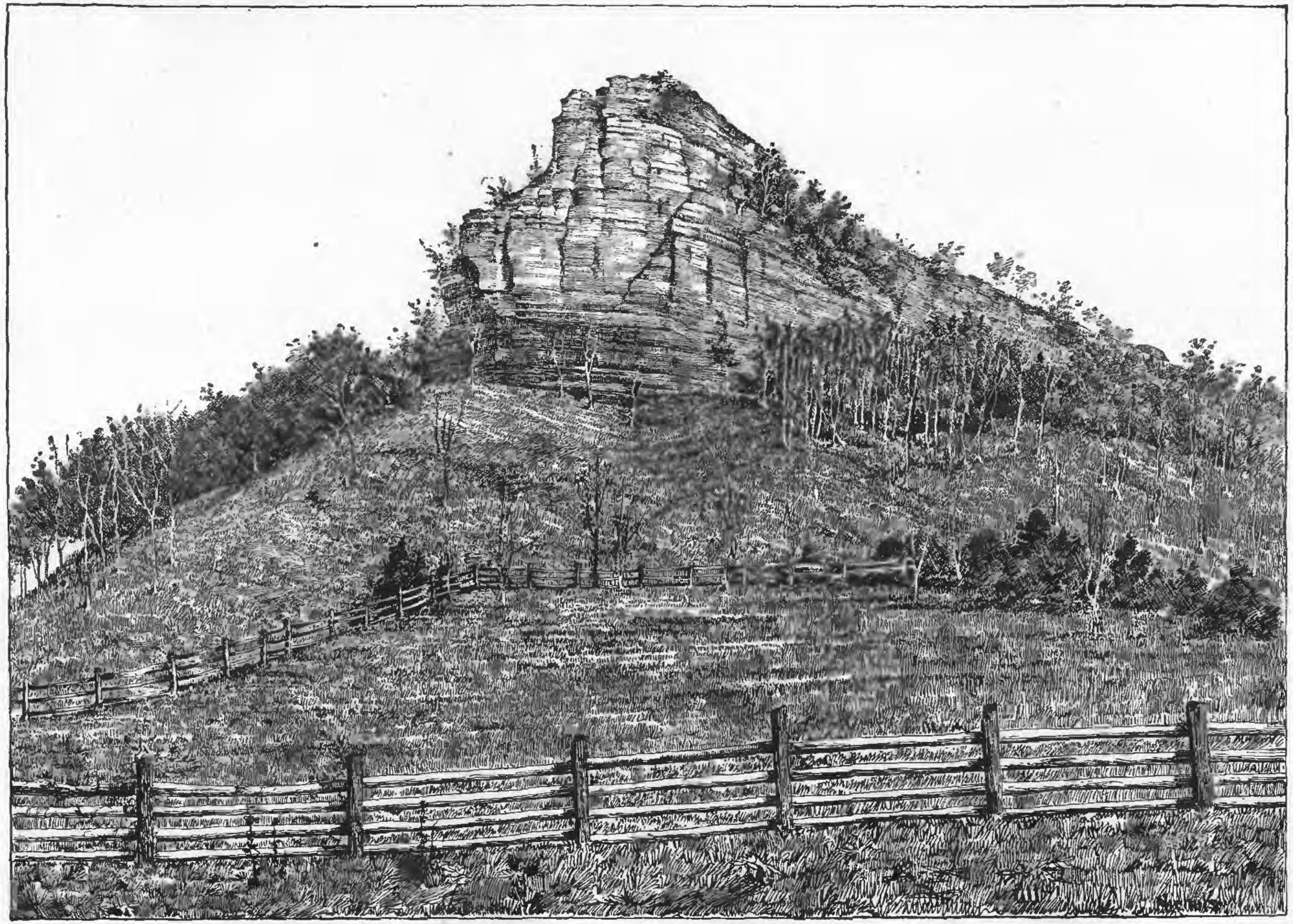
If the tourist now deserts the water-way, after tracing it from its first estate as a respectable river to the narrower one of a goodly millstream, and takes a west-southwesterly course, he will cross the



"ONEOTA" (MINNESOTA BLUFF), FROM THE SOUTHEAST.

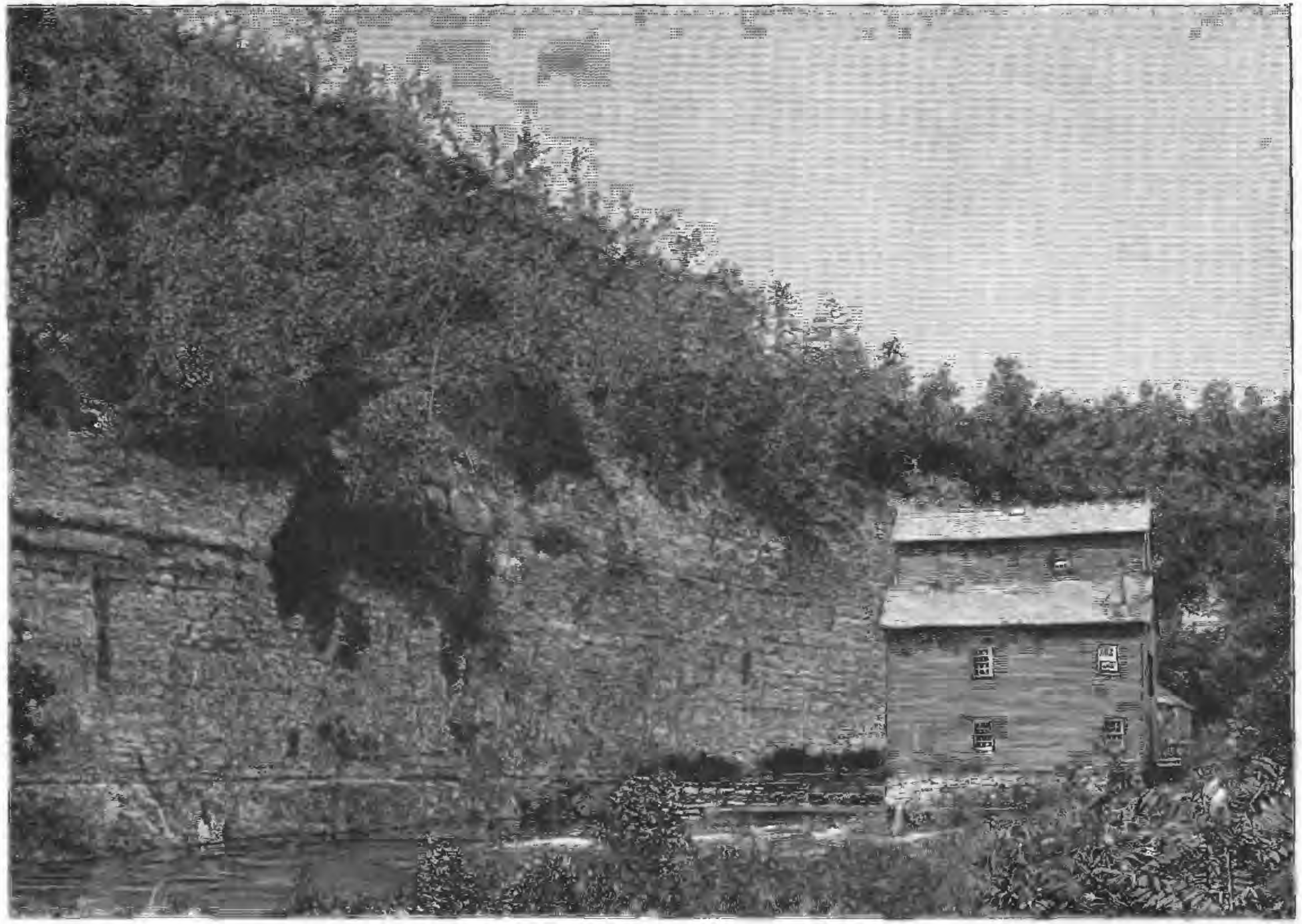


IOWA BLUFF, FROM THE WEST.

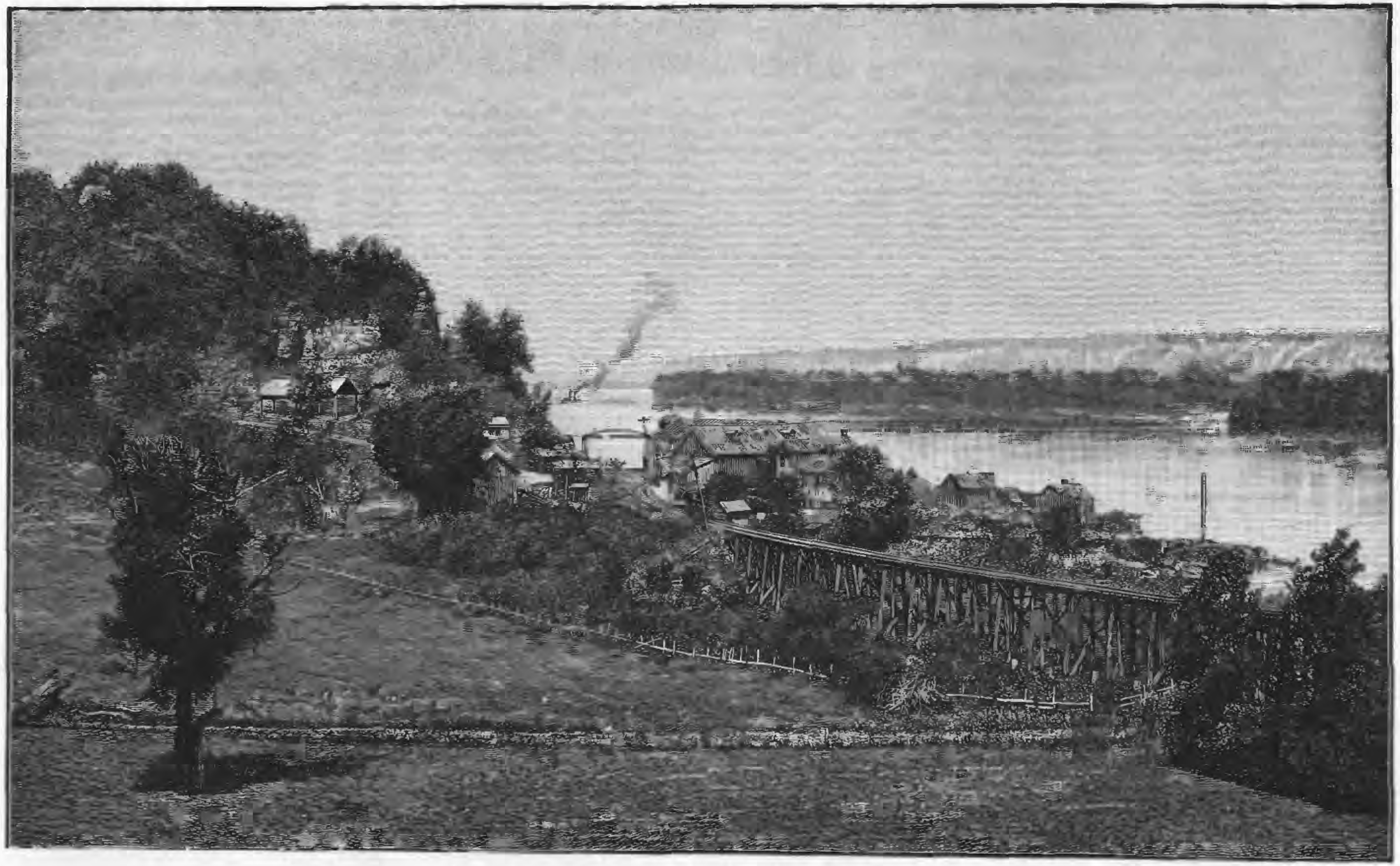


IOWA BLUFF, FROM THE NORTH.

THE ONEOTA RIVER AND BLUFFS.



THE ONEOTA RIVER AT BLUFFTON.



A TYPICAL DRIFTLESS AREA LANDSCAPE, BUENA VISTA.

A TYPICAL PRAIRIE LANDSCAPE, NEAR NEW OREGON.

upper reaches of the other rivers of Northeastern Iowa at right angles and traverse a typical drift margin and a typical drift plain.

It is twelve or fifteen miles by road from Decorah to the Military Ridge (for this is yet the broken country in which the traveler must measure his distances along the curves of the roads rather than in air lines). Next to the Mississippi, this ridge is the most prominent natural feature of the driftless area. It begins in southeastern Minnesota as an inconspicuous elevation, rising (relatively to the surrounding country) to the southeast, until it forms the divide between the Oneota and the Yellow on the left and the Turkey on the right, and then stretching southeastward to northeastern Clayton County it is trenched to its base by the Mississippi; but it quickly rises again beyond the ancient river and extends eastward seventy-five miles before it is lost in the central Wisconsin drift plain.

From the summit of the Military Ridge southwest of Decorah, 600 feet above the Oneota at its mouth, the tourist looks down upon the nearer part of the basin of that river as upon a map, and sees the maze of hills and the labyrinth of ravines flattened by perspective to a sharply undulating plain which rises into the crests of the divides and sinks into the troughs of the water-ways, like the mighty billows upon which little wavelets play; and could he restore the picture that greeted the pioneer, he would find the landscape toned by a variegated forest mantle, of gray green oak, elm, and hickory on the slopes and dark green pines and cedars along the water-ways, with thickets of hazel and crab apple dotting the glades and fringing the intervals over the divides. Turning southwestward he looks upon another land. At his feet, indeed, he sees Turkey River embosomed in a winding bluff-skirted valley 100 to 200 feet deep, with many precipitous cliffs overlooking its waters, yet even on its banks the summits of some hills are smoothed and rounded by the ice plow; but his background, extending from the farther bank of the Turkey to the limits of vision, is naught but an earthen floor as flat as the ocean becalmed.

Descending to the river and giving attention to minor features he may observe now and then horizontal ledges of buff limestone charged with nodules of chert—the Niagara formation—peeping out along the roadside; he may catch sight of stray bowlders, pebbly gravel, and coarse sand; but in general he finds the surface mantled with the yellowish brown clayey loam (which is the local aspect of the loess) and its basal pebble bed. On approaching the river he is impressed anew with the greater ruggedness of the topography at low levels than at high, and may imagine himself transported back to the upper Oneota; and on reaching the water's edge he finds again the thin bedded blue Trenton limestone of that river laved by the waters of the Turkey. On crossing the narrow rocky channel and ascending the opposite slope he catches more than one glimpse of a coarse buff dolomite (the Galena, or lead-bearing limestone) with the light blue clay of the overlying Maquoketa shales, and both quickly followed by the cherty Niagara) for all these formations are thin in the north; and while he finds the lower hills rugged, and occasional flat topped mesas or precipitous bluffs at higher levels for a mile, he soon leaves all this behind him and passes upon the bowlder-dotted drift plain.

Could he now put himself once more in the place of the pioneer, he would see before him only smooth prairie land stretching to an unbroken horizon, without tree, bush, or shrub, save for the narrow belts of fire-stunted forest along the larger water courses, with never a hill, or valley, or other topographic form save the plain, and that plain smooth, level, ill drained, and bounded only by the limits of vision save where diversified now and then by a low mound of unknown origin (Pl. XII). But man has made his mark on the face of the land, and the vision of the tourist is obscured by artificial groves, by houses and barns dotting the surface and not concealed by its slight irregularities for a score of miles in either direction; his course is constrained by the barbed wire fences of the lanes into

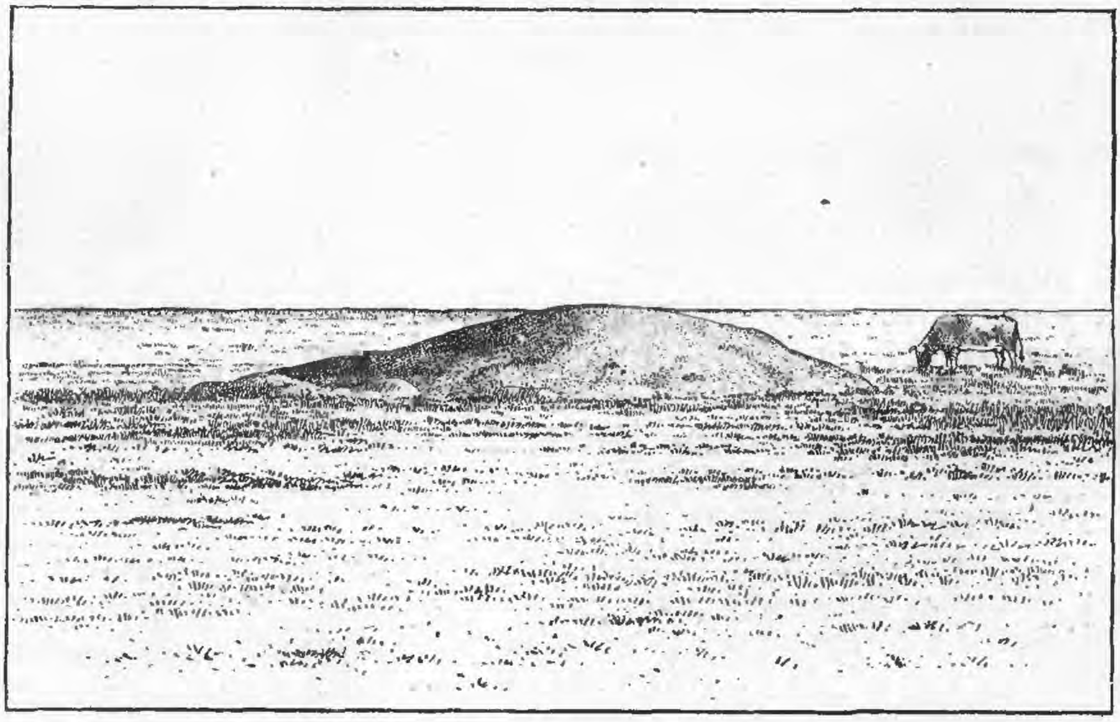


FIG. 1.—Drift bowlder of granite.

roads running upon the land lines, stretching straight as arrows to west and south for scores of miles with no hill too steep to be crossed without grading nor valley so deep as to require embankments; and he finds the smaller bowlders sown in myriads by the ice-king gathered in lines along the fences, heaped up by the roadside, and built into foundations of houses and barns, though many of the larger—

great granite masses high as the haystacks of an eastern farmer—yet maintain their preemption upon the land.

Journeying southwestward over the prairie the traveler reaches a creek (Little Turkey, Crane, Little Wapsipinnicon, it matters not which) whose shallow channel meanders through a flood plain of sandy alluvium half a mile, a mile, or possibly a mile and a half in width, and 5 or 10 or 20 feet in depth; and were his eye trained to such observation he might look forward and backward and perceive that this pseudo valley is the axis of an irregular trough 5 to 20 miles wide and 25 or possibly 50 or 100 feet deep—a trough which is so shallow that the earth's curvature deforms it and the sides of which are the gently undulating and ill drained plain of bowlder-marked drift.

Beyond the Little Wapsipinnicon the traveler finds himself upon monotonous prairie land (with seldom a bush and never a tree save the artificially planted "wind-breaks" west and northwest of the houses, lines of quick growing silver maples and Lombardy poplars planted to mark the lanes and make fence posts, and a few natural belts of indigenous woodland along the larger water-ways) laid off in chess-board squares by wire-fenced roadways following the rectangular system of land lines. Frequently here, as sometimes east of the Little Wapsipinnicon quite to the headwaters of the Turkey and Crane, the roadbeds are low carriage-wide causeways; and in early days the tracts traversed by these causeways were impassable except during autumn droughts or winter frosts. They were the sloughs (locally pronounced *slews*) of the vernacular: the human pioneer found them inhabited by geese, ducks, cranes, herons, and other wild fowl, which nested year after year in their impassable expanses of morass; he found them clothed with rushes and flags and skirted by belts of moisture-loving blue-joint grass rising higher than the head of a tall man; he found the central portions of each besprinkled with the pyramidal houses of the half aquatic muskrat, built of mud bound together with grasses and rootlets and baked dry in the sun, standing 3 to 6 feet high; toward the bounding belts of blue-joint he found at every second step the cylindrical mud chimneys of the crayfish, rising just above high water level; and within and without the blue-joint belt, half way to the highest divides, he found the surface broken into miniature hummocks, each marking the site of a crayfish chimney, and greater hummocks, each marking the site of a muskrat house, both built when the land was wetter than now. Today the lowlands are mostly drained or their superabundant waters evaporated with the gradual destruction of the primitive carpet of grass; the sloughs are mainly converted into pasture land, and some have yielded to the plow; the muskrats are banished and the crayfish driven to the roadsides and the few unreclaimed morasses of the fields and pastures; but the hummocks yet remain in myriads to tell of the gradual conversion of watery waste to fruitful land. (Pl. XIII.)

The slough was a niggard, for it harbored neither beast nor fish and afforded but scant food for the bird. It was the characteristic feature of the vast drift plains when the white man first looked upon them, and the early traveler was fain to wander here and there in a series of great detours to find foothold for himself and his animals. To-day the slough is little more than a name of modified meaning; but even yet the original condition of the land is reflected in the present condition of its inhabitants. The lanes are long, the houses few and widely scattered; the fields are broad and ill tilled because each landowner seeks to possess a whole landscape for himself, and frets because the mile-square sections are too small for his needs and because the roadways laid out on their lines cut his fields into bits; and the land is tilled, the seed planted, and the crop harvested by the power of the horse and the craft of the machine, only guided by the intelligence of man. To-day the traveler finds unwieldy maps on a scale as liberal as that of the fields, and marks his course by schoolhouses (without belfries, for no bell can be heard over the miles from which the farm children gather), low spired churches, straggling villages, and scant peopled cemeteries.

As he journeys westward the tourist crosses the Wapsipinnicon, the Cedar, perhaps the Shell Rock, and generally finds these streams simply enlarged copies of the smaller water-ways toward the eastern margin of the drift plain. But they are skirted by wider flood plains and the alluvial sands are either bound together by the roots of fire-stunted forest trees or blown into shifting dunes; though the dune, like the slough, has commonly yielded to the intelligence of man and is to-day wooded or grassed. Now and then, too, he finds along the river sides knolls and hills, and even considerable tracts of upland, sculptured into the forms of the driftless area, but upon a smaller scale; and he finds these eminences, like the driftless area margin, mantled with loess which looks down in all directions upon the bowlder-charged drift. Sometimes, too, the rivers cut the upland to its base and expose a nucleus of horizontally bedded limestone or shale of the Cedar Valley, and the tourist is surprised to find that the limestone rises as high as or perhaps higher than the level of the circumjacent plain.

Such is the surface of the country over much of Howard, Mitchell, Floyd, Chickasaw, Butler, Bremer, Grundy, Black Hawk, Buchanan, and parts of Fayette and Delaware Counties. It is true that along the Cedar, and to a less extent along the Shell Rock, Wapsipinnicon, and Maquoketa, there are occasional blotches of wooded loess; it is true that along all these rivers there are occasional outcrops of rock, sometimes forming mural precipices of 20 or 30 feet in height; it is true that there are a few loess ridges and a few moraine-like hillocks over the divides between the rivers; it is true that sometimes the drift is thin, with glacier-rounded bosses of limestone (generally the light buff or gray argillaceous limestones of the Devonian) cropping out; but it is also true that throughout these counties the surface is so smooth that the roads run on the land lines with neither cutting nor filling for dozens of miles, and that the engineer locates his railway with far less reference to the topographic configuration than to the township tax and village bonus, crossing summits without cuts and building embankments only to approach bridges.

Let the tourist now begin another journey across the territory, and if he desires to examine the southern extremity of the driftless area, and at the same time to see the drift plain diversified in a unique and anomalous manner, he may well travel in a course nearly parallel with his last; and he can do no better than cross the "Father of Waters" at the pioneer city of the State, one time the "Key City" to the entire Northwest—Dubuque.

Here he finds the great river hemmed between high bluffs but a mile apart, with its eastern waters laving the base of a precipice of brownish gray Galena limestone 160 feet high, with slopes rising from its verge for another hundred feet to rounded summits crowned with the tumuli, temples, and effigies of a prehistoric people; crossing the swift flowing river he sees it ever swirling and eddying over a rough and often rocky bottom under a 4-mile current, and occupying but half its cañon bottom; and on the west he finds a strip of flood plain rising quickly into steep but round topped limestone bluffs 250 feet high, with the city straggling along the narrow shelf at their base for 2 or 3 miles. Recalling the uplands of Allamakee County, where the Trenton limestone caps the highest summits 600

FIG. 2.—Bluffs and bottoms of the Mississippi at Dubuque, looking southeastward. The nearer bluffs are Galena limestone and those in background are Niagara limestone.

feet above the level of the Mississippi, he is surprised to find the same rocks here exposed in the river bottom and only at low water; and his next surprise comes with the discovery that the 20-foot bed of

Galena limestone seen on the upper Turkey River has multiplied in thickness, and forms the whole of the 250-foot cañon walls.

Journeying westward once more, he finds cross-country roads radiating in all directions from the Key City, over hills and through ravines, yet seldom on the land lines; for he soon discovers that

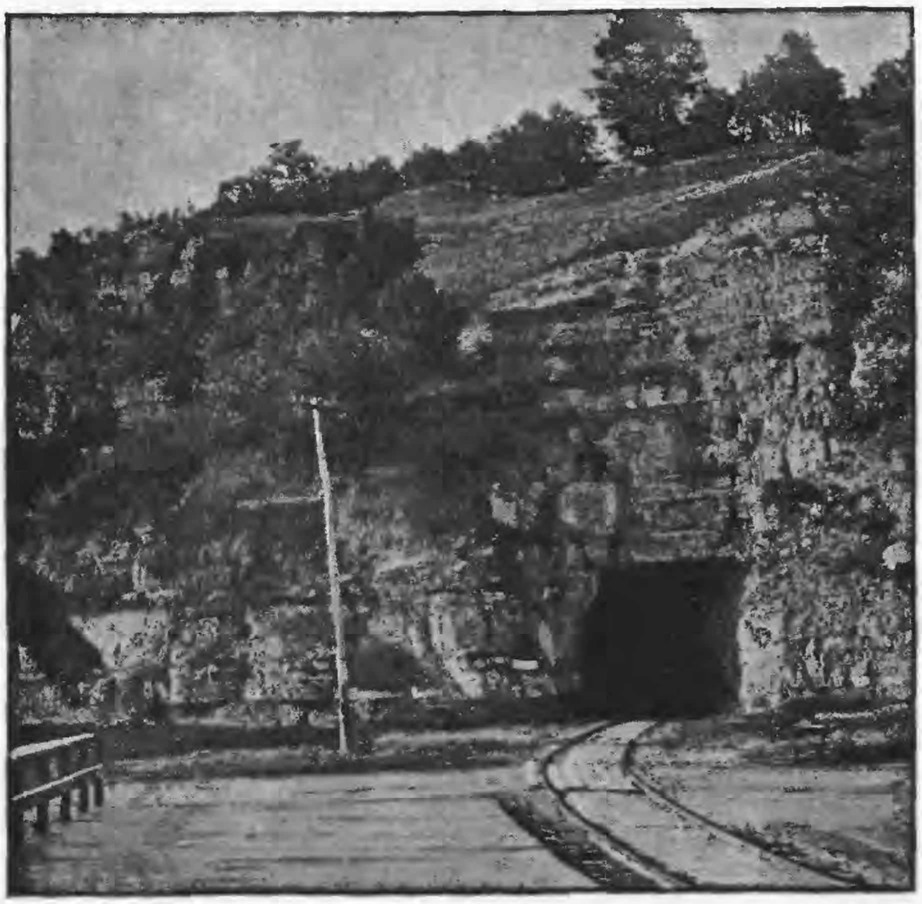


FIG. 3.—Bluff of Galena limestone opposite Dubuque. Aboriginal tumuli crown the grassy swell rising from the verge of the cliff.

although the ravines are as steep sided and labyrinthine and the hills as round topped and many sided, the cañons are but half as deep and the hills but half as high as in the extreme northeast, so that while the roads cross hill and valley alike they are adjusted to the easiest slopes and shortest distances. From the verge of the cañon wall he scans an area of five miles radius, all round topped hills defined by cañon-like ravines; he perceives that the summits of these hills, both at his feet and beyond the rock-bound gorge of the great river, rise to a common plane, and at a second glance sees that the plane is at first gently inclined southwestward, and then rises more rapidly in the same direction in a series of smoothly rounded slopes, unbroken by pinnacle or precipice, to a line of cliffs, salients, and isolated crests, higher and more conspicuous than the immediate bluffs of the Mississippi, though 600 feet higher and half a dozen miles distant from its waters—he looks upon the deeply dissected plain of the rugged Galena limestone, rising through the gentle slopes formed by the clays of the Maquoketa shales (here 125 feet thick) into the bold escarpment of the Niagara limestone, the most conspicuous topographic feature of the State.

As he climbs the river bluffs through Julien avenue or Miners' avenue, which connect the cañon-bound city with the adjacent upland, the tourist finds the massive ledges of Galena limestone on

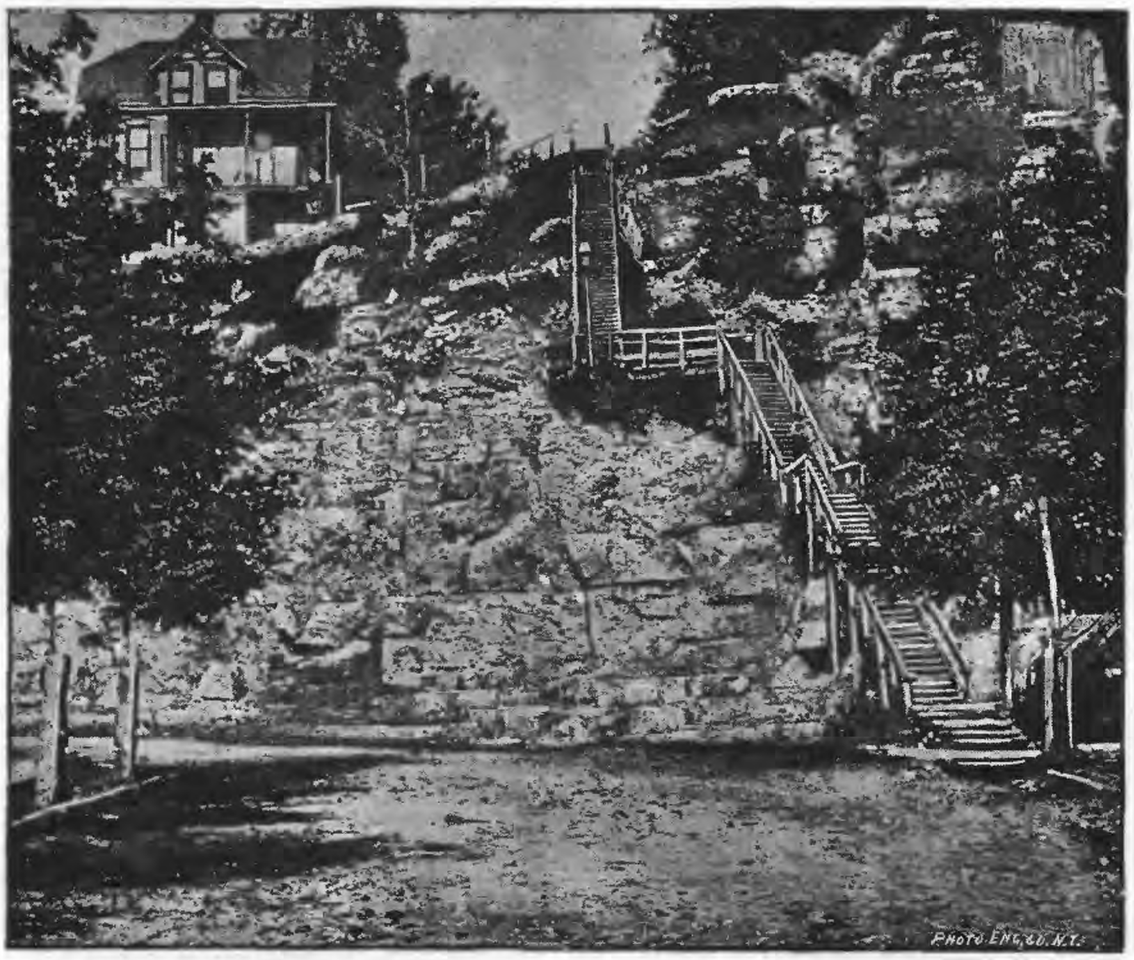


FIG. 4.—A typical bluff of Galena limestone at Dubuque.

either side overlain, first by red brown loam like that above the Trenton limestone in the northeast (and here as there a residuum of rock decomposition), and next by a heavy bed of yellowish buff loam with an underlying gravel bed, sometimes thick and again inconspicuous; and over the uplands to the very base of the Niagara escarpment he notes the same residuary loam and the same loess sheet maintaining the same relation save that the intervening gravel bed thickens westward and that over the gentle slopes of the Maquoketa shales the residuary loam becomes a tenacious red or gray clay. Over all he finds numerous and generally well kept meandering roads, flanked by comfortable and even elegant farmhouses, with church or schoolhouse for every mile: he finds flourishing young apple orchards, and vineyards in plenty despite the rigorous climate, and the hazel, crab apple, cherry, and even the oak, the hickory, the walnut, and other hard-wood trees springing up in every neglected nook and fence row; and he might justly infer from the luxuriance of the arborescent growth and the wealth of the cultivated produce that the land once supported a luxuriant forest long since felled as the eager tiller of the soil wrested the acres from nature's prodigal dominion.

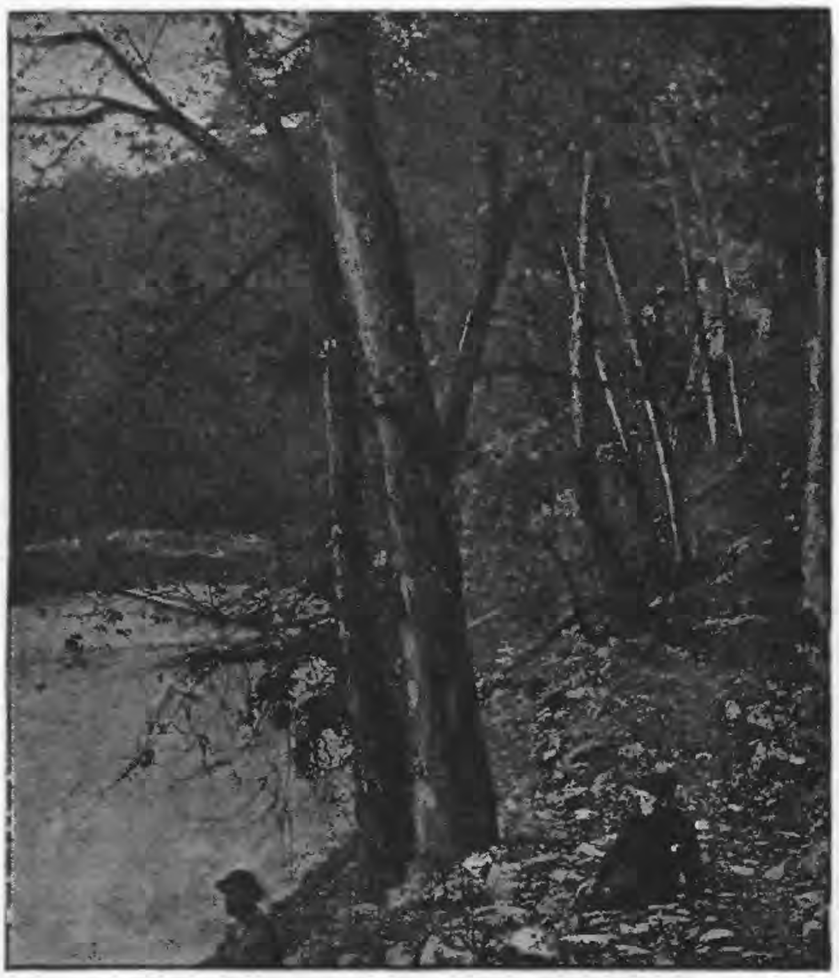
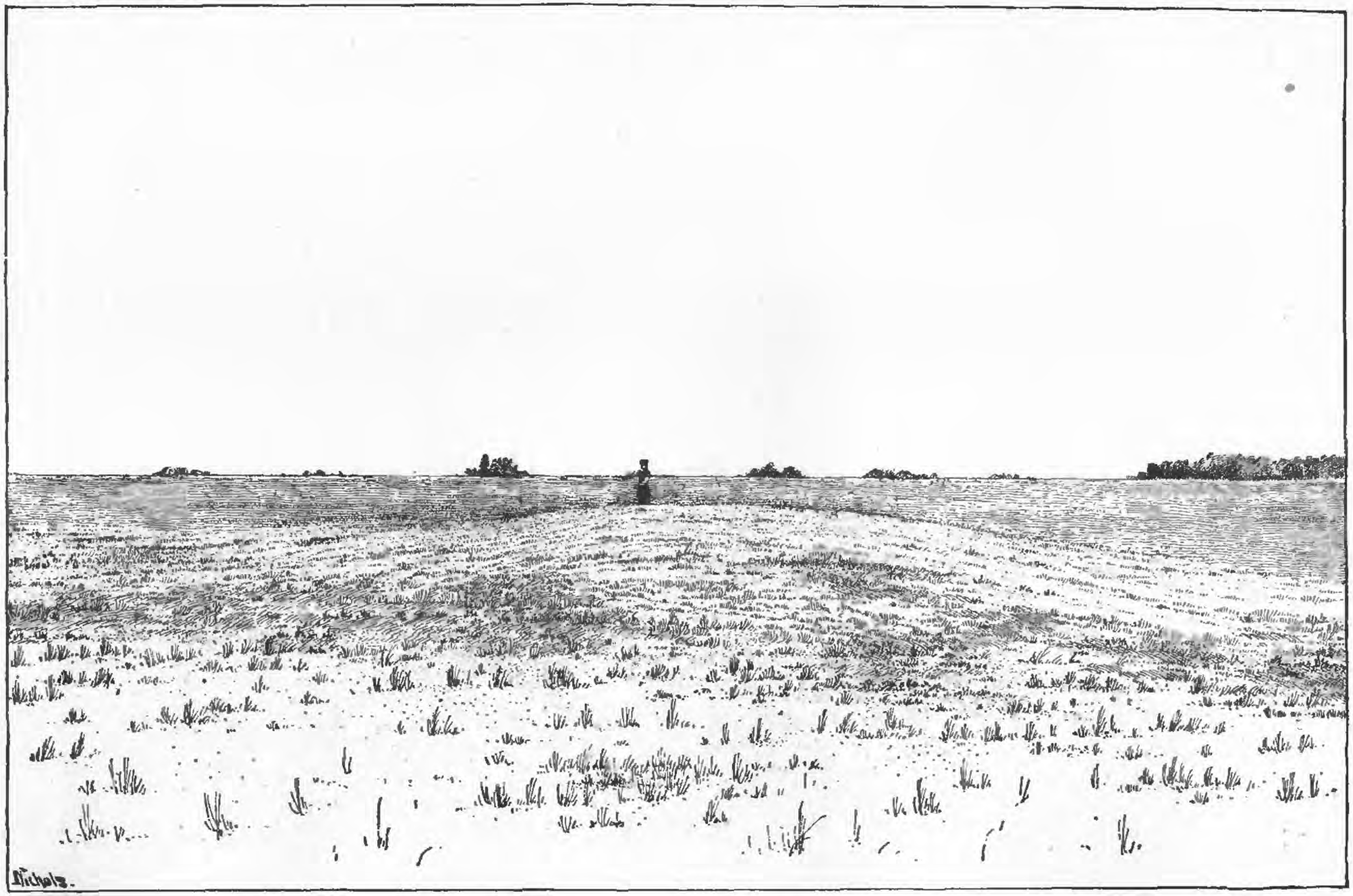


FIG. 5.—Base of a wooded bluff of Galena limestone on Little Maquoketa River.

In traversing the region about the Key City the eye of the stranger can not fail to fall upon odd conical mounds and craters of red earth and stones, dotting the slopes and crowning the crests of the hills, sometimes sparsely scattered, but again a dozen to the acre; wherever he turns, these débris heaps—giant ant hills in form—meet his eye, many old and grass-grown, some fresher, and a few scarcely touched by the weather; and he perceives that they are artificial, and represent an enormous expenditure of human energy. When he stops to inquire of the resident he finds that these are the "diggings" of the lead miner, and that the hills are literally honeycombed by his shafts and drifts; for in the early days, when the Mississippi and Dubuque were the ultima thule of the Northwest, the mining craze ran riot here, and despite recent discoveries in the new West it has not yet entirely subsided. The memory of



PRAIRIE LANDSCAPE, WITH NATURAL (?) MOUND IN FOREGROUND.

her prestige as a mining town is yet vivid in Dubuque. The rude wooden stockade and stone heap erected over the grave of the pioneer miner, old Julien Du Buque, have indeed fallen before the vandal; but he has more lasting monuments in the names of the city and its principal avenue of outlet, as well as of a neighboring village; and the far famed Indian beauty who lured him to the lead

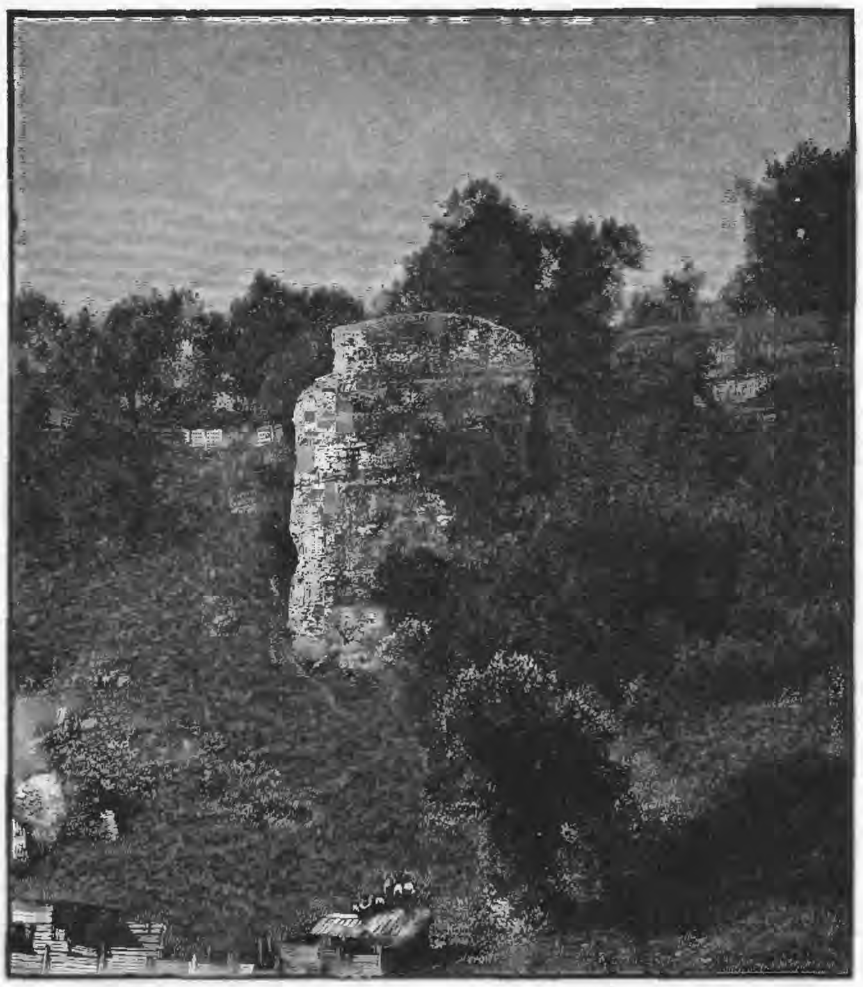


FIG. 6.—A typical erosion form of the Mississippi bluffs about Dubuque.

region is commemorated in the name of a charming lakelet, Peosta, and of another neighboring village. And, just as for decades the ruins of pumps, windlasses, smelting machinery, and other relics of the mining plant will lie along the streams, so for generations the snow-white stalactites and the fantastic stalagmites extracted from the mines will adorn the verandas and lawns of the Dubuquer; and so, too, for centuries the Titanic ant heaps and burrows will mar the smooth crests of the hills.

Wending his way westward. the tourist ascends by a circuitous route the steep slope of the Niagara escarpment, gaining its crest near Centralia, and, turning about, sees before him perhaps the grandest prospect of "The Plains." At his feet lies an embossed map of gently sloping divides and round topped, polygonal hills with margins marked by lines of cliffs, divided by the sharp cut zigzag gorges of the Little Maquoketa and the Catfish in their many branches; ten miles away the surface is cleft by the rock bound cañon of the Mississippi; beyond the great river the gently sloping divides and round topped hills conceal the ravines by which they are bounded and rise to a cuspid plain, stretching away northward and eastward until their summits blend in a level horizon line; but in the hazy blue of the distance this horizon line is broken by two sharp conical swells—the Platte mounds—40 miles away to the northeast in Wisconsin. Toward the east, too, the horizon is broken by the sharply defined cone of Sinsinewa (shown in Pl. XIV), also in Wisconsin and 16 miles distant in an air line. Facing southeastward, a group of conical knobs, Scales Mound and its neighbors, 20 miles and more away in northwestern Illinois, catch his eye; and turning further he sees on the hither side of the river, Table Mound, Hog Back, and half a dozen other salients and isolated knobs stretching from his very feet 15 miles southeastward, to the cañon of the Tête des Morts—all these knobs and salients rising 200 or 300 feet above the embossed plain. To the northward a similar series of salients and isolated buttes fades away in perspective to rise again in the conspicuous dolphin-backed Sherrill's Mound 15 miles distant.

Such is the eastern part of Dubuque and Clayton Counties in Iowa, and much of Jo Daviess County in Illinois, and La Fayette and Grant Counties in Wisconsin, upon all of which the tourist looks down—a single strongly undulating plain, trenched by the Mississippi and its greater tributaries, overlooked from the southwest by the frowning escarpment of the Niagara limestone 250 feet above its level, and guarded by half a dozen outlying knobs of the same limestone.

Turning toward the sunset the tourist once more faces a new land—a land of smooth plains, of low gentle swells in lieu of knobbed hills, of rectangular roads, of direct railways, and of broad plains; for in Clayton, Dubuque, and Jackson Counties the Niagara escarpment is the margin of the driftless area, and the bowlder clays extend just to its crenulate line but fail to pass beyond. True, the margin of the drift plain here is masked by a mantle of loess which, like the deposit everywhere in Iowa, is wooded; the drainage toward the lower plain has cut reentrants and ravines extending a little way into the area of the Niagara limestone, and given its scarp the ruggedness of river bluffs; and so the transition from driftless area to drift plain is more gradual than in the north.

Continuing his journey the tourist finds himself first upon loess, occasionally cut through by ravines, wagon roads, and railways, and exposing the drift at its base; and he finds that where the loess

A RECLAIMED SWAMP.

is 10 or more feet in thickness it exhibits a topography of its own—a plexus of short, steep slopes, and deep, meandering ravines, simulating in miniature the characteristic round topped, polygonal-knob configuration of the driftless area, and quickly and justly infers that this peculiar topography is an infallible proof of the presence of the deposit. Here in the western part of Dubuque County, too, he detects certain other external features of the loess. He observes that the apple, the vine, and all small fruits grow well upon it, and that unless cleared by the farmer it is everywhere wooded, while the adjacent bowlder-marked drift areas are obstinate under the treatment of the horticulturist and are naturally woodless, so that surface bowlders and forest covering do not go together. He finds also that where the slopes are not so steep that the soil washes away, its fields are fertile to the extent that its area may be traced by capacious barns and overflowing granaries, sleek cows and spirited horses, commodious residences and elegant schoolhouses, high steepled churches and extravagantly monumented cemeteries—for a beneficent soil makes prodigal farmers.

A few miles west of the prominent Niagara escarpment the tourist becomes conscious that he is descending in altitude, and observes that some streams turn away from the Mississippi, and that the loess is thinning; and near the village of Epworth his route carries him from the loess area upon a low-lying, bowlder-dotted plain of drift. Here he discovers another characteristic of the loess of this part of the State, i. e., its habit of avoiding low-lying plains and seeking eminences. He finds, moreover, that its western margin is curiously lobed or digitate, extending west-northwestward in ridges, or lines of isolated hills, separated by tongues of drift which invariably lie at lower levels; and should he wander long about the common margin of drift and loess, he would now and then find an elliptical, flat bottomed basin of bowlder-dotted drift completely surrounded by the loess upland, and drained in one or more directions through narrow gaps in the encircling rim of loess.

Journeying westward from Epworth he traverses a ridge of loess extending to the North Maquoketa, a dozen miles away, and skirting the southern side of a low-lying lobe of drift 10 miles long and 3 miles wide. From the summit of this ridge near Farley, 600 feet above the Mississippi at Dubuque, he looks northward over the bowlder-dotted drift plain, here so level that at the time of first settlement half of it was impassable slough, to a less definite ridge of sharply ravined and erstwhile wooded loess, and over its crest catches the gently swelling summits of half a dozen more such ridges gradually rising to the Niagara escarpment within two or three miles of the Turkey; and if the air be clear he will catch the glint of sunlight on the roof of the "Church of the Holy Cross," near Pin Oak, and on the higher spire at Liberty, each 12 miles away as the crow flies, and almost upon the verge of the escarpment. Facing westward he surveys the drift lobe stretching west-northwestward to the North Maquoketa, where it is nearly cut off by the loess hills and sand dunes, as well as the belt of hard wood forest, skirting that stream; and

FIG. 7.—Middle latitude prairie landscape—Farley. Drift plain in foreground; loess ridge in right background; with lower swells of loess in left background.

through the vistas of clearing in the forest belt he sees the drift lobe expand quickly into the broad prairie land already traversed a hundred miles northwestward. Turning to the southward, he scans a stretch of loess hills cleft by steep sided but flat bottomed ravines—the hills hidden beneath luxuriant crops and crowned by ample homesteads, and the ravines lined with sward through which many bowlders peep—inclining to the southward to, and again beyond, the North Maquoketa. And if he tarried long and wandered far in this section of the State, he would find that these landscapes, with their mingling of low-lying drift lobes, loess ridges, and broad loess uplands cut through to the drift by wide branching ravine systems, represent fairly considerable portions of Fayette, Clayton, Delaware, Dubuque, Jackson, Jones, Linn, Cedar and Clinton Counties.

Continuing his journey southwestward from Farley, the tourist finds the ravine-cut loess tract extending to the North Maquoketa near the village of Rockville. Here he finds the stream confined in a narrow gorge of Niagara limestone rising in precipitous walls 40 or 50 feet, and then in gentle slopes to the loess-crowned upper bluffs 150 feet above its waters; and on reaching the crest of the farther bluffs he sees before him a landscape, common enough in Northeastern Iowa, but unlike any that he might find beyond the limits of that territory—a relation between river and upland without parallel elsewhere on the globe. Glancing north and south he perceives that the river skirts the flanks of a rock-ribbed, loess-mantled, and forest-covered plateau, generally keeping within it, but occasionally breaking through its crenulate escarpment to the lowland beyond, only to reenter the upland within a mile; to the westward he sees a level, bowlder-dotted prairie (broken by occasional rounded bosses of Niagara limestone, elongated swells of loess, and steep sided moraine-like hillocks) 50 to 150 feet lower than the river bluffs and stretching away for 10 miles to a line of wooded loess hills like those upon which he stands. Yet he looks in vain for the river draining this broad valley; for the valley is the divide, and the waters part within it and flow through the bounding hills in gaps but a few feet lower than its highest levels to rivers occupying narrow gorges in the uplands.

Traversing this anomalous divide, the tourist observes as he approaches Hopkinton that the drift passes beneath loess, and at the same time that the surface rises rapidly into a broad, wooded ridge; and climbing to its crest he sees at his feet the Maquoketa, flowing in a rock-bound gorge similar to that of the North Maquoketa. He may perchance find himself opposite a tributary ravine in the farther bluffs, and see that they, too, are but a narrow line of loess-capped hills, bounded beyond by a low drift plain ("The Bay" of the resident) whose surface rises westward in the almost imperceptible undulations of the bowlder-dotted drift prairie of this latitude. He justly estimates from the sluggish current of the streamlets draining it that the bottom of "The Bay" rises scarce 20 feet above the river, while its own bluffs are eight times as high, with mural precipices of Niagara limestone rising halfway to their summits; he perceives that loess and forest alike terminate at the farther base of the river bluffs; and looking through the vista toward the southwesterly horizon he sees a drift-floored valley, the homologue of that which he has just traversed, sweeping in undulations too low to conceal house or orchard tree to another line of wooded bluffs 15 miles away.

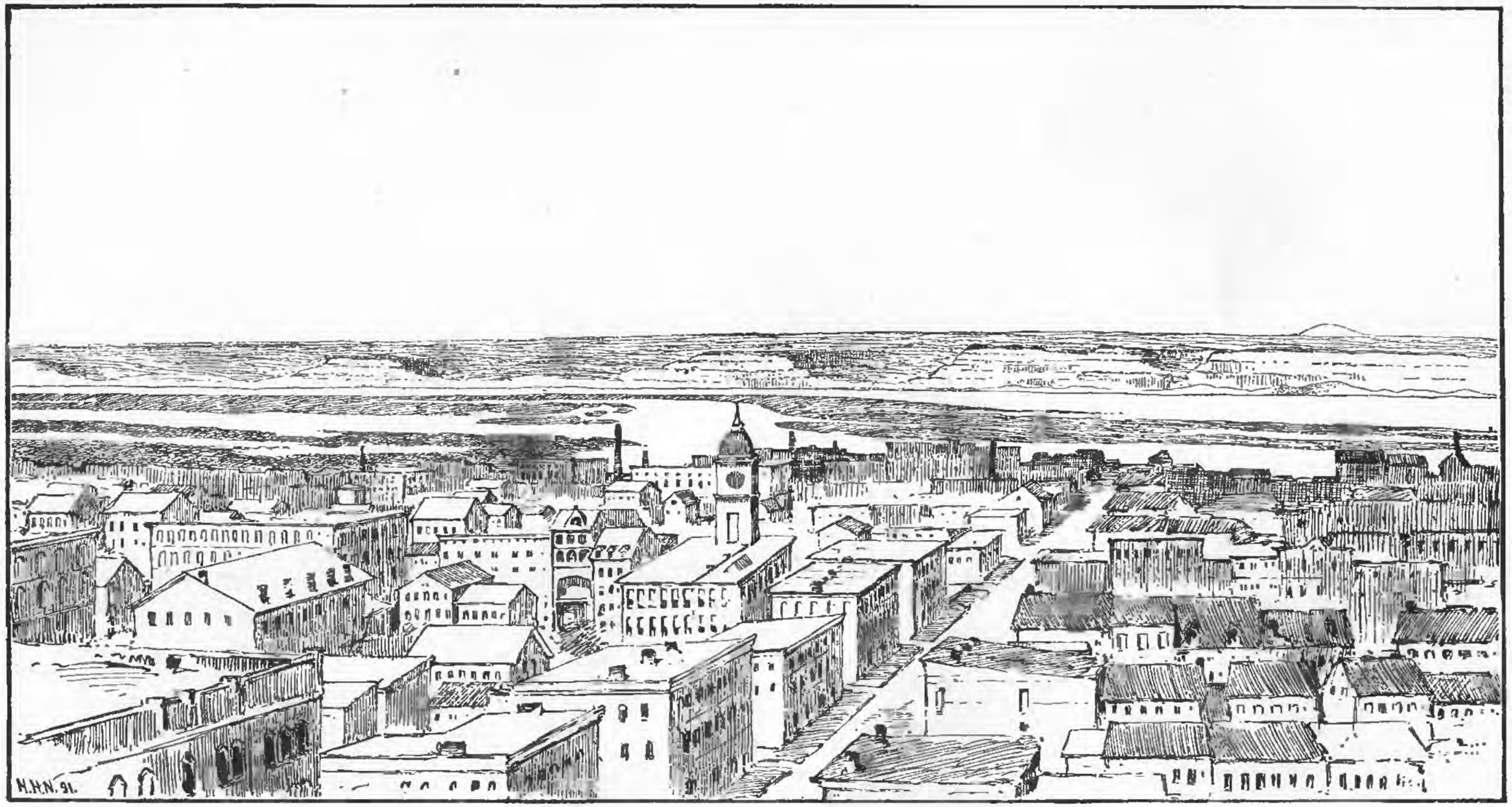
Descending from the river side to the second paradoxical divide, and looking back as he recedes from the seemingly inverted valley of the Maquoketa, he observes that although it appears regular and even from a distance, the ridge is really broken in plan by a series of tongues or slender salients jutting out toward the west-northwest on its western side and toward the east-southeast on its eastern side, and that these are separated by low-lying lobes of drift like those of Dubuque County; every tongue of loess being wooded, and every lobe of drift bowlder-dotted. And, however far he diverges to right or left, he never finds the common boundary of drift and loess a direct line, but always a serrate or digitate one; and a constant law governs the extension of the digits. In Fayette County the loess fingers extend N. 45° or 50° W. In northern Delaware County they extend N. 50° to 60° W. In western Dubuque County they extend N. 60° or 80° W. In southern Delaware County and in Jones County their direction is about the same. In Scott County their extension is sometimes within 5° of exactly westward, and their direction becomes more and more northerly in passing through Cedar, Johnson, Linn, and Benton Counties, until in Tama County it becomes almost exactly northwestward. Neither does he find forest tree and bowlder in company; where the one stands the other lies far beneath the surface, and where the other lies the first seldom takes root.

Continuing his journey, the tourist finds the surface, like that of 100 miles northward, flat, sometimes to marshiness, dotted with bowlders 5 or 10 or 20 feet in diameter, once grass-carpeted, but now furrowed by the plowshare, and reticulated by rectangular roads and hedges and commanded everywhere by artificial groups of slender poplars surrounding well kept and sometimes luxurious farmsteads; but he finds the plain, unlike that of the north, faintly diversified by a low, inconspicuous ridging of the surface parallel in direction with the loess digits, and now and then more strongly diversified by a similar but higher and shorter ridge, capped with loess and crowned by a natural grove perhaps no more extensive than the artificial one surrounding the neighboring farmhouse. These loess-capped eminences, sometimes elongated to ridges miles in length, sometimes shortened to elliptical hills, are sui generis; they are unknown elsewhere; and here they go with paradoxical rivers and anomalous divides. Let the tourist follow the aborigines of the Dakotan stock, who long ago christened them *paha.*

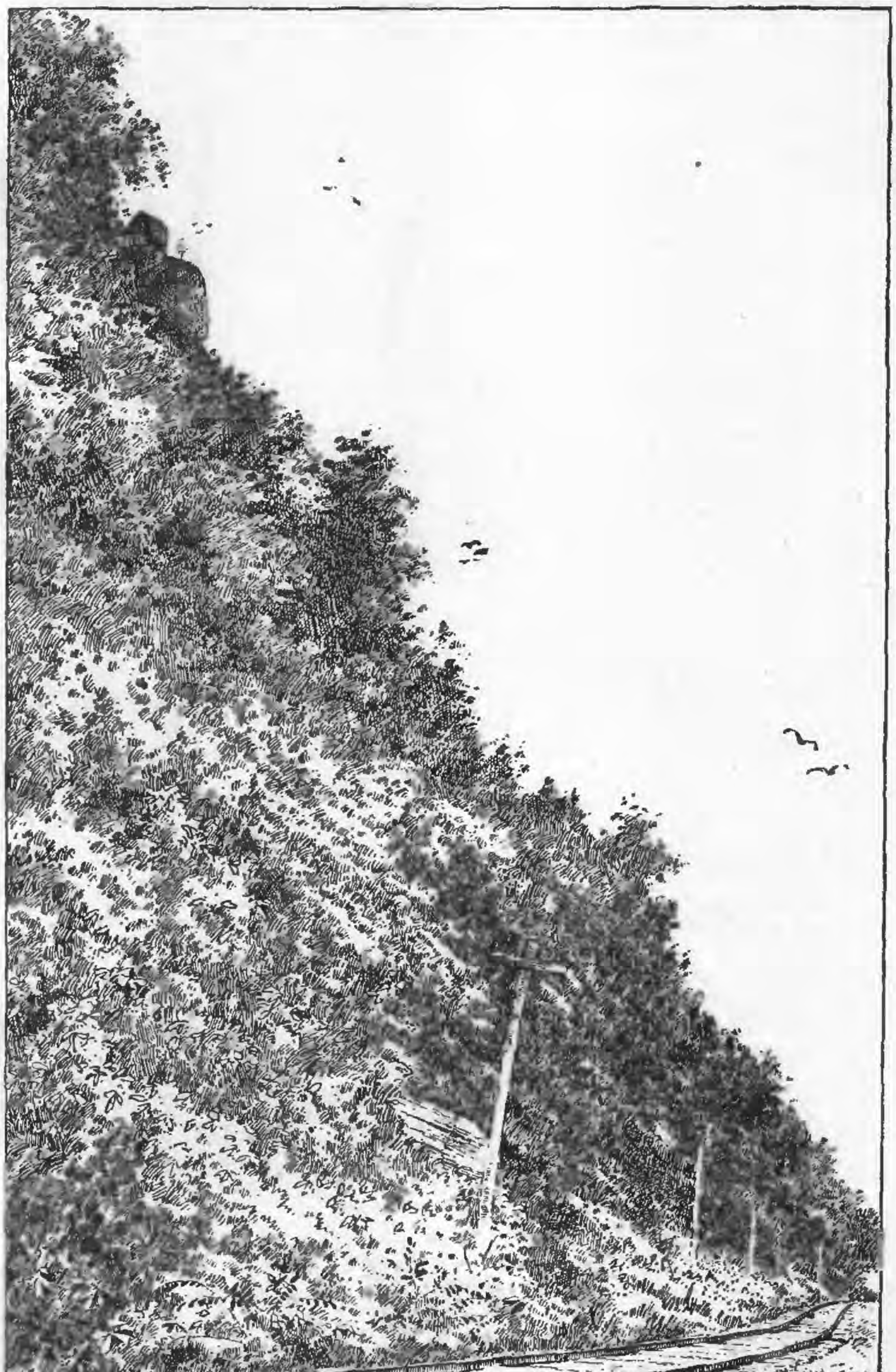
Reaching the farther side of the plain, he finds himself upon another ridge, cleft in its axis by the cañon of the Buffalo, as the last was cleft by the Maquoketa, and in the cañon sides catches sight of cliffs of Niagara limestone, sometimes rising to the level of the drift plain; and over the crest of the cloven ridge his vision easily sweeps the low-lying divide between the Buffalo and the Wapsipinnicon to the wooded bluffs of the latter river five miles away.

Crossing the intervening plain to the Wapsipinnicon ridge, the tourist is not surprised to find the river dividing it and confined in a rock-bound gorge whose precipitous walls rise almost to the level of the prairie; for in this part of the State all the rivers seek the upland and avoid the lowland. Descending into the gorge between Paris and Central City he might observe the cherty buff limestone of the Niagara passing beneath the gray limestones of the Cedar Valley midheight of the bluffs; or if he crossed a dozen miles below (near Anamosa), the most extensive quarries of the State in the former; or if a dozen miles above, rugged cliffs of the peculiarly brecciated limestone beds of the latter. And over the cloven ridge, down its steep inner slopes to the water's edge, and down the gentler slopes toward the prairie land, spread the varied greens of luxuriant hard wood forest foliage.

If the tourist tires of the vernal verdure, of the green and gold of the midsummer harvest, even of the russet browns and grays and the kaleidoscopic glory of the autumn, let him tarry here for a time; for it is in winter, when the foliage is cast and the surface of the land uniformly toned by a mantle of snow, that the characteristics of this land of topographic paradoxes stand out most strongly. Let



GORGE OF THE MISSISSIPPI AT DUBUQUE, LOOKING SOUTHEAST.



WOODED BLUFF OF GALENA LIMESTONE, NEAR BUENA VISTA.

him then return at Christmas time; and let him climb once more the southern crest of the ridge cleft by the Wapsipinnicon near Central City.

Facing the winter sunset, he surveys a striking scene, representative of the territory in which he stands, but unique as regards the world at large. At his back he hears the rippling river murmur a lullaby, interrupted anon by the harsh crash of crushing ice as the floating cakes grind together; from his feet the soft contoured slopes fall steeply to the river side and more gently toward the west; and before him lies a sea of snow so smooth that the shadows cast by the belated traveler stretch out in grotesque perspective until faded by diffusion of light—a frozen sea, flecked with wakes of dark shadow behind each great bowlder, fretted here and there with long, low rollers a mile apart and high as the deck of a vessel, and again broken by higher but shorter swells, gracefully curved as the bending backs of giant dolphins, though perchance forest-fringed; and the whole so smoothly spread out in low relief before him that he might measure distances by the fences of the mile-wide fields. As from a promontory of the veritable ocean, he notes the illusory rise of the foreground toward the horizon; in the middle distance he observes first the church spires, then the housetops, and finally the 4-foot fences rise above the horizon and stand out in relief against the sky; looking still further he sees the curved earth conceal first the fences, next the lower stories, and then the church windows and walls, as small craft and the hulls of ships are concealed in the offing at sea; and finally, glimmering through the haze of 20 miles, his eye catches the farther shore of the sea of snow-covered prairie land—the forest-crowned loess bluffs skirting Cedar River. Then the shadows quickly lengthen, the disk of the sun drops behind the horizon, the dusk quickly deepens, and snow-plain and woodland, bowlder, dolphin-back, and church spire, blend in misty gray, and relief is lost.

Such is the winter landscape in much of Linn, Jones, Delaware, and Benton counties.

But the mantle of snow conceals the rocks and soils and masks the culture of the region; so the tourist would do well to abandon winter work and await another summer.

Resuming his journey at the Wapsipinnicon ridge, the visitor traverses another paradoxical divide to the Cedar, which he finds confined in a broad valley excavated in an indefinite upland, the valley being largely lined by alluvial sand; and now and then at the bases of the bluffs on both sides of the river he finds the waters washing cliffs of the earthy, ill bedded limestones of the Cedar Valley; and he finds the river itself a wide, shallow stream rippling over white sand and meandering through a cottonwood-clothed flood-plain, perhaps a mile in width, a flourishing city of manufactures and railroads a few miles below, and a great bend a few miles above where the river turns out of a low drift basin like "The Bay" at Hopkinton and into an elevated rock-lined and loess-covered plateau—for the larger like the smaller streams here seek the highlands.

Crossing the river a few miles above Cedar Rapids the tourist looks from its bounding bluffs upon a succession of ridges like those crossing the Wapsipinnicon-Cedar divide, but higher, closer, and more generally loess covered and forest crowned;[1] and as he journeys onward he perceives that these ridges stretch down from the high prairie toward the northwest, in ever increasing width and height and depth of loess-covering, until they approach Prairie Creek, where they terminate so abruptly that the creek scours their bases, while on the opposite side of the creek a low lying drift plain extends for miles as do those of the northern counties save that few bowlders appear upon it—for Prairie Creek differs from the Maquoketa, the Wapsipinnicon, and the Cedar, in that it has only one high bank, the other being low and level. But 5 miles south of Prairie Creek this surface rises rapidly into wooded hills—the elevated loess ridge followed by the Iowa River.

Tarrying for a day on the Cedar-Iowa divide, the tourist finds the continuous loess area frequently flanked by graceful, dolphin-backed hills like those diversifying the surface of the plain between the Cedar and Wapsipinnicon, but higher and larger, reaching 75 feet in height and a mile in length, and here as there built of loess rising sharply from the drift plain and generally forest-crowned; yet when he pauses to examine the gullies alongside the road intersecting such a hill he finds the loess passing down into sand, generally fine, brown or grayish, and indistinctly stratified; and beneath the sand, but rising well above the level of the adjacent prairie, drift clay charged with pebbles and bowlders. And if the road cutting be deep enough, or if he is so fortunate as to find a well in process of excavation, he may ascertain that the drift clay itself reposes upon a nucleus of Paleozoic rocks also rising as high as or higher than the prairie level. Perchance he may notice, too, that the rocks approach nearest the surface in the northwestern extremities of the paha so that the loess is heaped up about and in the lee of buried crags, as driftwood gathers about rocks projecting above a torrent. If he happens on an open well, half dug, in the adjacent prairie, he may discover too that the bowlder-charged clay is not a unit—that the drift sheet of great granite bowlders and buff color forming the surface is but 5, 10 or perhaps 20 feet thick, and that it rests on an ancient soil, supporting stumps, filled with rootlets, and crowded with crushed

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[1] Illustrated in the hypsographic map of a representative topographic area forming Pl. XLIII.

and battered logs, knots, and twigs of coniferous trees; and if he awaits the completion of the well he observes that this old soil passes down into a thicker drift sheet of smaller greenstone bowlders and blue color, which is gravelly and water-bearing toward its base. For here, as in nearly every part of the drift plain in Northeastern Iowa, there are two glacial deposits with a forest bed between, a discontinuous mantle of loess above, and a gravel bed lying on the Paleozoic rocks below.

The tourist may wander widely in the land of the paha, the hill-bound river, and the valley divide, yet he ever finds the surface (save among the higher river bluffs) reticulated with land-line lanes of wire in the north and osage orange in the south, with here and there a hedge of willow so rank of growth that the branches meet and mingle above the 60-foot roadway and transform the lane into a dank, dim-lighted aisle; he never escapes the hourly scream of the passing locomotive on the frequent railway; he finds the paha cleared of the indigenous forests and given over either to fruitful orchards and vineyards, or to scant peopled but richly monumented cemeteries; and he finds the intermediate prairies claimed by the plow and sparsely dotted with farm-houses, with a village every seven miles. Luscious fruits come from the paha and river bluffs, and grain and stock in abundance from the prairies; and wealth comes to the farmer and villager. A by-product of the smiling fields and fecund orchards is intelligence; and so the land of the paha sends many representatives to the State University, supports divers other educational institutions, distributes teachers among other counties and states, supplies the bench, the bar, and the pulpit even far beyond its own limits, furnishes lawgivers for the State and the Union, and thus makes an impress on the intellectual development of the century.

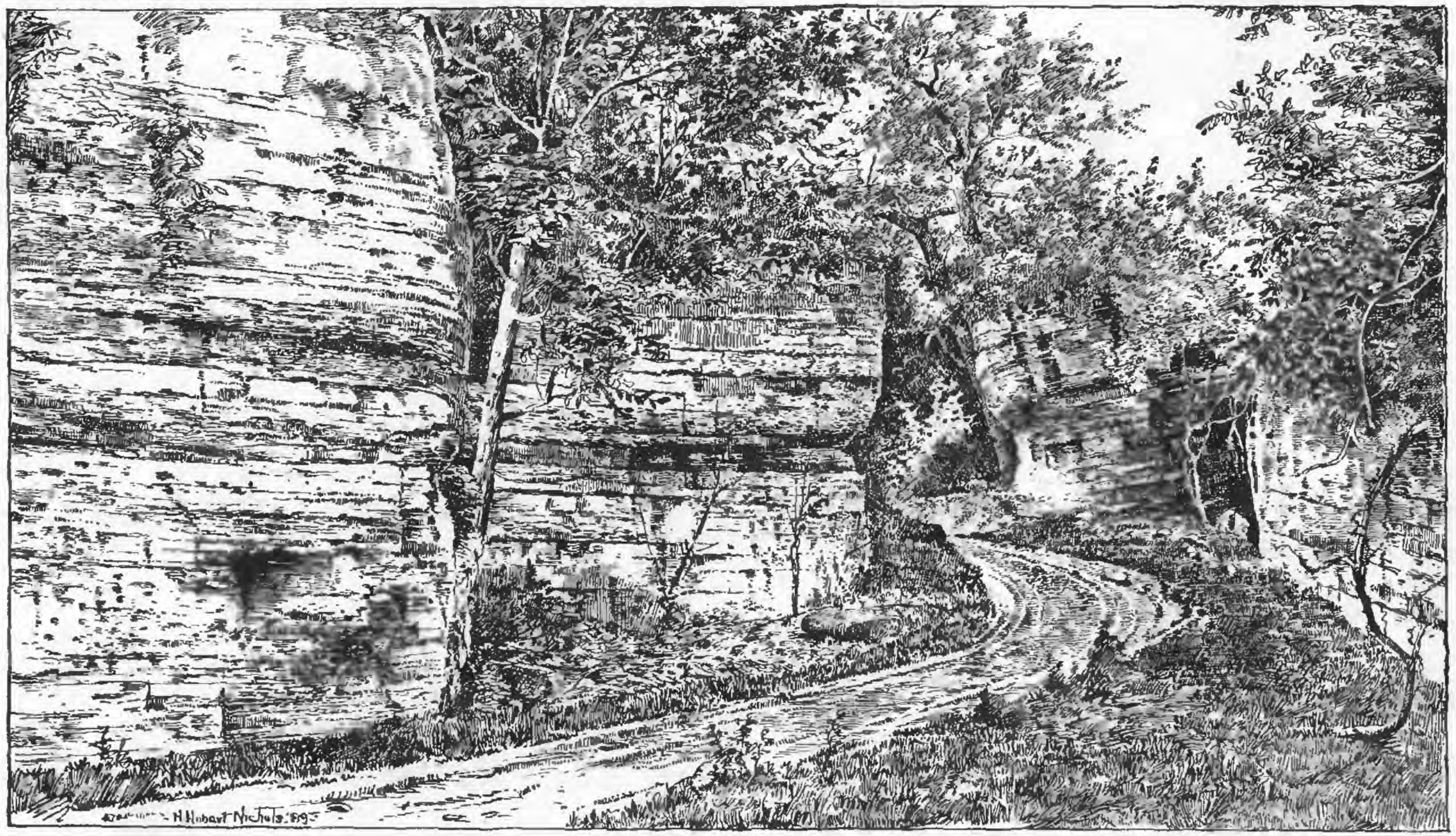
Such are the counties of Dubuque, Delaware, Buchanan, Black Hawk, Tama, Benton, Linn, Jones, Clinton, Scott, Cedar, and Johnson, in whole or in part.

But let the tourist return to his journey. Leaving Prairie Creek five miles behind him, he ascends the upland of loess to which the drift here gives way. On reaching the summit of this upland he finds that the Iowa River skirts its southern side, so that the farther crest is narrow and broken, while the hither crest is broad and its minor configuration distinct from that of the loess plateaus along the more northeasterly rivers or in the driftless area. There are steep-sided ravines in plenty, and he infers from their depth that the loess is 30, 40, or 50 feet thick; he perceives that the whole ridge is crenulate as to margins and dissected as to interior by such ravines; but he finds the interior divides truncated, the marginal hills no longer rounded but flat topped, and the central mass of the ridge a uniform plain so level that the surface is imperfectly drained 50 yards from the verges of ravines. And on surveying carefully his surroundings he perceives that the plain surfaced ridge, the truncate divides, and the flat topped hills are all nearly the same height (diminishing slightly southward), and that their summits fall into a plain as smooth as the surface of a quiet lake; he sees that the hills, divides, and ridge must be remnants of a broad tract, once continuous and level, but now tilted slightly southward and carved by creeks and rills into a plexus of narrow valleys, V-shaped ravines, steep hillsides and flat hilltops.

Descending the southern margin of the loess upland, the tourist overlooks the broad flood-plain of black alluvium through which the Iowa River meanders, and notices that the plain is diversified by crescentic troughs and low bars and sand spits, testifying to repeated changes in the course of the river; he may catch a glimpse of a quarry of brown sandstone (an outlier of the Coal Measures) half way down the northern bluff; and he can not fail to notice that half the Iowa River here flows through an artificial canal 7 miles long, nor fail to see the seven picturesque villages of the curious German religio-social community of Amana—for here these communists of odd customs and strange costumes have cleared the land of forests, have converted a fertile bottom-land and its bounding hills into one of the finest farms in America, and have built mills and factories, and diverted the river to drive them. But this is only the largest of the many fine farms of the Iowa bottom and the adjacent plains.

Crossing the river and ascending its southern bluffs, the traveler finds himself upon a nearly continuous ridge of loess (or of the sand which underlies it) reposing upon pebbly drift clay so thick that he would barely find its base did he bore 300 feet; and before him sees a plain, inclining gently southward and diversified by ravines, at first shallow but gradually deepening toward the south and southeast—a plane as perfect as that on the north side of the river, like it inclining gently southward but tilted up at its northern extremity into the Iowa bluffs, and like it devoid of bowlders on the surface because mantled with loess; a plain unlike those of drift, because the irregularities of the drift plain are embossed, while here the irregularities are carved. Journeying over this plain he sees as he approaches English River that the surface becomes more and more broken by the deepening ravines, that the loess is no longer separated from the drift by an intermediate bed of sand or an unconformity, and that the two deposits intergraduate so completely that he would find himself at every section unable to say where the one ends and the other begins; he observes that the loess does not here seek eminences and avoid depressions as in the northeast, but that it is a continuous mantle, thinnest on the hills and thickest in the valleys; and he sees, too, that this low-lying phase of the loess is seldom wooded over

INNER CAÑON OF THE MISSISSIPPI AT DUBUQUE, LOOKING SOUTHEAST.



DEVIL'S TOLL GATE NEAR BUENA VISTA.

the broad divides formed by the sculpturing of a once continuous plain, but that the forests generally seek the sides of the ravines and the bottoms of the valleys where the loess and the drift are intermingled. But he finds the commodious farm buildings, the fine orchards, the frequent school-houses and churches, and the blooded cattle and horses that tell of fertile fields.

Such are Jasper, Poweshiek, Iowa, and parts of Johnson, Marshall, and Tama Counties.

If the tourist now looks over his record of altitudes, he finds that within the first 10 miles of his journey southwestward from Dubuque he ascended 550 feet; and that though he crossed the rivers at right angles to their courses, he then descended 350 feet in the 40 miles thence to the Wapsipinnicon, 100 feet more in the scant 20 miles to the Cedar, and another 100 feet to the Iowa; and he may be impressed as much by the fact that the rivers flow at right angles to the general slope of the surface as by the fact that in portions of their courses they avoid valleys and lowlands and flow in the axes of ridges or through uplands.

To completely familiarize himself with the general features of Northeastern Iowa, the tourist would be wise to make another but briefer journey across the southeastern portion of the territory from the Mississippi to the Iowa; and he would do well to commence his journey in the extreme southern angle of the driftless area.

Approaching the great river from the east at Savannah, he finds at low water a meandering main channel half a mile wide, and a network of interlacing bayous and sloughs intersecting an alluvium-lined flood-plain, 3 miles in width above the city and below it expanding into the broad savanna from which the city takes its name—the northernmost of the once periodically flooded but now levee-protected intervales skirting the lower Mississippi and affording the richest source of the cotton, corn, and cane of the South. But if he comes during the vernal freshet or "June rise," he finds the 7-mile valley occupied by a single river, sluggish over shoals but a boiling torrent carrying destruction in its course through the main and minor channels, washing the very bases of the bounding bluffs with its muddy waters. The eastern bluffs rise in steep but seldom precipitous faces 150 feet above the current, exposing heavy bedded Niagara limestone toward their summits, which are capped with friable, earthy loess and crowned with forests.

Crossing the river he finds the village of Sabula—at first a wooding station for the Mississippi packets, but to-day the site of a bridge across the Mississippi and the terminus of a railway or two—located on what was once a sand-bar but is now a spit rising just beyond the reach of freshets, alongside the main channel, but inclining gently away from it to the bases of the Iowa bluffs, a mile distant. He finds the village connected with the higher lands toward the west by a wagon-road causeway a mile long and by lines of trestle work for the railways, with the depot set on stilts, 20 feet above ground in autumn, but just above the floods of spring; and he finds the western bluffs a single mural precipice of heavy bedded Niagara limestone 150 feet high and stretching north and south along the river for 5 miles, with stunted cedars clinging in its crevices and at its base a steep, wooded talus occasionally breached by a spring-formed amphitheater exposing in its sides the blue shales and clays of the Maquoketa. As he ascends to the verge of the bluffs through some narrow defile, he finds them capped with just such earthy brown loess as that developed on the east side of the river; and as he surveys the upland he observes that the same deposit mantles hill and dale everywhere save along erosion lines, and that it bears a scant pebble bed at its base.

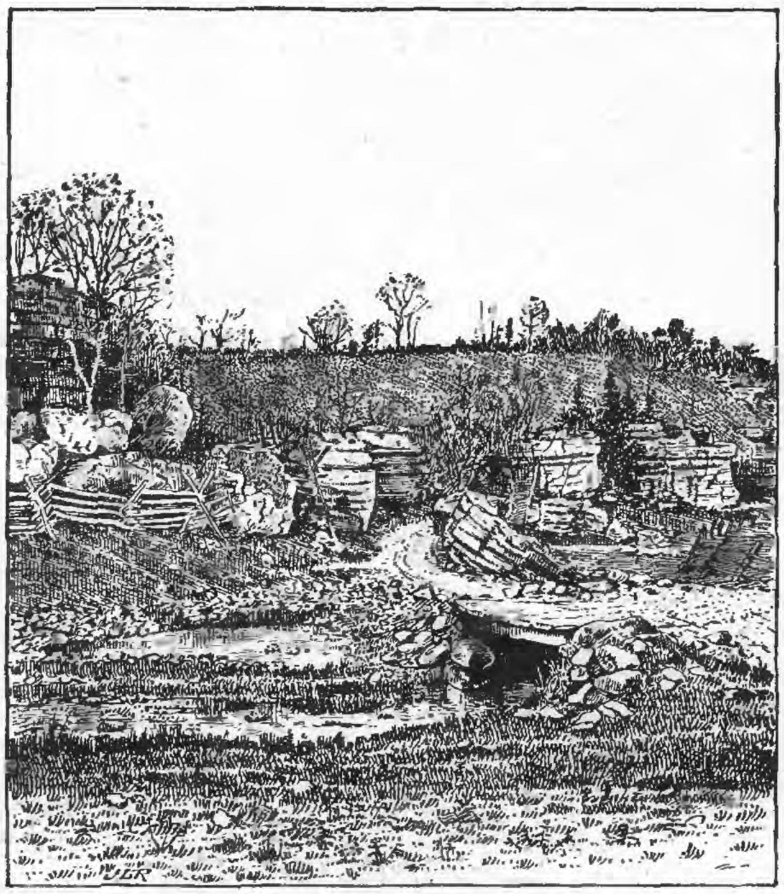


FIG. 8.—Typical landscape of the drift margin, showing rounded summits and precipitous bases of hills.

Four or five miles west-southwest of Sabula the tourist finds himself upon a strongly undulating plain cleft by tortuous ravines, once wooded but now transformed into fairly fertile fields, reminding him of the country west of Dubuque and in eastern Allamakee County, though the relief is lower. But looking west and southwest he notices that the hilltops become more and more smooth and gracefully curved, then truncated, and finally almost flat-topped; and seeking the base of the everywhere prevailing loess in the roadside gullies, he finds now and then a handful of pebbles, or perhaps even a 15-inch bowlder of granite or greenstone from northern Minnesota or beyond; yet he finds the ravines as deep and rugged and nearly as free from erratic débris, and the lower slopes of the hills as steep and craggy, as if the ice-plow had never pressed upon the hilltops. (Pl. XIX.)

Ten miles more of journeying over hills not quite high enough and ravines not quite steep enough to deflect the roads from the land lines, but high enough and steep enough to render travel slow and laborious, carries the tourist to a point on the upland southeast of Preston from which he may obtain a far-reaching view. Toward the east his eye wanders over smooth ridges and hills, ever growing sharper and steeper toward the great waterway, and conspicuously interrupted five miles away by the valley of Elk River; and he is surprised at the width of the valley of the pygmy river—unless, indeed, he noticed, in crossing its headwaters, that along its line the rocks ridge upward into a monocline, low yet notable in this section of horizontal strata, that the stream has cut through the limestone to the soft Maquoketa shale, and that the bounding cliffs have receded through the undermining of their bases. Looking northward he sees the smooth topped hills stretching away from his feet and gradually growing sharper in the distance as toward the east; his eye follows their gradually sharpening contours to the very verge of the Mississippi bluffs at the mouth of the Maquoketa, 10 miles away; he traces the irregularly meandering cañon of the Maquoketa, 150 feet deep and half a mile wide, from the gateway in these bluffs nearly to Preston; and beyond it he might scan the undulating plain for a dozen miles, and even detect the gradual retreat of the Niagara escarpment from the Mississippi bluffs and its division into salients and isolated knobs toward Bellevue. Turning farther to the westward he discerns a green ribbon of tree tops peeping through the undulating plain, and marking the narrow, meandering gorge of the Maquoketa, cut down so sharply that, were it not for the trees, he might fail to see it until within rifle-shot of its waters. But he can not fail to be impressed by a broader and more conspicuous gorge leaving that of the Maquoketa at its elbow near Preston, sweeping southward within a mile of his feet, and stretching away toward the Wapsipinnicon until lost in the distance—an alluvium-lined, rock-bound cañon, broad, deep, and steep-bluffed as that of the Mississippi, capacious enough to accomodate the Amazon, but without river, brook, or even rivulet between its highest bluffs five miles to the southward; the great channel occupied by the swollen Mississippi during a part of the ice period and abandoned as the ice withdrew. Looking westward beyond the abandoned channel he surveys a diversified landscape of round-topped and loess-capped bluffs rising into a half-wooded upland, partly drift prairie and partly loess hills, much like western Dubuque County, though ridged like the low-lying divide between the Cedar and the Wapsipinnicon. Looking southward he sees the round-topped hills upon which he stands gradually smooth into a drift plain of long, low rollers with an occasional dolphin-backed paha, capped with loess and crowned with forest, rising above the general surface. (Pls. XX, XXI.)

Tarrying an hour to examine more closely the hills and the deposits immediately about him, he finds first that the residuary clays of the Driftless Area are generally absent and replaced by a peculiar drift, largely of local chert from the Niagara limestone, but partly of crystalline pebbles from the far north, overlain by a mantle of loess with its basal pebble bed, but all so thin that he might sometimes penetrate them with his staff; and next he discovers that the hilltops are characteristically ice-worn. Yet, he finds the ravines as tortuous and steep-sided as ever, bounded by rugged cliffs and flanked by slender pinnacles, with red residuary clay resting on the honeycombed surface of half decayed rock in the slopes, and with a mantle of loess everywhere save in the channels and on the naked cliffs, and no northern drift save a few pebbles intermixed with alluvium—he finds the configuration of the hills characteristically ice-carved and that of the ravines characteristically water-carved. Were he familiar with glaciers of the Alpine type, he might see here a paradox as puzzling as that of the rivers 100 miles westward; for in the Alps the ice streams grind the valleys and leave the crests untouched, while he is forced to infer that, however it may have been brought about, the moving ice here pressed hard upon the hills and bridged the valleys.

A dozen miles down the rocky bluffs into the abandoned channel, across its marshy bottom, up its farther wall, and over the loess-flecked and corrugated drift of the upland beyond, bring the tourist to the outer margin of the driftless area loess—to the verge of a digitate loess escarpment 50 or 100 feet in height, and the hither margin of a bowlder-dotted drift plain, half a dozen miles northwest of De Witt. The low-lying plain is so level and ill drained that much of it was impassable slough in the days of the pioneer, and even to-day the muskrat and crayfish dispute the rights of the stock pastured upon it. It stretches southwestward to the shallow, elm-shadowed flood-plain of the Wapsipinnicon 10 to 15 miles distant, rarely interrupted by scattered sand dunes and by low ridges of drift, of which half a dozen of the highest are loess-capped. It is completely surrounded by loess, and is the largest of the insulated drift lobes of the territory.

Traversing the drift plain the tourist finds the Wapsipinnicon a broad, shallow, sand-bottomed sheet of water, much like the Cedar at Cedar Rapids, wandering through a flood-plain of sand or sandy alluvium a mile or two in width. This flood-plain is bounded only by a low bank on the northeast, but on the southwest 50-foot bluffs of Niagara limestone rise precipitously; and above the rock the surface rises more gently into a ridged upland of drift. A mile or two away from the river these ridges increase in height and become loess-covered, and they stretch miles west-northwestward; but toward the east-southeast they terminate abruptly at the river bank, between Massillon and Big Rock, as do the loess ridges at Prairie Creek. And here as there the tourist finds on careful examination that, although covering so great an area, the loess is but a veneer on the highest hilltops, that the paha are mainly of drift, and that their nuclei are obdurate knolls and ridges of Niagara limestone.

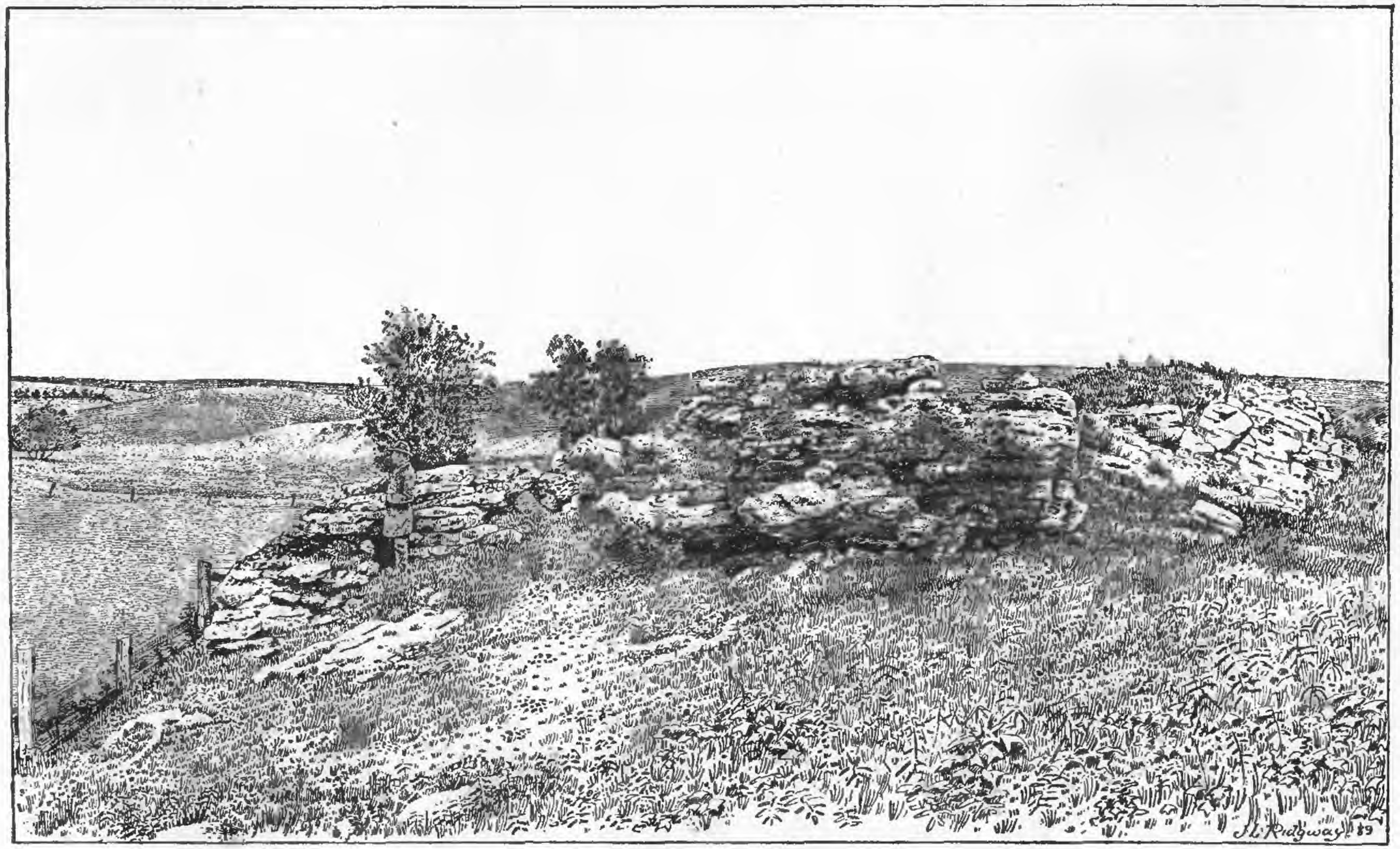
Continuing his journey toward Cedar River the tourist finds the high, loess-covered ridges in the vicinity of the Wapsipinnicon gradually giving place to low, inconspicuous rolls, 10 or 20 feet high, a quarter of a mile to three miles apart, 3, 5, or 10 miles long, and only potent enough as water-partings to determine the courses of the smallest drainage ways, though their directions coincide with those of the rivers; he observes that superficial bowlders fail, and where bowlders are exposed in artificial excavations he finds them notably smaller and better rounded than in the northern part of the State; and on scrutinizing the drift in the shallow road cuttings, he discovers that while it is pebbly as that of the north to within 1, 2, or 3 feet of the surface, the pebbles gradually disappear above and its upper portion (which can not be separated from the lower by any distinct line of demarkation) is a clayey loam, always resembling and sometimes closely approaching loess, in color, composition, and structure. And however widely he searches in the drift area of Cedar, Scott, and Muscatine Counties he finds the same relation holds; for while the drift of the north is practically homogeneous with its pebbles and bowlders uniformly distributed, the drift of the south is assorted, and coarse and pebbly below but fine and loamy (or loess-like) above.

Approaching the Cedar the tourist again encounters loess-capped and forest-crowned ridges like those of the Wapsipinnicon but finds it difficult to determine their outlines by reason of the ever thickening layer of loam overlying the drift of the prairies into which they graduate; and he perceives that the relief of the surface increases southwestward, as well by the deepening of valleys as by the rising of the loess-covered river-bluffs above the level of the divides as in Linn and Benton Counties. Ascending to the summit of the bluffs of the Cedar near Rochester, he looks down upon a sandy flood-plain, rising into low, sandy ridges—the bars and banks of the river when flooded by melting Pleistocene ice—through which the shallow, sand-bottomed stream winds in great loops, ranging from a furlong to half-mile wide, obstructed by bars and shifting islands of sand, and shadowed by spreading elms, cottonwoods, and sycamores. Looking beyond it he sees its 70-foot bluffs rising to a plateau as flat as that of the Iowa north of Amana, and turning to the southward he discovers that within 2 or 3 miles the river bottom, here but three-quarters of a mile in width, suddenly expands into a smooth surfaced alluvial plain 4 or 5 miles wide.

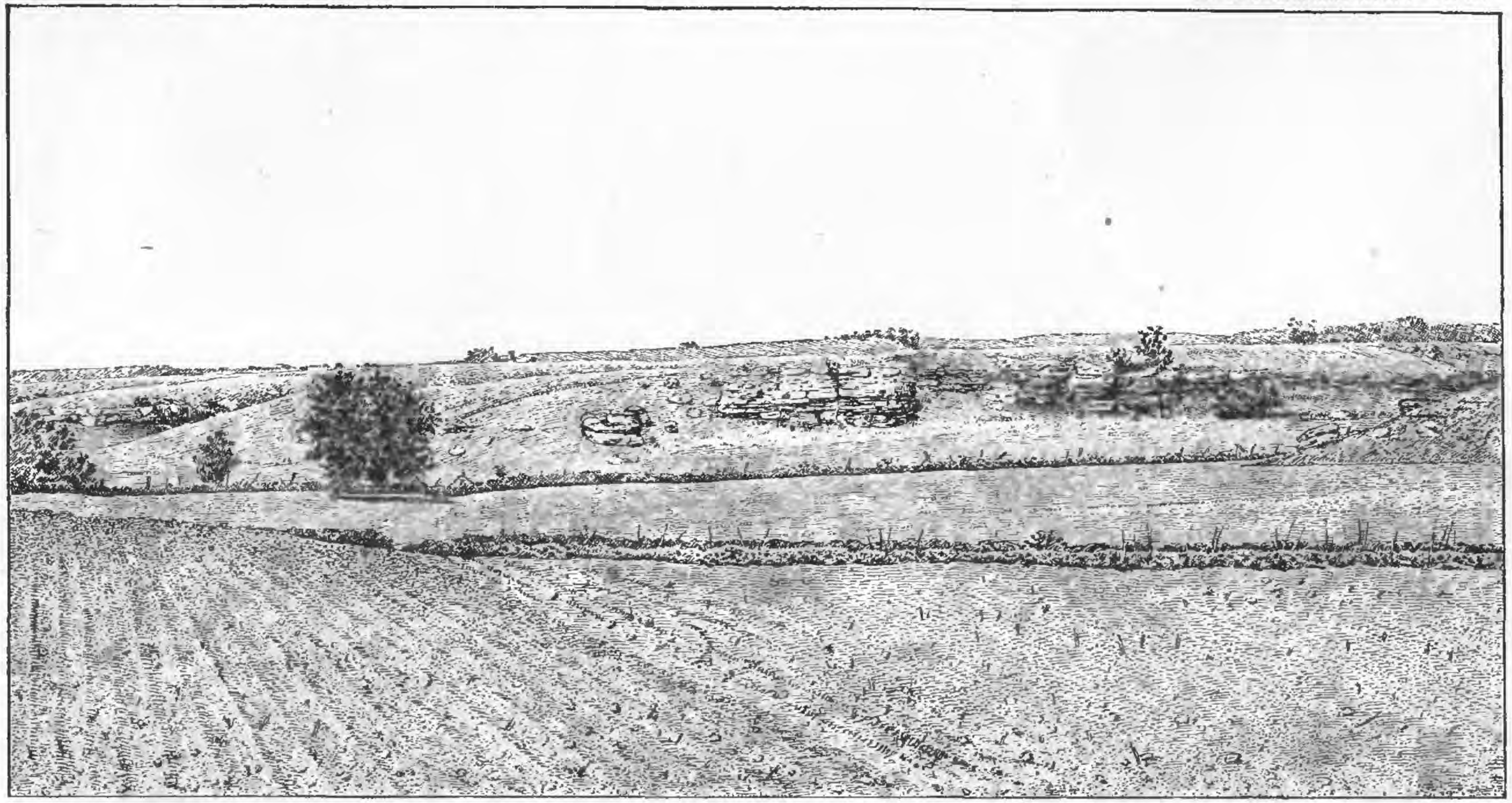
Crossing the river at Rochester he finds that the plateau over which his journey leads him inclines perceptibly to the southwestward, or away from the river which skirts its flanks, and that within four miles it breaks up into a series of loess digits separated by drift lobes, as do the loess tracts generally, and that the tongues of loess are the extremities of low drift ridges such as corrugate the surface of the Wapsipinnicon-Cedar divide behind him; and from the last of these eminences, near Atalissa, he sees that the loess plateau extends to the elbow of the Cedar at Moscow, that the broad alluvial bottom of the river seen from Rochester here swings round to the west side of the river, and that the ridges of drift, loess-capped or not, as may happen, all terminate at this bottom; and did he take the trouble to go down to Moscow he would find that the loess at the terminus of the plateau graduates down into great masses of stratified sand reposing upon a rather thin drift-sheet, and that it has a rock nucleus (blue shaly limestone of the Cedar Valley) rising to half the height of the bluffs, or higher than the drift prairies east of the river or west of Atalissa—that in this portion of its course, as well as above, the Cedar has sought a plateau for its course, and has avoided the lower lands on either side.

Continuing his journey to West Liberty, the tourist finds that the disproportionately broad Cedar bottom here extends to and just beyond the shallow valley of the Wapsinonoc, which, indeed, marks the western margin of the late Pleistocene flood-plain of the Cedar to Nichol, a few miles above its mouth. If he ascends to the higher ground west of the Wapsinonoc, he passes upon a rather strongly undulating plain, exhibiting the characteristic configuration of the loess of Iowa County, though commonly exposing the drift in all cuttings more than 5 or 10 feet in depth. He perceives that the divides and summits fall into a plane, stretching from river to river, but inclining gently southward; and he finds again a relief quite unlike that of the corrugated drift plains in that it is produced by carving and not by embossing. But if he veers to the south to avoid the upland, he finds himself upon an alluvial plain, diversified by an occasional sand dune and broken by the scarps of two or three low terraces (the upper loamy and the lower sandy) looking toward the river, so broad that the scarps lose themselves in the distance, and so level that the houses on the farther side are half concealed by the earth's curvature; and near Nichol he finds this plain to merge into a similar but narrower flood-plain skirting the Iowa.

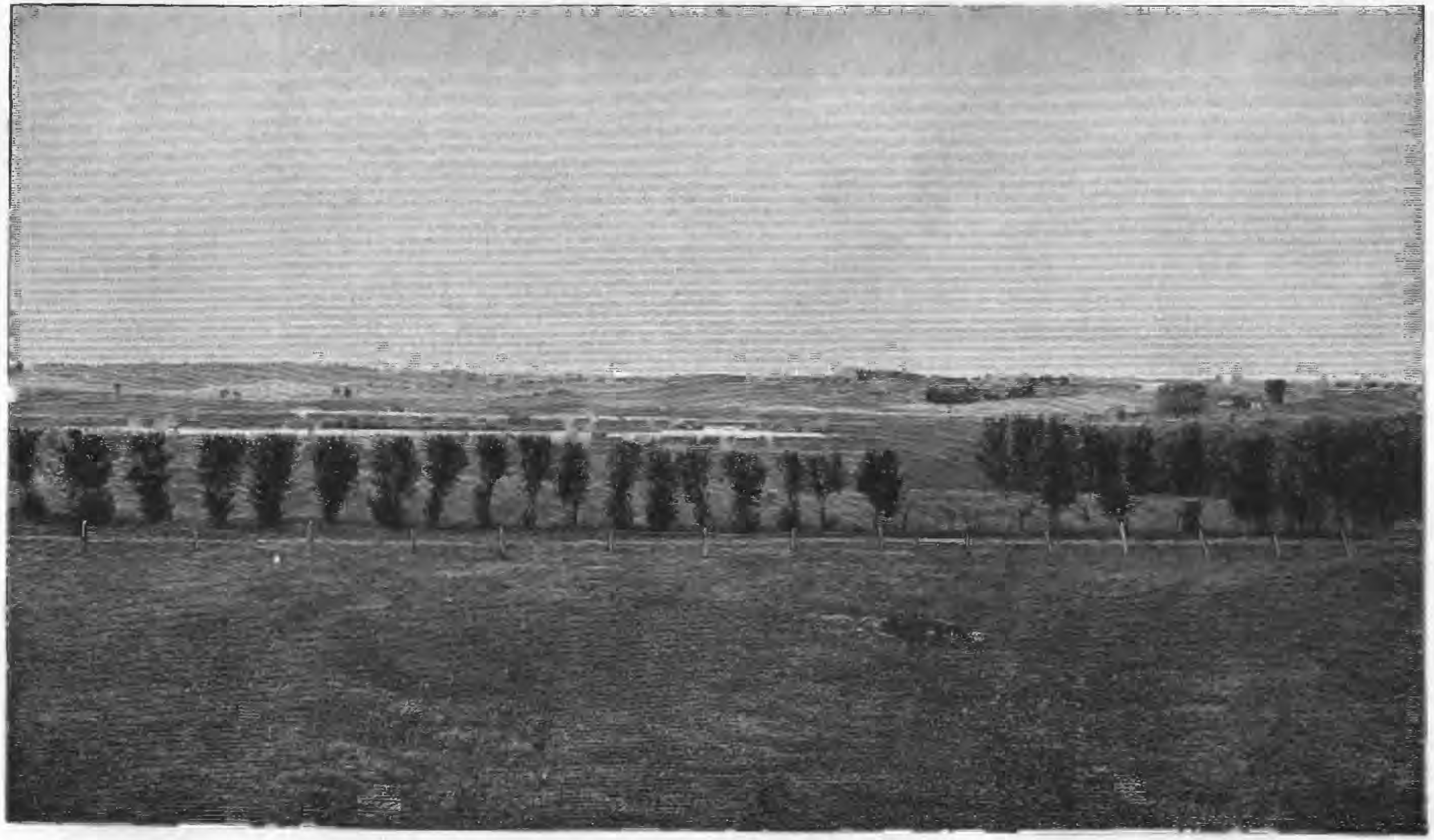
TYPICAL PAHA, NEAR MOUNT VERNON.



TYPICAL LANDSCAPE OF THE DRIFT MARGIN, NEAR PRESTON.



TYPICAL LANDSCAPE OF THE DRIFT MARGIN, NEAR GOOSE LAKE.



LATE PLEISTOCENE CHANNEL OF THE MISSISSIPPI, GOOSE LAKE.

On completing his third journey, the tourist finds himself in a position to generalize his data and picture to himself the broader features of the territory thrice traversed.

Combining his observations on topography in a single mental picture, he perceives that the northeastern tenth of the territory (the driftless area) is a tract of high relief, the summits rising to a strongly undulating plain dissected by cañons and ravines to depths of 300, 400, and even 500 feet, the whole once supporting indigenous forests but now partly cultivated. Fringing this tract he sees an elevated belt—the highest land in the territory—narrow in the north but expanding and breaking up in the south, overlooking the undulating plains to the northeast and the smoother plains to the southwest, and itself made up of rounded hills cleft by steep-sided ravines like those of the driftless area save that the hills are smaller, the slopes shorter, and the ravines narrower and shallower; he sees that this belt merges gradually into the driftless area, though a distinct but sinuous and even digitate line of eminences overlooking the undulating plain roughly marks the common boundary; and he sees unmistakable signs that the whole of this elevated belt, even to the extremities of its longest salients, was indigenously forested before it was possessed by the plow. Stretching from the hilly belt forming the culminating crest of the entire territory he perceives a smoother plain extending and inclining toward the southwest; in the north a champaign unbroken save by its enormous bowlders and shallow water ways, further southward diversified by greatly extended digits jutting out from the second zone, by minor ridges corrugating the divides, and frequently by greater ridges in which the cañons of the rivers are carved; still farther southward broken only by channels and ravines carved within it; and in general a natural prairie land, save that the higher ridges are forest-clad.

Fixing his attention upon the rivers, and at first in the extreme northeast, he perceives that they meander irregularly but ever adown the general slope toward the Mississippi; beyond the culminating crest he observes at first a striking parallelism in the water courses, but on more careful scrutiny discovers that the parallelism is only approximate—that the streams really radiate, in curvilinear courses, from a central area in the northwesterly part of the territory, and that their courses are not directly down the prevailing slopes, but on the average at right angles to the mean inclination of the land surface; in the central part of the territory he perceives that the rivers do not always, or even generally, occupy lowlands, but that they frequently flow in narrow, rock-bound gorges cut in the axes of ridges, and in many cases turn out of direct courses to avoid low-lying valleys and enter elevated plateaus.

Combining his observations on the superficial deposits of the territory, he perceives that most of the rivers are skirted by belts of alluvium, vast in volume in the half-clogged channel of the Mississippi, trifling along the lesser tributaries, shallow and narrow along the rivers of the plain in its northern portion, but progressively deeper and wider toward their mouths, and perhaps altogether absent along the smaller streams of the plain, particularly in the north; along the larger rivers everywhere and along all streams in the extreme northeast he notes the presence of terrace deposits of stratified loam or sand and gravel; and skirting the flood plains of some of the interior rivers, where larger grown, he sees drifts and dunes of sand interspersed with ponds and lakelets.

He perceives next that the elevated ridge skirting the driftless area and forming the crest of the territory is covered with a mantle of loess 5, 10, 20, and in some cases along the slopes overlooking the Mississippi, perhaps 70 or 75 feet in thickness; he sees the same deposit running down the slopes nearly or quite to the great river and covering nearly all of the driftless area in Iowa; in the northern drift plain he finds it fringing some rivers; midway from north to south he sees it capping all conspicuous crests of the low ridges, occasionally intersecting obliquely the divides of the higher ridges cleft by the water courses, of the broad plateaus toward which the rivers turn, and of all other eminences; in the south he sees it forming a continuous mantle, thinnest over divides, thickest in depressions, and seeking lowlands as persistently as it seeks eminences in the north; and he perceives that everywhere over the plains the deposit sustains a curious relation to the curvilinear river courses—for whether he gives attention to the tongues and digits jutting from its broader areas, to the cañon-cleft ridges which it caps, to the flat-topped plateaus in which it skirts the southwestern rivers, he can not fail to observe that it is distributed along lines diverging and curving coincidently with the rivers, while in the low plains of the south he perceives that it hugs the cañon sides. So he may sum his generalizations and inferences and conclude that in the driftless area the loess is nearly independent of the rivers, that in the central plains it seeks the eminences and is sought by the rivers, and that in the south it seeks the rivers.

Turning now to the plains overlooked by the loess, he perceives that they are everywhere formed of glacial drift, with abundant and large bowlders dotting the surface in the north, and with few bowlders visible save in excavations in the south; he observes that in some cuttings both north and south there is a bed of vegetal soil, perhaps containing sticks, stumps, and logs of wood, intercalated within the glacial deposits, and is led to separate it into upper and lower members, divided by this "forest bed;" he sees that the lower member is the more compact, its bowlders smaller and of distinct rock species, its color darker, and its thickness greater than the upper; and he remembers that in the south the lower member grades upward into finely laminated, tenacious, silty clay, either forming the surface or overlain by the "forest bed" and the upper member.

Then, over the driftless area beneath the loess, he perceives a continuous sheet of brown clay, sometimes sandy and again limy, formed by the slow disintegration and decay of the rocks upon which it rests.

Fixing attention next on the stratified rocks, he perceives that along the Iowa River, along the Mississippi in Muscatine and Scott counties, in western Marshall County, and elsewhere, there are small irregular areas of dark brown sandstone, containing thin coal seams, lying unconformably upon the older strata—all outliers of the Coal Measures. Even beyond the center of the territory, at Rockville, just across the western boundary of Dubuque County, he may perceive another outlier of brown ferruginous conglomerate or sandstone resting on much older strata, and may feel disposed from its position and apparent relations to certain Cretaceous outliers in Minnesota to assign it to the Cretaceous rather than the Carboniferous.

Beneath the southern sandstone outliers he sometimes sees, and elsewhere infers the presence of, a series of oolitic and pure limestones with some sandstones and shales, altogether nearly 500 feet thick, characterized by four distinct faunas; the limestones all inclining southwestward, and outcropping only in the southwestern corner of the territory or beyond its limits. These are the lower Carboniferous formations of the Mississippi Valley.

Looking farther northeastward, he perceives that the western part of the Cedar basin is occupied by a heavy bed of shale resting on a series of argillaceous limestone strata fully 200 feet thick; he may, perhaps, remark a thin bed of black shales lying beneath this limestone, and, on collating all observations, conclude that the limestone and shales together—the Devonian strata—occupy about two-fifths of the territory, and, like the superimposed strata, everywhere incline to the southwestward.

Turning now to the culminating crest of the territory, he perceives that the Niagara limestone of which it is composed and whose escarpment it marks, thickens and widens from a 30-foot bed in a scant mile outcrop in the north to a series of magnesian and pure limestones with some shales not less than 350 feet thick and flooring a belt 100 miles wide in the south, and observes that these strata incline southwestward even more decidedly than those of the Devonian.

At the base of the Niagara limestone he perceives a bed of shale—the Maquoketa—only a few feet thick in the north, but expanding to 100 or 125 feet, and at the same time becoming partly calcareous about the southern extremity of the driftless area; and he may observe that in places these shales grade into the subjacent magnesian and argillaceous limestones of the Galena, which are quite inconspicuous in the north but thick and extensive in the vicinity of Dubuque.

Looking now toward the driftless area in the northeast, he perceives, beneath the Galena, the Trenton limestone, 200 feet or more thick in the north, but thinning to 75 feet southward, forming the surface over an area of a few hundred square miles; below it in turn the sands and sandstones of the St. Peter, perhaps thinning southward, and sometimes difficult to distinguish from the sandy dolomites of the Oneota formation on which they lie, and which form the most picturesque cliffs and precipices of the Oneota and the Mississippi; and in the extreme northeastern angle of the State, and then only well down in the cañon walls, he sees 200 or 300 feet of the gray and brown sandstones of the Potsdam; all of these lower Silurian formations, like the Niagara above, inclining strongly to the southwestward.

Uniting all his observations upon the strata, measuring the thickness of those exposed in the northeast, and estimating from dip and width of outcrop the thickness of those in the southwest, he perceives that the relations of the various formations, superficial and regularly bedded, are as shown in the accompanying table:

Formations of Northeastern Iowa.

System.	Group.	Formation.[1]	Thickness.
			Feet.
Cenozoic	*Modern*	Alluvium	0—200?
	Pleistocene	Terrace deposits	0—100?
		Loess	0— 75?
		Upper drift sheet	0—150?
		Forest bed	0— 5
		Lower drift sheet	0—250?
	Perennial	Residuary clays	0— 50?
Mesozoic?	Cretaceous ?	Rockville conglomerate	0— 20?
Paleozoic	Carboniferous	Lower Coal Measures	0—100?
		St. Louis	80
		Keokuk	90
		Burlington	125
		Kinderhook	200
	Devonian	Hackberry shales	50?
		Cedar Valley limestone	100—300?
		Independence shales	25
	Silurian	Niagara limestone	30—350
		Maquoketa shales	15—125
		Galena limestone	10—250
		Trenton	75—200
		St. Peter sandstone	100
		Oneota limestone	200—300
	Cambrian	Potsdam sandstone	300

[1] The formation nomenclature is discussed in chapter III.

Giving attention now to the population and its culture, he perceives that here, as elsewhere, man and his institutions reflect the local geography and geology. Along the natural commercial artery afforded by the Mississippi he finds flourishing cities born of water traffic and nurtured by inland commerce—the early metropoles of the State, now lagging behind the interior cities in rate of development; and in the broken bluffs flanking the river, among which little more than one-half or perhaps only one-quarter of the land is tillable, and from which the indigenous hard-wood forest has now been largely cleared, he finds a notably heterogeneous population, ranging from the cultured capitalist, whose success measures his sagacity in selecting his place of life and means of living, to the thriftless "river rat"—the parasite upon civilization, whose ambition ends with an ill-gotten meal or a debauch; for with the evidence of the enterprise of the pioneer miner and merchant seen on every hand, there is equal evidence that the heterogeneity in population of the mining camps has been inherited in part by the second and third generation. He finds the railways few, because expensive in a region of hills, and the wagon roads widely separated, tortuous, and difficult; he remarks a tendency of the population in general, and of the intelligent and cultured portion in particular, to segregate in centers surrounded by relatively little inhabited and ill developed belts; and he is not surprised to learn that here altruistic movements encounter indifference and sometimes even strenuous opposition, and that here social class distinctions are pronounced.

Away from the river, and yet in the driftless area, he finds a population as sedentary as the soils, because the hilly roads and the dearth of railways restrain travel; but at the same time he sees over the limestone formations fine farms, flourishing villages frequently boasting colleges and academies, and the country between besprinkled with the ubiquitous church and schoolhouse.

Over the broad plains of the interior he finds every acre available for cultivation, and in consequence a uniformly distributed population, depending directly and indirectly upon the soil and its products, and yearly increasing in density; he finds smooth roads, facilitating travel and social interchange, and the land literally possessed by the railway, and bound so closely by its interlacing lines of steel that he may hardly escape the sight or the sound of the locomotive wherever he wanders; he perceives that he is in the paradise of the inventor and manufacturer of labor-saving devices, where horse and machine both plant and harvest, while man only guides the expenditure of energy by his intelligence; he finds a competence, if not moderate wealth, within reach of every man, and going with it the leisure and means for fair education; he finds the country schoolhouse always in sight, and the village dominated by the high school or academy; he observes a wonderful homogeneity in population and a singularly uniform diffusion of current knowledge throughout the land; and he is not surprised to find here the home of practical philanthrophy and farsighted legislation, nor to observe a notable absence of the class distinctions inevitably growing out of varied interests.

Finally, he may for a moment cross the boundary which divides the field of generalization in the domain of phenomenal science from the field of inference in the domain of noumenal science, and, calling to his aid reason and imagination, may picture in mental panorama the history recorded in the rocks, the superficial deposits, the unique deportment of the rivers, and the peculiar configuration of the surface. He perceives that the stratified rocks are mostly shales above, limestones medially, and sandstones below, that they contain only Paleozoic fossils, and hence that all must represent a complete long cycle of deposition within the primary eon of known life. He perceives that the fossils from the lowest formation are Cambrian, and those from the uppermost Carboniferous, and thus that the deposits represent practially the whole of the Paleozoic; and he perceives that there are no newer stratified rocks (save a few isolated outliers of the Cretaceous), and also that the rock surface is elaborately sculptured by erosion, and hence that the territory must have stood above sea level during most of the Mesozoic and Cenozoic eons. Giving yet more careful attention to the story of the stratified rocks and their surface, he perceives that the sculpturing by erosion is not deep, and that but a few hundred or at most a thousand or two feet of Paleozoic strata have been carried away, even from the cañon of the Mississippi, and that, while the territory has risen above the surface of the sea as dry land for untold millenniums, it must have stood low; for erosion was dilatory. Attending specifically to the significance of the Pleistocene deposits and of their relations to the underlying rocks, he perceives that the territory was long ago invaded by an ice sheet which entered from the northwest as a part of the great lobe covering the upland between the Mississippi and the Missouri, and that this ice flood crept sluggishly southeastward, along lines ever curving and diverging toward the east, until it reached (but failed to pass) the culminating crest of the territory; he perceives that the ice sheet must have been thin, since it bore lightly upon the land and seldom scored the subjacent rocks save in the more prominent knobs and ridges; he perceives that the ice reigned long, but at length yielded to the sun and withdrew far beyond the limits of the territory, and that over the slime left on its trail a luxuriant forest spread; and he infers from the depth of the soil and the luxuriance of the forest growth that the reign of the sun was long, far longer than that of ice. He perceives that then the ice once more invaded the land, creeping nearly along its old lines and about to its old limits, but pressing even more lightly upon the surface, and so overwhelmed the forests but left logs, stumps, and roots, and the old soil in their places; that this reign was shorter than the last, and that at its end the ice yielded incontinently, leaving the line of retreat littered with its waste. Considering carefully the rivers, and the ridges in which some of them flow, he perceives that the thin ice sheet must have been most obstructed in its movement over the knobs and ridges of the rocky surface; that there the flow of the ice was retarded, and the rate of superficial melting thereby relatively increased, and that along the lines of obstruction surface rivers, born of the melting ice, found place. He perceives that these rivers trenched the ice to its base while it yet lay thick over the divide between, and that their flow then became so sluggish that the finest flour of the ice mill was dropped in the trenches; he perceives, too, that the rivers were oftimes confined between the ice walls until they cut their trenches down beneath the ice and so deep into the knobs and ridges forming the obstructions that they were unable to escape to the lower grounds, even when the ice walls were finally melted; and thus he perceives that the rivers mark conjointly the lines of ice flow and the lines of rocky obstructions to the ice flow. So he perceives that the northern ice has twice invaded the territory, has spread a double mantle of débris over most of its surface, has filled old valleys and built new ridges, and has forced its river progeny into incongruous beds.

CHAPTER II.

PRINCIPLES AND DEFINITIONS.

SECTION I.—GENERAL STATEMENT.

A few elementary principles are worth stating in order to set forth the bearing of the investigation herein recorded upon the science of geology.

Geology deals with the material phenomena of the earth and the causes of these phenomena, or with the earth and the manner of its building.

In the ultimate classification, the subject-matter of the science is divided into *processes* and *products*. The processes are the physical forces, and the products the tangible effects produced by these forces —the processes are causes and the products material phenomena.

The geologic processes comprise the molar movements of water (including ice), air, and the solids transported by them, of liquid, viscous, and solid rock matter, of animal locomotion, and, perhaps, of plant growth, together with the molecular movements involved in chemic action, change of temperature, etc. These movements, molar and molecular, are observed in constant progress, and their occurrence in past times is inferred, from the characteristics of material phenomena, through analogy.

The geologic products are masses of rock matter and the forms of these masses. The most voluminous masses are rocks, which are both crystalline and clastic. In a general way the crystalline rocks are the older, and the clastic rocks are made up of fragments derived from them. The most conspicuous masses of rock matter are the superficial deposits of clay, loam, sand, gravel, the alluvium of rivers, the beach sands and bottom silts of seas and lakes, the sand dunes, etc., overlying the solid rocks. In general these superficial deposits are newer than the crystallines and the clastics, and are derived from their destruction. The forms assumed by the masses of rock matter are continents, islands, mountain ranges, bays, river channels, and a multitude of other geographic features, as well as mountains and plains, hills and valleys, and a multitude of other topographic features. These forms represent stages in the destruction and construction of masses of rock matter through the operation of geologic processes.

The processes of geology may be indicated more specifically, and in the order of their sequence in the formation of the visible earth, in another way: The initial movements were distortion or displacement of the solid or solidifying exterior of the earth in such manner as to produce irregularities of surface. These are the movements involved in the elevation of continents and the lifting of mountains, and, although the earliest in origin, they have continued in operation throughout geologic time and remain in active progress to-day. Collectively the movements constitute *deformation;* and the quality of the movements may be characterized as diastatic. The movements are chiefly vertical and most easily measured from a fixed datum plane, such as sea level, and are therefore commonly separated into *elevation* and *depression.*

The first consequence of diastatic movement was the lifting of lands above sea, the exposure of rocks to the weather, the birth of rivers, and thus the initiation of the various processes of aqueous erosion and deposition; and these processes are in operation to-day, perhaps as actively as during any past eon. The combined processes tend to obliterate irregularities of the terrestrial surface produced by diastatic movement, degrading eminences and filling depressions, and so may be called *gradation;* and the antithetic operations comprehended under the term are respectively *degradation* and *deposition.*

The processes of gradation were accompanied and followed by a complex series of molecular changes. A part of this series comprises the chemic and chemico-mechanical alterations of the structure of the earth's strata brought about by the weathering of the land surface, the compression of deposits beneath their own weight, etc. The antithetic processes may be grouped as *rock destruction* and *rock construction,* and all may be combined under the term *alteration.*

Another part of the series of processes accompanying and following degradation and resulting from primary deformation comprises the mechanical and chemico-mechanical processes of volcanic action, including not only the extrusion of solid and gaseous matter from volcanic vents, but also the closing of the spaces formerly occupied thereby. These processes are commonly combined as *vulcanism,* and properly include *extravasation* and its converse, and incidentally the earthquake movements (or *seismism*) resulting therefrom.

There is another class of movements resulting from the transfer of matter from land to sea. It has recently been shown that the earth's crust is in a condition of hydrostatic equilibrium or isostacy, and so that when the rivers bear detritus from the mountains to the seas the unloaded mountains rise and the loaded sea bottoms sink; and a part of the deformation of the outer shell of the earth and certain volcanic movements are thus consequent upon the processes of gradation. In general these movements are local and give origin to mountains and montanic valleys, and so may be called *orogenic;* while in general the initial or antecedent diastatic movements produce continents and the greater elevations of land, and so may be called *epeirogenic.*[1]

Yet another class of processes depending largely upon the primary deformation of the earth is represented by the action of the wind upon the land directly in the transportation of dust, and the formation of sand dunes, etc., and indirectly through the action of waves in the building of beaches and the carving of sea cliffs. These are the processes of eolic gradation, or *eolation;* and they are both destructive and constructive. All of these processes have been in operation from the earliest stage in the history of the earth that comes within the ken of the geologist.

Reason and the outcome of elaborate research indicate that life appeared upon the globe some time after the initiation of diastatic movement and the consequent division of the earth's surface into land and sea; and ever since the exterior shell of the earth became so stable as to retain a definite record of the successive stages of world growth the remains of organisms have been imbedded within the rocks and have furnished the accepted geologic chronology. At first the organisms were simple and lowly and affected the rocks chemically through the processes of growth and decay; later certain organisms came to contribute largely of their own bodily substance to the growing strata; and still later the highest organisms, with man at their head, have come to interfere with gradation, alteration, and eolation, through budding instinct and blossoming intelligence. These vital forces are multifarious and widely varied in action.

Reason and observation alike indicate that the earth is a gradually (but not uniformly) cooling planet, and that long after the principal processes of earth formation came into play the temperature was so lowered that ice gathered about the poles, glaciers formed in the higher mountains, and more than once great ice fields extended over the lowlands even half way to the equator. In general the effect of the ice was to transport débris from place to place and to grind down eminences and fill depressions; but sometimes it accentuated preexisting irregularities of surface, certainly by moraine building and probably by basin cutting. So glacic degradation or *glaciation* was inaugurated and remains in active operation on certain parts of the globe to-day.

Each category of processes recognized by the geologist is represented by a corresponding category of products: The antecedent diastatic movements are represented by the continents and ocean basins, by the greater mountain ranges, and by many gulfs and larger valleys; the consequent diastatic movements are represented by many smaller mountain ranges and narrower valleys; the process of degradation is represented by hills, by cañons, and in general by the sculpturing of the earth's surface; deposition is represented by

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[1] A term proposed by Gilbert.

the clastic rocks and by some superficial deposits; alteration by the widely distributed mantle of disintegrated rock, by mineral veins, and by the state of aggregation in nearly all rocks; vulcanism by an important part of the crystalline rocks, by some aqueous and some eolic deposits, both indurated and superficial, and by certain minor deformations of the earth's crust; eolation by dunes and beaches; vital action by the state of aggregation of some rock masses, by the composition of some rocks, by the volume and distribution of certain rock strata, and by the organic remains found in most rocks, as well as by the soil universally covering the surface; and glaciation is represented by a considerable part of the superficial deposits of polar and temperate lands, by characteristic surfaces and forms, and by some lake basins and river valleys.

Each category of products recognized by the geologist forms the subject-matter of a subordinate branch of geologic science: The phenomena of deformation are dealt with in what is commonly called structural geology, or, more properly, diastatic geology or diastrophic geology; the phenomena of degradation form the subject of geomorphology, the novel branch of geology, or the New Geology which is just coming into prominence; those of deposition long ago gave origin to stratigraphy, or stratic geology; those of alteration to chemic geology, lithology, petrography, mineralogy, etc., in whole or in part; and those of vulcanism to vulcanology and seismology. The phenomena of eolation have scarcely been comprehensively grouped and studied; the phenomena of glaciation form the subject of glacic geology, and the phenomena of the life of the past ages form the subject matter of paleontology and the principal basis for geochrony.

Curiously, the extension of inquiry into the domain of the unknown has not followed the order of the accessibility of the phenomena. Indeed, in geology, as in science in general, it has commonly been the distant or the obscure or the mysterious that first attracted attention; and so the sequence of succesive steps in knowledge has generally followed the inverse order of the proximity or the accessibility of the phenomena. The stars were known and the constellations mapped before a tenth part of the surface of the globe was explored by enlightened men; the geography of half of the earth was outlined before the significance of the simplest geographic form was perceived; the origin of the earth had been vaguely set forth by a score of cosmogonists before a single rock or fossil or hill or valley was carefully studied. Even when geology found birth the first subjects of investigation were the crystalline rocks of distant mountains or the clastic strata of deep mines, and the older formations were studied before the newer; it was long before students found a subject worthy of their skill in the superficial deposits, and then they began with the most obscure and puzzling of all, the glacial drift, and passed to one of the most rare, loess, turned next to the restricted alluvium, and came last to the nearly universal product of secular rock decay; and not yet has the everywhere prevailing soil received a tithe of the systematic study given to the rock masses it mantles, or more than a fraction of the attention its importance demands. And the newest branch of earth lore, the New Geology, which is concerned with the configuration of the land surfaces on which men live and move, has just sprung, albeit full fledged, into active being.

The researches recorded herein relate (1) to disastatic geology, in which certain new facts and significant relations are set forth; (2) to geomorphology, in which most of the work is novel, and in which relations between past history and present configuration, unknown elsewhere, together with certain hitherto unrecognized peculiarities in the deportment of rivers, are set forth; (3) to stratic geology, though little is added to this branch of earth lore; (4) to that branch of lithology which deals with the products of rock destruction, in connection with which a few local facts but no new principles are set forth; and (5) to glaciation, in which the work was largely new at the date of study, particularly in the interpretation of Pleistocene history, the elucidation of the connection between glaciation and certain unique topographic forms, and the determination of the origin of a joint product (the loess) of glaciation and aqueous deposition.

SECTION II.—DIASTATIC GEOLOGY.

The earth movements of the past are inferred from the rock structure of the present; and the most decisive and satisfactory evidence of earth movements is found in regularly bedded and only moderately disturbed clastic rocks like those of the indurated formations of Northeastern Iowa.

Certain clastic strata lie in sensibly horizontal attitude, with the materials so little altered as clearly to represent the original character of the sediments of which they are formed. Such strata are undisturbed. Again, little altered strata may exhibit decided dip or inclination in a certain direction, when the structure is monoclinal. Once more, little altered strata may be bent upward in the form of an inverted trough, when the structure is anticlinal, or bent downward in trough shape, when the structure is synclinal. In some cases little disturbed strata are thrown into a succession of anticlinal and synclinal folds, and, viewed in the large way, the structure is corrugated or folded; and sometimes the folds are so closely appressed that parts of the strata are completely overturned. All of these classes of structure represent deformation by flexure.

Another type of structure may be displayed by little altered clastic strata: A single stratum or a series of strata may be separated by a plane of division, commonly approaching the vertical direction. Such a division plane is a joint. Jointed strata may be otherwise undisturbed. Again, a stratum or a series of strata may be displaced on opposite sides of such a plane of division, which then becomes a fault; and the part of the rock mass which is moved relatively upward is characterized as heaved, while the part which is moved relatively downward is characterized as thrown. The inclination of the fault, measured from the vertical, is denominated its hade. Commonly when the faulted strata are but slightly flexed, the fault inclines towards the depressed portion of the rock mass, when the fault is said to hade to the downthrow; but there are many cases, particularly among profoundly flexed strata, in which the fault inclines toward the heaved side, or hades to the upthrow, perhaps at a high angle, and this type of disturbance is sometimes characterized as the reversed or overthrust fault. These are simple structural classes representing deformation by fracture.

In some cases strata are both profoundly flexed and intensely fractured, perhaps to such extent that the original bedding is obliterated, and in such cases the sediments are commonly altered, even to the extent of transforming the original clastic mass into a crystalline one; and such profoundly altered strata are frequently cut by dikes of intrusive rock, or by veins of alteration products; but these more decided types of alteration of structure and texture are not found in Northeastern Iowa, and need not be followed out.

The indurated rocks of Northeastern Iowa have a decided and fairly uniform southwesterly dip—i. e., they form a gentle monoclinal extending from what may justly be regarded as a continental nucleus to what was undoubtedly, in one stage of American geologic history, a continental periphery. Moreover, the strata are thrown into a series of widely separated and gentle anticlinal and synclinal folds, approximately parallel among themselves, yet curving slightly so as to become approximately concentric with the supposed original continental nucleus. Other folds of like character, but of progressively increasing magnitude, have been brought to light beyond the limits of the territory and the State; and these appear to be connected with the more profound corrugations of southern Missouri and Arkansas. Finally, one of the indurated formations—the Cedar Valley limestone—is frequently both flexed and faulted in a slight degree, and this structure is associated with a peculiar crushing or brecciation of the rocks.

Many well known phenomena and certain considerations which need not be set forth in detail indicate that, while the original continent-making movements of the North American interior were purely antecedent or epeirogenic, they became involved in later stages with consequent or orogenic movements; the former being predominantly central and essentially vertical in direction, and the latter predominantly peripheral, with a horizontal component in the direction of movement.

Now, the diastatic movements recorded in the slightly disturbed strata of Northeastern Iowa appear to fall into two categories: the general monoclinal structure may be considered to represent epeirogenic movement; and the corrugation, together with the folding, flexing, and crushing of the strata, may be ascribed to feeble orogenic action connected with the more profound movement.

The structural features thus characterized are of small magnitude and of limited extent; but they acquire importance from the fact that they apparently represent a part of a continuous series, connecting an original continental nucleus with its Paleozoic periphery, and thus epitomizing the history of American Paleozoic deformation.

SECTION III.—GEOMORPHIC GEOLOGY.

PRIMARY CLASSIFICATION.

A new period in the development of geologic science has dawned within a decade. In at least two American intellectual centers and one abroad it has come to be recognized that the later history of world growth may be read from the configuration of the hills as well as from the sediments and fossils of ancient oceans. The volcanic cone displays characteristic features; the uplifted mountain range has a characteristic physiognomy; the ice-swept hills and valleys exhibit characteristic and unmistakable lineaments; and the water-carved cañons, hill-slopes and plains, take on a distinctive expression; and to-day these features and lineaments—this physiognomy and expression—are discriminated and interpreted by half a dozen geologists. The field of the science is thereby broadened by the addition of a coordinate province—by the birth of a new geology which is destined to rank with the old. This is geomorphic geology, or geomorphology.

In geomorphology the external forms of the earth are studied and their origin sought, and they are ultimately classified by the causes and conditions of their origin. Thus continents, some great islands, most mountain ranges, and certain other earth forms, together with the oceans, some valleys and lake basins, and most great seas and bays, are ascribed to the profound earth-crust movements comprehended under deformation; certain volcanic peaks and craters, and some caverns and fissures, are classed among the products of the great processes of vulcanism; drift plains, moraines, some rock basins, and a variety of other distinctive forms are classed as glacial in origin; sand dunes, with associated ponds, are ascribed to eolic action; and by far the greater part of the minor land forms of the surface of the earth are direct products of degradation by hydrodynamic erosion. This method of classification has been set forth in greater detail in other publications.[1]

The hills, valleys, plains, and other land forms of Northeastern Iowa are either of glacial (or aqueoglacial) origin or the product of water carving. The former class is discussed in a later section. The latter has been discussed with some fullness in other publications.[2]

In brief, the primary and most widely extended class of land forms produced by water sculpture are those due to the action of the falling rains and flowing rivers upon land surfaces having free drainage to the sea and not disturbed by orogenic movement. Rivers developed upon such surfaces, the valleys which they quickly excavate, the confluent ravines and gorges and the longer valleys of tributaries, the hills defined by the main and minor valleys, and the entire surface eventually formed, are classed as *autogenetic*. When the general surface is not simply sculptured by moving water, but suffers general deformation either before or after rising above the level of the sea, the topographic forms eventually assumed fall into another class designated *tectonic;* and these forms have been classified in detail by subordinate conditions of origin.

The autogenetic forms, too, are sometimes classified by subordinate conditions of genesis; but it happens that all of these conditions are so far subordinate to the great primary processes of hydrodynamic erosion that the subclasses are ill defined and either overlap or merge. Thus, Davis characterizes certain areas of autogenetic sculpture as mature, others as immature, the distinction resting upon the degree of development of the forms by erosion, which itself depends upon a variety of conditions. Chamberlin in like manner speaks of "topographic youth" and "topographic old age" in connection with the same general class of land forms. These subclasses blend.

Another distinction, the importance of which has not perhaps been recognized hitherto, must be made among autogenetic forms. In discussing bad-land sculpture, and the law of divides as exemplified therein, Gilbert clearly pointed out[3] that the typical bad-land profile is chiefly made up of curvilinear slopes with concavity upward, while the crest of the divide is convex upward; but although attention was called to this minor difference in profile, it was not explained.

Now, when the law of divides so well exemplified in the bad-lands is extended to more fortunate parts of the earth's surface, like features of profile are found, but the proportion of concave curvature to convex curvature varies. Thus, on passing from the bad-land

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[1] Classification of Geographic Forms by Genesis, Nat. Geog. Mag., vol. 1, pp. 27-36, 1888; Some Definitions in Dynamic Geology, Geol. Mag. (London), vol. 5, 1888, pp. 489-495; The Field of Geology and its Promise for the Future, Bull. Minnesota Acad. Sci., vol. 3, 1891, pp. 191-206.

[2] Ibid.; 7th Ann. Rept. U. S. Geol. Surv., 1886, pp. 538-562.

[3] Geology of the Henry Mountains, 1877, p. 123.

to the fertile plain, both being of autogenetic sculpture, the divides are found to widen and flatten, though yet retaining the convex profile, while the slopes are found to shorten and flatten, though yet retaining the concave profile. And on scanning the endless succession of hills and valleys, divides and water ways, uplands and lowlands, formed by water carving, it appears that the concave profile really represents the water way and the convex profile the land surface between water ways. So every water way, great and small (provided it be not affected by diastatic movement or unequal obduracy of rock bed), flows down a curvéd slope ever diminishing as the waters converge and the stream volume increases. In other words, concave slopes express the *law of water-course profiles*, while convex surfaces express the *law of land profiles*.

Now, it is known from observation that bad-lands comprise assemblages of evanescent forms; with every storm the configuration of peaks, crests, slopes, and gorges changes in shape and expression, so that the occasional traveler may be lost on what he supposed familiar ground; the rills and streamlets and rivers discharge great quantities of débris; and miniature examples of bad-land sculpture come and go—e. g., in the "old fields" of the South—within the memory of a generation. So, too, it is known from the ascertained laws of hydrodynamic degradation that water courses are continually corraded, and that concave slopes, which represent congeries of water courses, are constantly under attack; and both observation and reasoning show that the converse is true of regions of predominantly convex profiles. Accordingly, autogenetic forms may be classed according to the relative extent of concave slopes and of convex profiles; and the former may be designated *unstable* and the latter *stable*. These subclasses blend, as do all others thus far proposed for autogenetic forms; but they are none the less useful.

While the prevailing profile of the water course is curvilinear, with the concavity upward, there are many departures from this simple form. The more conspicuous of these departures are due either to diastatic movement (as, for example, the cascades of the coastal plain rivers along the fall line) or to heterogeneity in the terranes upon which the rivers flow (as, for example, the cataract of Niagara and the falls of Minnehaha), and may be classed as *abnormal;* but there are more numerous though less conspicuous departures from simple curvature, due to causes residing in the stream itself, which may be characterized as *normal*. Certain relatively unimportant stream terraces may be provisionally ascribed to the vertical wandering of streams departing from the usual concave profile; and these and other river terraces are discussed at some length on another page.

THE LAW OF LAND PROFILES.

It has already been noted, and it is elsewhere shown in detail, that the portion of the Wisconsin driftless area extending into Iowa displays a distinctive topography, entirely unlike that of the drift plain. The configuration is autogenetic; the water ways fall into wide-branching, dendritic drainage systems, and the uplands and divides are evidently determined by the water ways. But while the drainage lines are deep, steep-walled ravines and narrow gorges, the prevailing profiles are convex upward. There is a reason for this configuration which may be briefly stated in general terms and without exhaustive analysis.

The category of erosive processes is an extensive one, but the principal process is hydrodynamic erosion. Hydrodynamic erosion is itself a complicated process, but its chief factors are *disintegration* and *transportation*. The raindrops beat upon the surface and by their impact dislodge particles of rock and earth. The dews of the night soften and expand the superficial portions of the rocks and earth, and the rays of the sun cause them to shrink and thus fissure and separate into fragments; and during winter days the superficial portions of the rock and earth are permeated by water, while during winter nights the imprisoned water congeals and expands, bursts its bonds, and separates still more widely the fragments of rock and earth. The oxygen of the air comes in contact with fresh surfaces produced by the breaking up of rocks and earth, and some of their constituents are oxidized and thus decomposed. The roots of trees and shrubs and smaller plants pierce the earth and press themselves into crevices in the rock, and with their growth burst the earth and rock asunder, and when the plants decay form channels through which water freely finds its way; some earths and rocks are directly decomposed by the action of water, and nearly all their materials are decomposed by the action of water when charged with the acids set free upon the decay of plants. In these and in other ways the rocks are broken up and decomposed, or, expressed in the most general way, disintegrated.

When the raindrops dislodge rock particles they toss the bits here and there, but generally down the slope; when the rain water gathers into rills, it collects some of the same rock particles and some others, and floats or pushes them down the runnels; when the rills gather into streams the water maintains its hold upon many of these particles, which by their impact against the rocks and earth dislodge others, and all are pushed against the bottom and sides of the channel to grind off still other fragments; and the streams carry all such particles, coarse and fine, toward the larger rivers. The rivers drop some of the coarsest débris, but carry the finer and triturate much of the coarser until it, too, is fine, and so eventually carry nearly all into the sea; and in this manner and in some other ways transportation is effected.

So the measure of transportation depends upon disintegration; for if the rocks were not disintegrated the waters would glide over them and rush down to the sea as pure as when they fell from the clouds. But disintegration is only remotely dependent upon transportation; and where the great agent of transportation, flowing water, does not exist, the rocks may nevertheless be completely disintegrated to great depths.

Mountains rear their heads high above the seas; clouds gather about their summits and sweep their slopes with frequent storms; the rivers rush down the defiles and through the cañons, and under the influence of rapidly running waters transportation keeps pace with disintegration, and the summits, slopes, and defiles may be washed clean of loose earth and disintegrated rock; and eventually the montanic tract so conditioned is carved into a series of sharp-crested peaks, aiguilles, sierras, arêtes, and a host of such positive forms as have been fashioned in the Alps, the Andes, and the Himalayas; these positive forms are separated by narrow ravines, defiles, gorges, passes, cañons, arroyos and a host of other negative forms equally well known in regions of high mountains; and all the profiles are curves, or combinations of curves, concave upward, save perhaps along the narrow crests of the arêtes and on the blunted apexes of the aiguilles.

Among older and lower mountains fewer storm clouds collect about the crests, the streams rush less swiftly down the gentler slopes, and the rivers flow more sluggishly through their flattened courses; so transportation does not keep pace with disintegration. In such regions the peaks are rounded into knobs, the aiguilles are blunted into cusps, the sierras are widened into divides, and the arêtes are reduced to subordinate divides. At the same time the negative forms are somewhat broadened and flattened, but to a less degree than the positive forms; and the profiles are combinations of the concave curves of troughs and the convex curves of crests.

Over a plain but little elevated above sea level the trade winds glide gently and storm clouds gather rarely, and rain is an agent of rejuvenation rather than of destruction; the waters falling upon the surface collect sluggishly and creep indolently down the easy slopes, and wander idly seaward; and disintegration may be far in excess of the transporting capacity of the sluggard streams. In such a region the knobs soften into plateaus, the cusps are widened into broad swells, the divides are expanded into uplands, and the subordinate divides are reduced to surface undulations; at the same time the negative forms are still further broadened and flattened, but ever in a less degree than the positive forms, and the prevailing profiles are convex curves over the uplands with relatively unimportant concave curves along the water ways.

A bad-land is a region of miniature mountains perchance in a lowland. Near the principal rivers transportation exceeds disintegration, and there the slopes are steep, the crests are sharp, and the profiles are concave; away from the rivers disintegration exceeds transportation, and the slopes are gentle, the crests are broad, and convex profiles may prevail; and thus a bad-land may, within a single landscape, illustrate the relations of disintegration and transportation to the prevailing curves of the surface. The "old fields" of the southeastern States were once wooded, and assumed a surface configuration, determined in part by that condition, of convex curves steeper than are stable without the protection of the forest mantle. The forests were cleared away and the fields were plowed, yet protected from excessive erosion by concentric cultivation, balks, hillside ditches, and barriers erected in the rain-formed gullies. But now many fields have been abandoned to nature, and the waters falling upon the surface have already begun to carve it into forms stable under the deforested condition, and have transformed once fertile fields into miniature bad-lands in which all the relations of transportation and degradation to surface configuration are exhibited.

So the characteristic convex curves of the driftless area of Northeastern Iowa exemplify a relation between the processes and products of erosion not hitherto recognized elsewhere, and at the same time express the law of land profiles and illustrate the stable type of land forms passing into the unstable type along the water ways; and it might be shown that they also indicate that the land has long stood low above the sea.

ICE-FASHIONED LAND FORMS.

The flowing ice stream is a distinctive phenomenon; yet it is but a term of a series. The glaciers of the Alps flow in definite channels, and their surfaces are marked by ice ripples and flow-lines; yet toward its source each glacier passes imperceptibly into the névé, or the field of little compacted snow; and in some seasons the terminal portion of a stream may be a stationary ice mass slowly melting under the glow of the sun and the breath of the wind. The glacier is one of a series of conditions of frozen water, running from freshly fallen snow through compacted snow, the granular ice of the névé, and the semi-crystalline ice of the upper glacier to the solid, translucent ice of perfect congelation; and in all of its forms the frozen water may be either mobile or stationary according to the conditions by which it is environed. So the glacier is difficult to define.

Moving ice bodies display certain characteristic features and produce certain characteristic effects; yet the various moving ice bodies of diverse form and magnitude merge in a continuous series. The glacierets of LeConte—the pygmy hybrids between névé fields and glaciers—found in the Sierras are only arbitrarily separable from the distinctive glaciers of British Columbia; these glaciers run into the ice fields of southern Alaska; these again belong to the class represented by the great Greenland ice sheet; and the Greenland ice sheet is justly regarded as the homologue and illustration of the vaster continental ice sheets which more than once invaded the north temperate zone, and twice, thrice, or oftener crept over northeastern United States. It is convenient to speak of glacierets, glaciers, ice fields, and continental ice sheets; but the distinctions implied in these terms are arbitrary: there is no difference in kind, either between the glacieret and the glacier or between the glacier and the continental ice sheet; and their products, whether deposits or land forms, are still more closely related. Frozen water possesses certain properties and consequently behaves in certain ways, but its behavior is determined by environment solely; and environment is not only ever varying but necessarily subordinate as a criterion for the classification of glaciers. So, moving ice bodies are difficult to classify; and, as shown in some detail elsewhere, it is impossible to classify ice-fashioned land forms in terms of the ill defined conditions under which moving ice bodies exist.

Now, moving ice may be either a constructive or a destructive agent, i. e., it may either form deposits of characteristic configuration, or sculpture rock surfaces in characteristic ways. Again, ice is in unstable molecular condition, and under terrestial temperatures melts with greater or less rapidity, and the "schmeltzwasser" thereby produced cooperates with the ice in both its constructive and destructive capacities. Moreover, ice masses by their presence or by their melting affect the regimen of rivers beyond the ice limits and produce, or at least are accompanied by, changes in relative level of land and sea, and so characteristic deposits of ice and schmeltzwasser are formed, and these sometimes assume distinctive forms when subjected to hydrodynamic erosion. Thus the land forms produced by ice action may be either (I) direct products, or (II) indirect products, the latter including certain river flood plains and terraces, certain coastal plains and shore lines, and certain sculptured forms (e. g., of the loess). The direct products result from, 1, glacial processes which may be (*a*) destructive, (*b*) constructive, or (*c*) compound; and from 2, aqueo-glacial processes which may be (*a*) destructive, (*b*) constructive, or (*c*) compound.

The topographic forms which result from these processes may be briefly characterized:

When a glacier occupies a water-carved cañon or gorge of considerable declivity, the gorge is transformed in a well known way. In the first place the V cross-profile characteristic of water carving[1] is transformed into a U-profile, i. e., the bottom of the gorge is scooped out and widened. Concurrently the ice pressure is concentrated at the lower ends of declivities in the profiles, and thus the departures from uniform curvature of the water-cut cañon due to varigradation[2] are accentuated, sometimes to the extent of scooping out rock basins. At the same time the extremities of lateral gorges not occupied by ice are cut off by the widening of the main gorge, leaving lateral cascades when the ice disappears. If the glacier heads in an amphitheater or coom the depression is first filled with a fairly uniform mass of imperfectly compacted snow; this mass subsequently settles beneath its own weight and by partial melting and regelation, and flow begins; when the movement is somewhat analogous to that of land slides due to deposition or alteration.[3] Thus a fault or "bergschrund" is formed a little way within the walls of the coom, and this bergschrund, originating at the surface and some distance from the rock wall, would seem to approach and finally encounter that wall at a greater or less depth, so that while the upper part of the coom wall is protected by the ice, the lower part is attacked by it, and the characteristic water-carved coom is thereby transformed into a cirque. If the moving ice body is larger and lies upon a plain, instead of flowing in a narrow gorge, its behavior is modified; instead of producing U-cañons with their attendant phenomena it develops irregular surfaces, reflecting the relative obduracy of the ice-ground rocks, e. g., generally elongated basins or troughs, the generally elongated swells knows as rôches moutonnées or tors, the lesser positive and negative forms combining to form ice-molded surfaces, etc.; and, upon smooth plains and in constricted gorges alike, the rock surfaces are fashioned into graceful forms, ground, carved, striated, and polished. Such are the principal destructive forms resulting from ice action.

The constricted glacier occupying a mountain gorge is commonly a destructive agent in its upper stretches, and a constructive agent in its lower. It carries upon its back trains of rock fragments fallen from the cañon walls and neighboring peaks; at its terminus these are discharged and piled in a bank or series of hummocks around the melting ice front, forming a terminal moraine; at the same time a part of the material collected at the bottom of the glacier in its upper part is intermixed with and frozen to the lower ice and so pushed forward to accumulate beneath the ice stream in its lower portion as a ground moraine, which, after the retreat of the ice, displays a characteristic surface configuration; and if the glacier pushes far beyond its parent gorge, parts of the ground moraine are

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[1] Actually the sides of water-carved gorges are not straight like the limbs of a V, but convave upward or inward in accordance with the law of water profiles; but in gorges of high declivity, and consequently of rapid vertical corrasion, the curvature is slight and may be neglected.

[2] This process is discussed on page 264.

[3] Seventh Annual Report, U. S. Geological Survey, 1886, p. 611.

thrust out laterally, and parts of the débris carried on the surface are dropped over the sides, and lateral moraines are built. If the glacier is larger and lies upon a plain, terminal moraines may be built,[1] when they are commonly larger and more complex than those of constricted glaciers, perhaps interlacing and blending in complicated patterns; lateral moraines are seldom formed; while the ground moraine attains its most extended development. The surface forms of terminal moraines are rounded knobs of glacial drift associated with "kettles" or depressions, often filled with water, and sometimes associated with overwash plains of gravel, sand, or silt, formed by the schmeltzwasser; the lateral moraines are ridged; while the ground moraines commonly display an undulating surface, perchance so smooth as to be ill drained and so extensive as to form counties (as in the northwestern part of the territory described herein, and still more notably a hundred miles westward, within the great terminal moraine), though sometimes ridged, knobbed, or otherwise diversified—the regularity or irregularity of surface commonly reflecting in slight degree the condition of the subterrane, while at the same time expressing the influence of the more general environmental features upon the ice. The depressions in the ground moraine, like the kettles associated with the knobs of the terminal moraine, may be occupied by ponds and lakes. Such are the principal topographic forms produced by glacial construction.

Some of the best American examples of the products of glacial construction formed by local glaciers are those of the Mono Lake region recently illustrated by Russell,[2] and some of the best examples of such forms produced by a continental ice sheet are those of the great terminal moraine illustrated by Chamberlin in various publications during the last decade.

The constricted ice stream is a destructive agent in its upper stretches, constructive in its lower; and about the locus of transition it operates in such manner as to produce compound forms. Thus, concentration of grinding at the bottom of a declivity may produce a shallow rock basin, while the cessation of grinding a short distance below may be accompanied by deposition in such manner that after the retreat of the ice there will remain a basin, partly excavated in the rock and partly bounded by morainic ridges, which may be occupied by a pond or lake. The larger glaciers upon plains similarly have their areas of prevailing destruction and prevailing construction, with an intermediate zone in which the processes are variously combined; and in this intermediate zone it is probable that the general effect of glaciation is to diminish preexisting surface irregular-

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[1] It is probable that terminal moraines are always built unless the ice sheet (1) embouches into a water body; (2) terminates on a plain so low and flat as to give imperfect drainage; or (3) pushes out rapidly over a plain in a thin sheet which subsequently melts rapidly from the surface.

[2] Eighth Annual Report, U. S. Geol. Survey, 1887, pp. 254-394.

ities of minor magnitude by grinding down eminences and filling up depressions, though the converse is probably true with respect to greater irregularities. It would seem probable, too, that in such zone the ice may change from a destructive to a constructive agent or vice versa, not only from place to place but also from time to time, with varying conditions of thickness, altitude of the land, etc.; and that the line of equilibrium between the opposing tendencies toward destruction and construction might be so unstable as to be easily changed by local conditions in a manner analogous to that in which streams are affected in varigradation.[1] Thus, it would seem that if a small mass of subglacial débris should accumulate in any manner about the line of equilibrium between destruction and construction, the forward pressure might be insufficient to remove it (the starting friction which represents its resistance after once stopping being greater than the moving friction measuring its previous resistance to thrust), and additional débris might be combed out from the ice sheet and there accumulated in an ice-molded hillock to remain after final ice melting either as a drumlin or a less conspicuous eminence such as abound throughout glaciated plains. These are some of the land forms produced by ice action through combination of constructive and destructive processes.

The land forms produced by aqueoglacial processes, or by the joint action of ice and its schmeltzwasser, are less thoroughly discriminated than those produced by ice action alone, partly for the reason that the joint process is so closely related to the great process of gradation (chiefly through hydrodynamic agency) by which the greater part of the earth's surface has been reduced to its present condition, that the products lack distinctive characters. Such land forms are little understood, too, for the reason that certain of them are produced in perfection only by continental ice sheets more extensive than any now known to exist on the globe. For these reasons it is inexpedient to classify such land forms in detail or to give more than passing notice to the forms resulting either from destructive or constructive action by ice and schmeltzwasser, or from the combined constructive and destructive action of these agents. Some of the constructive forms produced upon the plains, however, demand attention.

If a great ice sheet be conceived to occupy and terminate upon a plain, its behavior must be supposed to depend in some measure upon its thickness, upon the rate of superficial and peripheral melting, upon the relation of the plain to base level, upon the configuration of the surface of the plain, and upon other conditions. If the sheet is thin and the plain fairly smooth and somewhat inclined in

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[1] Cf. pp. 264-269.

the direction of motion, the ice may have a fairly uniform surface, ablation (or surface melting) may proceed at a rate fairly uniform over each zone from the periphery inward, and marginal melting may also be fairly uniform. Then if the glaciated plain lies near base level, the marginal débris may be swept upon the ice-free part of the plain and deposited in fairly uniform sheets, like those of the great gumbo plains of southern Iowa, northern Missouri, and parts of southern Illinois; while if the glaciated plain is more irregular, the destruction of ice and the building of débris masses must be less regular, and the general deposit of uniform character may be replaced by local deposits of diverse character and variable configuration. In this manner sand plains, such as those recently described by Davis,[1] silt plains, gravel banks, etc., may be produced. Other examples of topographic forms produced by glaciers and their schmeltzwasser in regions of rugose surface are the kames and eskers of Ireland and New England, the aasar (or osars) of Scandinavia, etc.

If the ice sheet is relatively thin and rests on a plain uniform in general configuration but diversified by occasional knolls of hard rock, its behavior will be modified. Each rocky knoll must interfere with the flow of the sheet, and a line of less rapid movement will stretch away in its lee—i. e., a partial lobation of the sheet will be produced, the interlobate lines on the surface marking the positions of the obstructing knolls below. At the same time ablation will be relatively accelerated along these interlobate lines of less rapid flow, and the lines will thereby be deepened and each will quickly come to be the course of a superglacial stream carrying away the schmeltzwasser of ablation, and the partial lobation will thereby become more pronounced. Then, after the melting by relatively accelerated ablation and by the flowing stream has lowered the ice surface along the interlobate line to about 10 per cent of the thickness of the ice sheet, the ice pressure on the subjacent surface will diminish along the interlobate lines to such an extent that the subglacial water will be forced by hydrostatic pressure from the centers of the lobes to their sides, and a subglacial stream of size determined by the rate of bottom melting will flow immediately beneath the superglacial stream. Thus the differentiation of the ice sheet initiated by an obstruction will be cumulative; the slackening of the ice flow in its lee relatively accelerates ablation, by which first preglacial and afterward subglacial streams are located, and the action of these streams joins with the tendency of the original obstruction to accentuate the lobation; and the cumulative process must persist until the once continuous ice sheet is divided into a series of tongues or ribbons.

But when the ice is cut through and the subglacial and superglacial streams unite in an ice cañon, the declivity of the upper

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[1] Bull. Geol. Soc. Am., Vol. 1, 1890, p. 87.

stream will diminish to the extent of the difference between the slopes of ice surface and land surface, and the subglacial stream will be relieved of hydrostatic pressure; and if the general slope of the ice and land is limited, the streams must begin to deposit the débris with which they may be charged. Now, without considering the possible sources of débris in detail, it suffices to say that by far the greater part of it must consist of glacial mud—the finest rock flour of the glacial mill. If, then, the interlobate cañon extends quite to the periphery of the ice, the débris will accumulate to an extent depending on the slope of the land surface; while if it terminates within the ice the cañon will be transformed into an ice-bound lake, within which the rock flour will be caught; and in a large area it may be assumed that a series of water bodies will be formed, some completely ice bound, some partially ice bound and partially confined by irregularities of the land surface, and others simply sluggish rivers bound between ice walls and opening upon land. In any event the fine deposits dropped within the water bodies may remain, after the final melting of the ice, to form eminences of distinctive composition and structure; and it is evident that in some cases a stream at first confined between ice walls might continue to keep its original channel even after the ice had retreated, so that the obstructing ridge might come to be cleft in its axis by a stream valley.

Ridges of peculiar composition and structure formed in this manner represent a category of the products of constructive action by ice and its schmeltzwasser, and most students are satisfied to assign kames, aasar, and several other kinds of sand and gravel accumulations to the general category; but the gracefully contoured ridges and domes of Northeastern Iowa are so distinctive in form and structure as to constitute by themselves a class worthy of distinctive designation. A suitable designation is not far to seek: They are the only notable eminences of the part of the territory in which they are well developed; they were the "hills" of the local aborigines, and the redmen of the Dakotan stock called them "paha"—singular and plural alike. This term was widely used among the Dakotas, and is an element in several aboriginal terms engrafted upon the geographic nomenclature of the whites, e. g., the Keyapaha of South Dakota, which flows alongside certain striking isolated buttes. Following, then, the usage of a former race of men, let these peculiar land forms be christened *paha.*

On reviewing the land forms produced by glacial action, they are found to fall naturally into the following arrangement, which represents a genetic classification, semi-arbitary as to some divisions it is true, yet the best which it seems feasible to frame:

Land forms produced by glacial action.

I. Direct products.
  1. Glacial processes:
    A. Destructive processes: U-cañons, rock basins, lateral cascades, cirques, rôches moutonnées or tors, striæ, lunoid furrows, etc.
    B. Constructive processes: Terminal moraines, lateral moraines, till-plains, drift-dammed lakes, kettles, etc.
    C. Compound processes: Lakes, plains, drumlins, mammillated surfaces, many ground moraines, etc.
  2. Aqueo-glacial processes:
    A. Destructive processes: Accentuated erosion forms.
    B. Constructive processes: Sand plains, silt plains, overwash gravel plains, kames, paha, etc.
    C. Compound processes: Great lake basins, etc.
II. Indirect products:
  Terraces.
  Coast plains.
  River flood-plains.
  The loess topography, etc., etc.

Northeastern Iowa is a land of the plain, and is destitute of the ice-fashioned land forms characteristic of montanic regions; but most of the ice-fashioned land forms of the constructive class characteristic of plains are there. Undulating and corrugated drift plains abound; knobs and basins of the terminal moraine type are inconspicuous, yet they are not unknown; plains of silt and clay ("gumbo") take the place of the typical sand plains; typical kames and aasar are indeed lacking, but they are replaced and the topography dominated by a wonderfully extended series of unique and characteristic land forms—the gracefully rounded and forest-mantled paha.

RIVER TERRACES.

ANALYSIS OF TERRACES.

The terrace is a plain of greater or less extent and of absolute or approximate horizontality of surface, overlooked on one side by more elevated land perhaps belonging to a similar but higher plain, and bounded on the other side by an escarpment; and commonly it is an implied term in the definition that the plain was originally at or below, but is now above, the water level. If the configuration and structure of the escarpment indicates that it is coeval with the plain, the terrace is *complete;* but if the escarpment was formed by erosion subsequent to the development of the plain, the terrace is *incomplete.* In the latter case two or more terraces may represent a once continuous plain out of which they have been fashioned; but, viewed genetically, each incomplete terrace is the remnant of a plain dissected by subsequent erosion—an accident quite independent of primary genesis—and thus the original plain from which the incomplete terrace is carved is homologous with the complete terrace. So, further analysis may be confined to complete terraces and to the plains from which the incomplete terraces have been developed.

In the simplest analysis, terraces may be separated into two categories, defined by general mode of origin, viz: (1) terraces of construction, and (2) terraces of destruction. Terraces of construction are formed of sediment deposited by streams or dropped and distributed by the waters, waves, and currents of lakes, estuaries, and seas; and the materials of such terraces rest, generally unconformably, upon a readily distinguished subterrane. Terraces of destruction are carved out of the firmer terrane by wandering streams and by the waves and currents of lakes, estuaries, and seas. A veneer of sediment is generally spread over the surface of such terraces, but this commonly yields to erosion upon elevation of the land or recession of the waters, and the undisturbed terrane with the residua derived from its decomposition in situ may alone remain to form the terrace plain and scarp. Sometimes hybrid terraces are formed by the processes belonging to the two categories combined, e. g., the sea cliff commonly comprises a wave-planed shelf of rock, which is connected with the subaqueous extension of the débris of the planing. But this classification of terraces is imperfect.

The same terraces may be again divided into four classes, defined by the specific mode of operation of the agencies by which they were fashioned, viz: (1) terraces of sedimentation, (2) beach terraces, (3) delta terraces, and (4) terraces of planation.

(1) Terraces of sedimentation may be built in sluggish rivers, lakes, estuaries, and seas; their surfaces and structure planes are usually inclined, and unless the water body in which they are built is subject to strong currents their scarps generally slope gently. When elevated above the level of the waters in which they were formed they represent geographic change due to lifting of the land or recession of the waters. They commonly grade into the second class of terraces.

(2) Beach terraces are fashioned by lacustral, estuarine, oceanic, and sometimes fluviatile waves and currents; they may be formed either by destruction or construction, or by both combined; they are preeminently characterized by linear horizontality of surface, and their scarps are commonly steep and, when formed by construction and complete, commonly of relatively coarse materials. When ancient, such terraces indicate the amount of lifting of the land since their formation by the altitude at which they stand; and they may indicate tilting of the land by departure from horizontality.

(3) Delta terraces are formed at the mouths of streams embouching into lakes, estuaries, and seas, and particularly those charged with matter carried in suspension and pushed along the bottom. As the current fails when the stream falls into the still waters, the matter held in suspension settles and that pushed along the bottom ceases to move,

while if the still water is saline the matter held in solution is precipitated; and thus there is built up a delta rising to, and eventually above, water level. Commonly the surface and structure lines of a delta terrace incline radially seaward from an apex; its surface is scored radially by channels of the shifting stream by which it was built; and its scarp is indefinite. The delta terrace grades into the terrace of sedimentation and into the beach terrace, and is also akin to the terrace of planation; and the part formed above the level of the body of still water is allied to the alluvial fan formed by a tributary of high declivity in the valley of a stream of less declivity.[1]

(4) Terraces of planation are fashioned by wandering streams which, either from the proximity of base-level or by reason of the presence of barriers, are incompetent to corrade vertically, and consequently expend their energy in lateral corrasion. They may be separated into two subclasses, (*a*) base-level terraces and (*b*) barrier terraces. When the land stands long at the same level with respect to the sea the river first corrades its channel vertically down to tide level, and afterward the shifting current impinges laterally against the bounding banks and the channel widens; and as the process continues the narrow channel is finally transformed into a broad flood plain over which the capricious stream wanders from side to side. In its wanderings the stream distributes detritus over the subterrane, and thus fashions an earth form which would constitute, if the land were elevated, a base-level terrace of destruction, masked by a veneer of evanescent alluvium. But if the land were either sinking or tilting away from the sea, its valley would be filled with the river detritus and the terraces subsequently carved out of the deposits would belong to the category of construction. Barrier terraces are formed in like manner when a dike, a ledge of hard rock, an alluvial fan, a beaver dam, an artificial obstruction, or diminished declivity due to tilting of the land interferes with the action of the stream; and the barrier terrace is homologous with the base-level terrace, save that it may occur at any altitude. Both are characterized by a gentle inclination of surface and structure line corresponding to the fall of the stream by which they were formed; and notable departure from such gentle inclination in terraces of either class is indicative of differential elevation.

All terraces of planation are river terraces; but the terraces found along rivers may include in some cases terraces of sedimentation, delta terraces, and perhaps beach terraces.

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[1] By at least one eminent American geologist such deposits are denominated "cones." "Fan," however, is not only a more appropriate designation for the greatly flattened conical segments to which the terms have been applied, but also has priority. In 1864 Haast and Hector applied the terms "fan" and "half-cone" to the subaerial accumulations at the mouths of "regular water courses" and "intermittent mountain torrents" respectively (Report on the formation of the Canterbury Plains, Haast, 1864, p. 20); they were followed in the use of the former term by Hochstetter in 1867 (New Zealand, pp. 507-509); and the same expression was again specifically applied by Drew to the characteristic accumulations of tributaries to the Indus on the road from Skardu to Leh (The Northern Boundary of India, 1877, p. 240; Quarterly Journal Geological Society, vol. xxix, p. 445).

THE FORMATION OF RIVER TERRACES.

Three theories of terrace formation, all applicable in the regions in which they were developed, have been prominently advocated by American geologists—by the elder Hitchcock,[1] Dana,[2] and Gilbert.[3]

The first of these relates to the terraces developed about drift-lined estuaries and lakes upon land surfaces just emerging from the waters, and upon which the rivers are newly born and the drainage systems are yet in process of growth. In such estuaries and lakes the débris gathered up by the rivers is supposed to accumulate, the coarser materials below, and the farther-transported and hence finer materials in newer strata, all successively laid down in the form of deltas and littoral shoals; and each grade of detritus is supposed to constitute a subaqueous shelf fringing the shores of the lakes and estuaries about the mouths of the rivers. In such a system each terrace is newer than the next higher member, and its materials are finer. The ideal section of such a system is reproduced in Fig. 9.

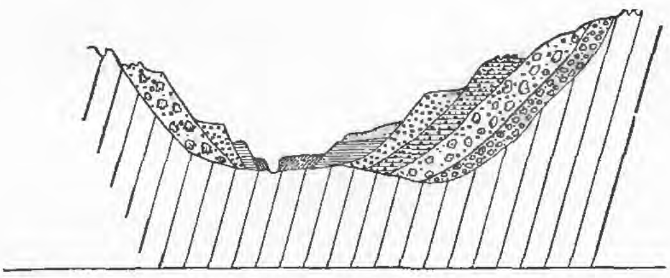

FIG. 9.—Hitchcock's ideal section of river terraces.

This may be called the deposition theory of terrace formation, and the products of the processes contemplated may be called *terraces of deposition*.

In the explanation of the terraces of the second class, there is postulated an ancient valley, completely clogged with sediments, and subsequently partially cleared by a secularly constant or progressively shrinking stream during either paroxysmal or uniform continental elevation, which may have been either uniform or more rapid inland, the excavation being effected by the gradual lowering of the flood plain, and the terraces constituting remnants of successive flood plains. In such a system of terraces each bench is indeed newer than the next higher member, but its materials are older, since each is a simple outcrop of partially eroded beds laid down in the natural order. All of the terraces are incomplete, and the degree of comminution of the deposits of each is determined solely by the condi-

[1] Illustrations of Surface Geology, Smith. Contr. to Knowledge, No. 90, vol. 9, p. 5 et seq., Pl. XII, Fig. 1.

[2] Am. Jour. Sci. 2d Ser., vol. 8, pp. 8-14, 86-89; Trans. Conn. Acad. of Sci., vol. 2, 1870, p. 84 et seq.; Am. Jour. Sci. 3d Ser., vol. 1, 1871, pp. 1-125; Ibid., vol. 2, p. 144; Ibid., vol. 5, 1873, p. 198, note, and 208-211; Ibid., vol. 10, 1875, pp. 409-438, 503-508; Manual of Geology, 1875, pp. 558-559, 644, fig. 944; and elsewhere.

[3] Geology of the Henry Mountains, 1877, p. 132.

tions of antecedent deposition and not at all by the agencies or conditions of the terracing per se. The ideal section of such a system of terraces is shown in Fig. 10.

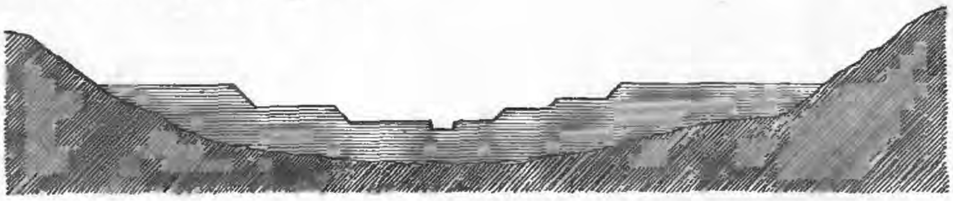

FIG. 10.—Dana's ideal section of river terraces.

Terraces of this character may be designated *terraces of reexcavation.*

In the production of the terraces of the third class there is required a water way (with its flood plain) lying not upon a sheet of drift, nor upon the débris clogging an ancient channel, but upon the normal terrane of the region; and the altitude is required to be such that the surface is progressively lowered by secular degradation, yet so slowly that a considerable part of the energy of the stream is expended in lateral corrasion. The remnants of successively parallel flood plains, perhaps covered with unconsolidated débris, constitute the terraces, which are thus "carved out and not built up." The ideal section through a system of terraces of this kind is reproduced in Fig. 11.

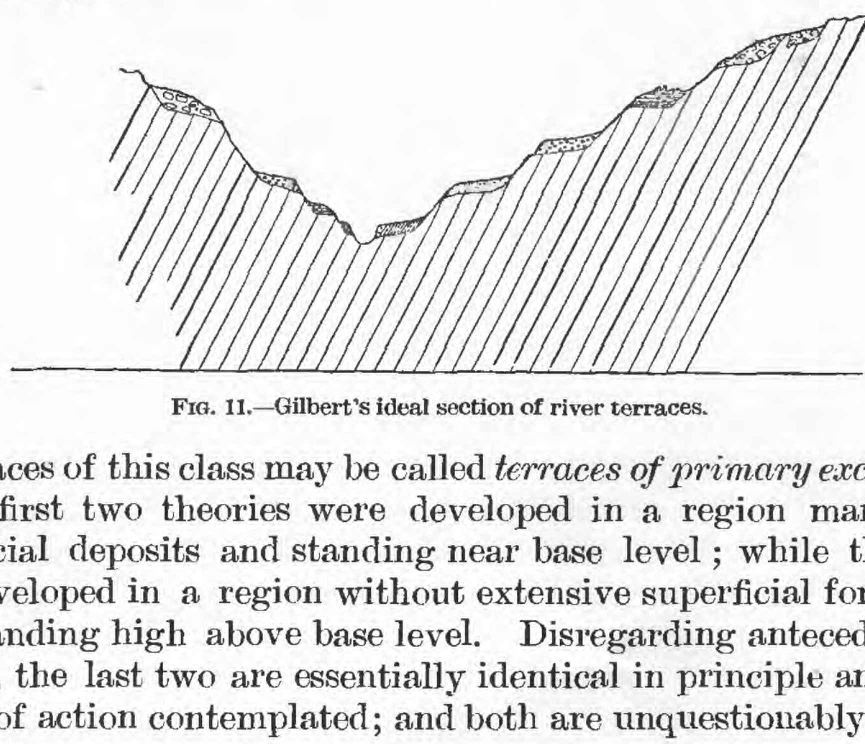

FIG. 11.—Gilbert's ideal section of river terraces.

Terraces of this class may be called *terraces of primary excavation.*

The first two theories were developed in a region mantled by superficial deposits and standing near base level; while the third was developed in a region without extensive superficial formations and standing high above base level. Disregarding antecedent conditions, the last two are essentially identical in principle and in the modes of action contemplated; and both are unquestionably valid.

Now, the river terraces of Northeastern Iowa may be thrown into two classes defined by structural characteristics: (1) In the larger valleys and about the confluences of the principal tributaries with the Mississippi there are extensive terraces, little affected by erosion, whose scarps are steep and built of coarser material than the bodies of the terraces. Such terraces are complete; they represent processes of construction; and they may be referred to the terraces of sedimentation of the foregoing analysis, or collocated with the deposition theory of terrace formation. (2) The terraces of stratified gravel, sand, and loam occurring on several rivers at considerable altitudes are, in part at least, remnants left after the partial reexcavation of previously clogged valleys, and so correspond with the reexcavation terraces of the foregoing review; yet they grade into low benches little beyond the reach of the modern waters and appear to represent one extreme of an unbroken series extending into the modern alluvium. There are no noteworthy terraces of primary excavation in the territory.

Classified with relation to the streams by which they were fashioned, the terraces may be separated into the high-level and low-level systems. The high-level terraces were unquestionably built under conditions unlike those existing to-day; the low-level terraces are unquestionably formed and destroyed alternately with secular changes in the regimen of the rivers; and it will be shown in a later chapter (V) that the two systems represent a continuous series.

Thus it would appear that the low-level terraces of the Iowa rivers and those features of the high-level terraces that are related thereto have not been fully explained; yet the manner of their formation was simple.

One who lives in a region of delicate adjustment between water work and configuration, such as the driftless area, can not fail to observe the alternate formation and destruction of miniature terraces in every minor valley and ravine within a period ranging from a year to a generation. The process is about as follows: In a valley of approximately uniform declivity and perhaps little alluvial accumulation a slight barrier is formed by an alluvial fan, a landslide, a beaver dam, a timber jam, or by artificial means. In the basin above the barrier the sediments of the retarded stream are dropped, and the basin is gradually filled; but deposition does not cease when the sediment reaches the level of the barrier, for the declivity (and with it the transporting power) of the stretch of the stream flowing over the little plain thus formed continues diminished, and additional detritus is spread over the plain surface during each freshet. Deposition may thus continue for years; and in consequence the plain rises, expands laterally, and extends upstream with a declivity gradually approaching that of the containing valley. If in prairie, the strath (applying the Scottish name for such circumscribed plains) becomes at once a fertile alluvial meadow, subject to periodic overflow; if in forest, the trees are killed by the deep burial of their bases and the strath more slowly becomes a meadow or glade.

The depth and extent attained by the alluvium vary with several conditions: If the barrier is an alluvial fan, the shifting tributary alternately flows upon and builds up the strath at the point where destruction must commence, and turns into the valley below, where the discharged débris constantly reinforces the obstruction. If, however, the barrier is a jam or landslide, its removal is more rapidly effected. In either case degradation finally attacks the obstruction and gradually extends into the strath, the locus of most rapid degradation being usually a rapid in larger and a fall in smaller or periodic streams.

When degradation has once become effective at the locus of the original barrier, the rapid or fall generally recedes upstream faster than the strath is extended, and forms a gorge in the alluvium, often reaching to the original floor of the valley. At the same time the walls of the gorge are eaten away by weathering and by the corrasion of tributaries and rain-formed rills, until eventually only narrow remnants of the strath fringe the valley sides and form veritable terraces extending upstream, with a somewhat less declivity than that of the valley, for a distance equal to that which the strath reached before its destruction began *plus* the sometimes greater amount of its upstream extension while destruction was in progress.

The completion of the first characteristic terrace (or pair of terraces, if the gorge follows the center of the strath) is often not effected, and destruction may hardly begin before a repetition of the cycle is inaugurated. After the recession of the gorge and the degradation of the strath are fairly initiated, one of three series of movements is nearly sure to come into operation: (1) An analogous strath may extend from downstream into the mouth of the lengthening gorge; (2) if the original barrier were an alluvial fan, a second fan may take the place of that degraded and develop a second strath within the first; or (3) the lessened declivity (and with it transporting power) of the stream at the foot of the gorge-cutting rapid or fall may cause an accumulation of detritus there of sufficient magnitude to initiate the formation of a new strath within the old. In any case the original process is repeated, and a second terrace or pair of terraces is developed.

In rare cases a third cycle is inaugurated before the obliteration of the first formed terraces is accomplished; but such third terraces seldom rise much above the normal flood plain while a vestige of the first remains.

Terraces thus developed are of rudely stratified alluvium, finest above; and the higher terraces are the older.

In some quite small periodic streams the cycle is completed in five or ten years, and the birth, development, decadence, and final dissolution of the successive straths and their resulting terraces have been observed in the same valley. In the larger periodic and smaller permanent streams the stages of half a cycle have been noted, progressing at such a rate as to require quarter or half of a century for its completion; in mill-streams single stages (but all stages in various streams) have been observed during such period as to indicate a cycle of some hundreds of years; while in still larger streams the stages are obscure, and the alteration during a score of years is too inconspicuous to attract attention.

The predominant and most effective natural barriers are those formed by tributaries. They may be either well defined alluvial fans, heaps of rock fragments swept from precipitous ravines, or the broad, gently swelling delta plains common to the debouchures of larger streams.

Now, alluvial fans are characteristic of great rivers as well as trifling streams; they have been observed and described by a score of geologists; in many cases they are associated with extensive systems of terraces; yet they have rarely been regarded as agencies in terrace formation.

The important modification of stream courses by alluvial fans was elaborately illustrated in 1873 by Drew in his description of "The alluvial and lacustrine deposits and glacial records of the upper Indus basin;"[1] yet, though the valleys are there beautifully terraced[2]—indeed, as noted by Hooker,[3] terraces are characteristic of the Himalayan region—and notwithstanding Godwin-Austen's previous description of Indian fan-dammed lakes[4] no genetic connection between the two classes of phenomena was here traced. Subsequently, however, the origin of the extensive saline lakes of Ladakh was referred to the damming of their valleys by alluvial fans,[5] and the fertile village tracts of the Indus valley were ascribed to a like cause.[6]

Some of the finest examples of fan-dammed rivers thus far described occur in British Columbia. According to G. M. Dawson, the Frazer and Thompson Rivers abound in fans which have formed unnumbered lakelets and several considerable lakes. Thus, Kamloops Lake, 17¾ miles long, 1¾ miles in average width, and 450 feet in maximum depth, is simply an expansion of Thompson River caused by the Deadman's Creek fan, and is itself nearly divided at two points by smaller fans;[7] the much larger Shuswap Lakes appear to be similarly formed; the smaller is separated from the larger by the Adams Creek fan, and both are deeply indented at several points by like accumulations;[8] and all of the numerous lakes mentioned in the report and depicted upon the accompanying maps appear to be of related origin. Terraces are a characteristic of the region. "The

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[1] Quart. Jour. Geol. Soc., 1873, vol. 29, p. 441 et seq.

[2] Loc. cit., pp. 450, 458, 460, 464, and elsewhere.

[3] "Himalayan Journals," 1855, vol. 1, p. 232.

[4] Jour. As. Soc. Bengal, 1868, vol. 37, pt. 2, pp. 84-117.

[5] The Jummoo and Kashmir Territories, 1875.

[6] The Northern Barrier of India, 1877, p. 240.

[7] Geol. Surv. of Canada, Report of Progress for 1877-'78, 17b.

[8] Loc. cit., 21b.

interior is marked with shore-lines and terraces from the present sea-level up to 5,270 feet."[1] Some of these terraces are supposed to "owe their origin solely to the damming up of valleys by glacier ice or moraines;"[2] but, singularly, no like effect is attributed to the fans.

It has been shown by Warren[3] that the upper Mississippi is similarly obstructed by the fans of all its principal tributaries, and that one of these, the Chippewa River, has caused the formation of the extensive Lake Pepin. But Warren laid no stress on the fact that the shores of Pepin are flanked by a low and well defined terrace of recent aspect, made up of stratified loams and sands, which forcibly suggests that the lake is either now decadent or has not yet reached the altitude of an earlier homologue; though if the recent view of Comstock and Harrison[4] that the bed is rising be correct, the latter (and theoretically the more probable) alternative alone is admissible.

The cutting off of the Gulf of California by the Colorado delta, described by Blake,[5] illustrates the same tendency on a still grander scale, as does also the upstream shifting of the mouths of the northern tributaries of the Ganges, pointed out by Fergusson.[6]

Swift as well as large rivers suffer retardation in like manner, for, as shown by Powell[7] and Dutton,[8] the rapids and falls of the Colorado in the tumultuous part of its course are chiefly due to the accumulation of coarse débris at the mouths of tributary cañons. In such cases the irregularities of gradient are, however, due to diminished corrasion rather than increased sedimentation above the obstructions.

Analysis of the laws controlling sediment-bearing streams indicates that this apparently eccentric behavior on the part of all streams, from the purling rill to the rushing river, is consistent and harmonious.

While, as shown by Gilbert,[9] the capacity of a stream is greater than that of the forming tributaries combined if the declivity remains constant, yet the departure from equality in declivity accompanying alteration in volume introduces a new and diverse series of values

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[1] Geol. Surv. of Canada, Report of Progress for 1877-'78, 135b.

[2] Loc. cit., 148b.

[3] Report to Chief of Engineers, 1867; "Essay concerning important features exhibited in the valley of the Minnesota River," 1874. Also, "Report on Bridging of the river Mississippi," 1878, chap. 2 (reprint), p. 5; Am. Jour. Sci., vol. 16, 1878, p. 420.

[4] Ann. Rep. of the Chief of Engrs., 1881, vol. 3, p. 2744.

[5] Explorations and Surveys for a Railroad from the Mississippi River to the Pacific Ocean, 1856, vol. 5, p. 236.

[6] Quar. Jour. Geol. Soc., 1863, vol. 19, pp. 342-347, pl. XII. Mentioned also by Blanford, "Manual of the Geology of India," 1879, vol. 1, pp. 405, 412.

[7] Exploration of the Colorado River of the West, 1875, pp. 82, 97, etc.

[8] Second Ann. Report of the U. S. Geol. Survey, 1882, p. 160. Tertiary History of the Grand Cañon District, 1882, pp. 441, 445.

[9] Geology of the Henry Mountains, 1880, p. 114.

for the several elements involved, and hence no far-reaching consequences can be directly deduced from the proposition. It is even possible that in certain cases increment of differential flow, etc., may exceed the decrement of velocity, when the proposition will fail.

Let a stream and its tributary have like velocity. Since friction varies roughly as the square root of the volume, it is in relative excess in the tributary. Hence greater declivity is required in the tributary.

Now, this excess in declivity of the smaller stream sustains a certain definite relation to the volume which, if formulated, would denote the general law of river gradient—the law expressed by Gilbert in the terms, "cæteris paribus, declivity bears an inverse relation to quantity of water."[1] This may be defined as the *law of river gradation.*

But capacity is largely increased by inequalities of current, as the last-named authority intimates,[2] even if it is not indeed mainly dependent upon differential flow, as urged by Dupuit;[3] and as differential flow is the direct result of friction, it follows that capacity is in excess in the tributary in an increasing ratio with the inverse volumes.

Also, corrasion depends on friction, and will hence progress the more rapidly in the tributary, and in an increasing inverse ratio with the volumes; and, since capacity is similarly increased, the products of corrasion will be all transported.

Moreover, corrasion is increased by contained detritus, and hence the tributary will, for another reason, the more rapidly accumulate detritus in a ratio increasing as some power of the inverse volumes.

There is thus the cumulative increase from three interdependent elements, and in more than the simple ratio of each element, in the corrasion and capacity of the tributary. Now, so little is known of the friction of compound fluids (such as detritus-laden water) that these elements can not be quantitatively evaluated for any particular case; but so rapid is the cumulative increase that it is safe to conclude from simple inspection that the general tendency of tributaries must be to overload the main streams and clog their channels, and to build alluvial fans. This conclusion is sustained by observation.

Finally, when deposition at the tributary mouth is once inaugurated, declivity will be reduced and velocity diminished there, and the capacity will consequently suffer diminution in the approximate ratio of the sixth power of the velocity. The building of fans by tributaries is hence a normal process, and must occur in all streams unless local conditions prevent.

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[1] Loc. cit., p. 114.

[2] Loc. cit., p. 106.

[3] "Études theoriques et pratiques sur le mouvement des Eaux Courantes." Cited by Humphreys and Abbot: "Physics and Hydraulics of the Mississippi River," 1876 (reprint), p. 135.

Like relations obtain between the various parts of a stream of increasing volume; hence in an increasing stream corrasion must be in excess toward the source, and if it be a depositing stream, sedimentation must be in excess toward the mouth until the normal gradient (i. e., the concave upward gradient determined by the law of river gradation) is developed.

As long ago demonstrated by Hopkins,[1] the moving force (of which capacity is a function) of a stream varies as the sixth power of the velocity, while corrasion varies roughly as the square of the same element.[2]

Actually the difference could never quite reach the value $v^6—v^2$. In Hopkins's analysis the pressure is supposed to act against a stationary particle ; but as soon as movement occurs the pressure is diminished; whence competence actually increases in a somewhat less ratio than the sixth power of the velocity. Minor elements also affect the process of corrasion, and serve to augment its ratio to something beyond that stated. Hence, if a stream is retarded and drop a portion of its load, the burden can not again be taken up without a material increase in velocity. If lithification of the dropped particles intervenes, the increase must approach $v^6—v^2$; if only partial lithification occurs, the increase may be correspondingly less; but it can never become so low as $v^6—v^6$ (or 0), because, even if mutual cohesion were nil, the agglomerated particles would exclude the water, and thus transform the equal pressure of Pascal's law into downward pressure of the superincumbent column of water. The disposition of a loaded stream is thus to increase such barriers as tributaries or other agencies may place in its way.

In the impossible case of a stream without detritus, and yet eroding its bed in the normal manner, the lessened declivity would diminish corrasion above the obstruction in the same ratio as it was increased below, and the tendency might be simply to perpetuate the barrier were it not for the slightly increased friction and differential flow accompanying the attenuation of the stream below, which factors would ever tend slowly to remove all obstructions having the normal obduracy of the terrane.

In a lightly laden stream (such as a clear running mountain brook) corrasion will similarly be diminished above and increased below any obstruction, which, if of finite length, will form a plane of low declivity above and a plane of high declivity below its crest, superposed on a plane of normal declivity (Fig. 12. The three planes, beginning with that of low declivity, may be numbered in their order, and together denominated *planes of varigradation*).

The impact of the more rapid water at the head of the first plane

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[1] Trans. Camb. Philos. Soc., vol. 8, pt. 2, 1844, p. 233; Phil. Mag., vol. 27, 1845, p. 58; Quart. Jour. Geol. Soc., vol. 8, 1852, xxvii. *For "moving force" Gilbert substitutes the more acceptable term "competence"* (op. cit., p. 104).

[2] Cf. Leconte, Geol. Mag., vol. 9, 1882, p. 288; "Elements," rev. ed., 1882, pp. 11, 20.

will there most rapidly degrade the channel, and thus relatively elevate its distal portion—the crest of the obstruction. Down the slope of the second plane the velocity, and with it the corrasion, will progressively increase from that normal to the first plane, to again diminish on the third plane. Thus the lower portion of the second plane and the upper portion of the third plane will most rapidly suffer degradation; and thus again the crest of the obstruction will be relatively elevated.

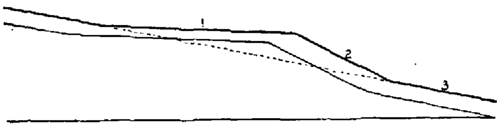

FIG. 12.—Planes of varigradation.

If the stream is so charged with detritus or if the barrier is of such height that deposition occurs on the first plane, then that plane will be protected from erosion in its upper part, and the waters flowing over the crest will be despoiled of the contained matter essential to effective corrasion; and the differential degradation will be accentuated.

Should the declivity of the first plane become so reduced as to develop wandering and convolution of the stream, degradation would be further reduced and the plane for another reason relatively elevated.

It follows that the tendency of all streams of increasing volume is to form barriers, and when the barriers are formed to increase their height, and thus ever to depart from the normal gradient.

In loaded streams the tendency is to drop the heavier particles immediately below the foot of the upper normal slope and near the head of the first plane of varigradation; and if this plane is long, a second barrier will here be formed, dividing the original plane of low declivity. It follows that such planes must be short; for if originally long they will suffer subdivision until the disposition becomes to heap up the first formed barrier. If, however, the original barrier is increased by other means (say by fan-accumulation), the declivity below must always exceed that which can be formed by the stream above; and hence the tendency may be to develop a long plane of low declivity, or strath, itself including diverse minor departures from its normal gradient.

In lightly laden streams corrasion will similarly diminish in the upper part of the first plane; and in like manner the tendency will be to form a second barrier at such point, and if the original barrier be an obdurate ledge, the disposition to form a variable plane of low declivity may equally obtain.

Neglecting the minor elements introducing irregularities, the distance to which detritus will be borne on the first plane, and similarly the point at which corrasion will reach a minimum, may be regarded as determined by the efficiency of the momentum acquired on the upper plane of normal declivity; and this in turn is regulated by friction. Hence the length of the successive planes of unlike declivity is a function of the volume, and increases in an increasing ratio with that element. The larger the stream, then, the longer the planes of varigradation.

If varigradation is long continued, the heaping up of detritus on the first plane will tend to produce ponding and increased deposition or diminished corrasion there, and unless the altitude is high, base-level back water will eventually accumulate at the foot of the second plane with like results. Moreover, after the declivity of the latter plane becomes considerable, the efficiency of corrasion will diminish as the sine of the angle of slope—a rapidly increasing ratio.

But before veritable ponding occurs, deposition will increase and corrasion diminish in the gradually deepening waters at the head of the plane of low declivity, and in consequence degradation there will gradually diminish until it no more than equals that at the foot of the same plane. The moment of incipient ponding is hence the measure of maximum departure from the normal gradient.

Now, incipient ponding is determined by facility of flow upon the plane, and is hence a function of friction. It will accordingly occur the sooner in the smaller stream in an increasing ratio with the inverse volumes, or proportionally with the normal gradients; but the smaller stream will, on the other hand, the longer continue corrasion and transportation at the locus of incipient ponding in the greater ratio afforded by the three coordinate and cumulative elements efficient in fan-building, and will consequently the more reduce the relative inclination of its plane of low declivity before ponding is definitely initiated; whence maximum departure from the normal gradient, as a function of the length of the planes of varigradation, is the less in the larger stream in a complex ratio of the inverse volumes.

It follows that the tendency to depart from normal gradient is not infinite, and can not, without material aid from rock structure or kindred elements, even produce water falls; also that varigradation diminishes in relative importance as streams augment in volume.

In two streams of unlike volume but proportionate barriers, the flow of the larger is the less impeded by friction, and this stream accordingly drops the less share of its load upon the plane of low declivity; also, it the sooner gains velocity and begins corrasion on reaching the plane of high declivity; and equally it bears the greater share of suspended detritus to aid in the corrasion of this plane.

Similarly, in lightly laden streams corrasion of the larger is the less diminished on the first plane and the earlier and more largely augmented on the second plane. The ratios, being functions of the friction, are complex, but increase cumulatively with the volumes.

Varigradation is accordingly the more rapid in the smaller stream in an increasing ratio with the inverse volumes.

The probability of natural formation of a stream barrier of given size may be supposed to diminish inversely as some power of its content. Then, when proportionate barriers are formed in streams of unlike volume, the larger stream will be the less impeded by resulting friction, and will hence the less rapidly drop its load or cease to corrade; also, the differential flow will be relatively less in the larger stream, and one of the effects of the barrier will be to increase this element, and with it the capacity of the stream; whence the proportionate barrier, if small, may fail to initiate varigradation in the larger stream.

It follows that the probability of varigradation is the less in the larger stream in a rapidly increasing ratio of the inverse volumes.

Recapitulating, it appears that all streams of progressively increasing volume are controlled by two antagonistic laws of unequal potency. In obedience to the major and more general law, all such streams, whether corrading, depositing, or both combined, tend ever to approach a uniform gradient describing a curve perhaps parabolic. In obedience to the minor and more special law, all such streams, whether corrading, depositing, or both combined, tend constantly, but in a degree varying inversely with the volume, to depart from such normal gradient in small amounts.

Now the fundamental categories of processes by which the surface of the earth is modified and geologic history recorded are deformation and gradation.[1]

Gradation comprehends degradation and deposition. The first comprises all those processes by which the land is eroded and its detritus carried into the sea. Foremost among these processes stands hydrodynamic degradation; but rivers deposit as well as degrade, and so establish for themselves their characteristic concave upward gradients, and the law under which they act has been called the law of fluvial gradation; and the minor law in accordance with which they tend to depart from this normal gradient may be called the *law of fluvial varigradation*, and the minor process may be called simply *varigradation*.

Both of these laws are in accord with the phenomena of alluvial fans in great rivers and in streamlets alike, and both may be seen

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[1] Nat. Geog. Mag., 1888, vol. 1, pp. 27-30; Geol. Mag., Decade 3, 1888, vol. 5, pp. 489-492; Trans. Minn. Acad. Sci., 1889, vol. 3, pp. 191-206.

in constant operation wherever waterways exist. The potency of the first is illustrated by the nearly universal increase in declivity toward stream source, so well exemplified in "bad-lands;" and the efficiency of the second is equally demonstrated by the alternation of pools and rapids in every mountain brook, and by the analogous but less conspicuous alternations in mill streams and rivers.

Under certain circumstances, varigradation must affect terrace formation, and the effect in half a dozen cases may be briefly considered. The following are the cases:

(1) Secularly uniform (though not necessarily non-periodic) stream volume with the land little elevated above base-level.

This case is that of the driftless area streamlets and of many of the fan-dammed rivers of to-day; and the processes and products have been already set forth. Lateral corrasion tends to exceed vertical cutting, and the constant wandering of the stream insures and hastens the ultimate removal of all strath remnants. Terraces formed under its conditions must be transitory and of relatively inconsiderable magnitude, though perhaps of great absolute volume (as are the Lake Pepin terraces) when built by large rivers.

(2) Secularly uniform stream volume with the land rising or standing high above base level.

In this case vertical cutting will tend to exceed lateral corrasion; and so, after channeling its strath, the stream will energetically attack the bed-rock below and leave the strath remnants to be reduced by the slow process of weathering, while their relative altitude will be increased by the degradation of the stream way, and their bases will ever be protected by the obdurate foundation upon which they rest. The ultimate destruction of these strath remnants may lag far behind the deepening of the channel if the land stands far above base level or is rising rapidly; and high, but perhaps narrow, terraces of coarse material should thus be developed.

(3) Increasing stream volume with low land.

In this case the transporting capacity and corrading energy of the stream will together suffer relative diminution, but predominant absolute increase; and accordingly vertical cutting will augment at the expense of lateral corrasion, and wandering of the stream will be checked, the base level of erosion will be slowly lowered, and inconsiderable strath remnants, protected by obdurate substrata, may occasionally escape destruction, despite the increased energy and width of the enlarged stream.

(4) Increasing stream volume with high or rising land.

In this case the elements favorable to terrace building in the second and third cases are combined, and hence the tendency must be to develop and perpetuate considerable strath remnants and to relatively elevate them far beyond the flood plain by progressive degradation of the channel.

(5) Diminishing stream volume with low land.

In this case lateral corrasion will remain predominant, and while the diminished energy and contracted width of the stream will conjointly reduce the probability of degradation of the strath remnants, this disposition will be antagonized and perhaps more than counterbalanced by the cumulatively increased wandering resulting from loss of velocity going with the diminution of volume; and the low terraces possibly formed during given cycles will be buried beneath the accumulating detritus of the enfeebled stream during succeeding cycles, and the channel will be clogged and a "drowned river" formed.

(6) Diminishing stream volume with high or rising land.

In this case the element antagonistic to the formation of terraces will be eliminated if the declivity remains, such that the stream continues to attack the bed-rock as each strath is channeled. Lateral corrasion will be reduced by contraction of the stream and concomitant loss of absolute energy, while the corrasive energy will be relatively but slightly augmented by the increase of friction and of differential flow going with reduction in volume; and if the terrane is such that vertical corrasion remains far in excess of the concurrent recession of the cañon walls through sapping, the strath remnants formed and the rock surface carved out during successive

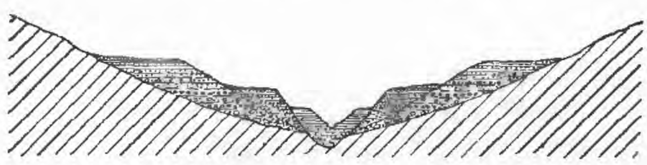

FIG. 13.—An ideal section of river terraces.

cycles in the vertical and horizontal wanderings of the stream may exceed in width and continuity, if not in number and height, those developed during any other case.

The last case is that of the rivers of Northeastern Iowa. As proved by a large body of cumulative evidence, the land stood low when burdened by the weight of the Pleistocene ice sheet, while with the recession of the ice the swollen rivers shrank and the land rose toward its present altitude; and it was concurrently with the shrinking of the streams and the rising of the land that the older terraces of the Oneota, the Turkey, the Maquoketa, the Wapsipinnicon, and several other rivers were formed. In structure these terraces are sheets of stratified débris, finer above and coarser below, and finer in the newer (and inner) terraces than in the older, slightly inclined, as to both surface and structure lines, in the direction of stream flow. A section which is at the same time a generalization of observation upon the later Pleistocene terraces of Northeastern Iowa and an idealization illustrating the last-described case of terrace formation is shown in Fig. 13.

The importance of varigradation in the formation of terraces must not be overestimated. Let it be observed that in every case in which the tendency is toward the development of considerable terraces the conditions of increased declivity or augmented volume are such as relatively to diminish the efficiency of given tributaries and of the primary movements of varigradation; that the characteristic process of varigradation by deposition, rather than by degradation, is antagonized by normal gradation; that, as regards high terraces, varigradation is but the initiatory process which induces and prescribes the courses for subsequent processes of terrace development; and that only in the formation of minor terraces is varigradation the sole agency involved.

The river is at the same time the most potent and the most capricious of geologic factors, the most stable and the most unstable of agents. The waters falling upon the land gather into rivers, and no power is sufficient to prevent them from thus concentrating their energy; the rivers carve for themselves channels, and the craft of man does not suffice to divert the great river from its channel; yet when the river is old and flows in a bed built within its former channel it strives to escape from that bed, and, bursting its self-imposed barriers with each self-produced freshet, wanders capriciously from side to side of the broader channel; but if the land is rising or the stream shrinking the old bed may not be revisited until it is beyond the reach of the waters, when a terrace is formed. In like manner it establishes a gradient of consistent slopes from the divide on which its waters first gather to the sea into which its augmented waters fall, and so persistently does it maintain this gradient that man can interfere with it only at great pains and cost; yet when the tributary interposes an obstruction to its course the river capriciously abandons its former gradient and cooperates with the tributary in increasing the obstruction until it has departed far from its optimum form, only, after a season, to attack the obstruction with latent fury, and not only obliterate but eradicate it; but if the land is rising or the river shrinking, a part of the sediments built behind the obstruction may remain beyond the reach of the stream in any subsequent vicissitude. So the lateral and vertical wanderings of the stream may initiate terraces, and if other conditions are favorable these terraces may be perpetuated.

Recurring to the review of theories of terrace formation, it appears that in Northeastern Iowa there are terraces of sedimentation and probably of reexcavation, though not of planation; and that there are also other terraces which, in accordance with the foregoing considerations, may be considered terraces of varigradation, since varigradation appears to be the agency by which they were initiated.

Recurring to the analysis of terraces, it appears that there is a class of incomplete terraces of construction formed by rivers in consequence of evanescent and self-constructed barriers which, although formed by processes akin to sedimentation, yet possess such individuality as to deserve place by themselves; and so the analytical conspectus of terraces assumes the following form:

- I. Terraces of construction:
    - 1. Terraces of sedimentation.
    - 2. Delta terraces.
    - 3. Terraces of varigradation.
- II. Terraces of destruction:
    - 1. Terraces of planation.
        - (*a*) Base-level terraces.
        - (*b*) Barrier terraces.
- III. Compound terraces:
    - 1. Beach terraces.

Recurring to the intimate relation between the modern alluvium and the later Pleistocene deposits of Northeastern Iowa (mentioned above and described in detail in chapter v), in consequence of which they may be regarded as representing the extremes of a single uniform series of events and episodes rather than two distinct series, it appears that the sequence is a veritable one through the terraces of varigradation: it appears that the lateral and vertical wandering of the streams beginning in the later Pleistocene initiated terrace formation, and that the wandering has continued down to the present and at every stage has initiated terrace formation anew. Yet the younger terraces are but pigmy representatives of a line of giant ancestry.

SECTION IV.—STRATIC GEOLOGY.

For centuries the traveler by the wayside, the husbandman on the hillside, the miner in his shaft or pit, even the child playing by the brookside, have noticed that the rocks of the earth lie in beds; and all have vaguely classified the beds as limestone, shale, sandstone, slate, marble, quartz, etc., according to their external appearance. At first this vague classification was accepted and elaborated by more systematic students of earth lore.[1] Thus the earliest conceptions of geology were formed.

Nearly a century ago William Smith, an English surveyor, noticed that the beds of shale, limestone, sandstone, chalk, etc., may be arranged in definite groups, and that each group contains certain characteristic fossils which are rare or absent in adjacent groups of beds; and so his disciples classified the groups of beds by their

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[1] Cf. Petralogy—A Treatise on Rocks, by J. Pinkerton. London, 1811 (2 vols).

contained fossils rather than by the appearances of the beds themselves, and correlated widely separated exposures of the strata by means of these fossils. Thus the science of geology found birth.

As the study of the rocks progressed, it was found that the animals whose remains are entombed within them differ from those now living on the surface of the earth and in its waters; and first the fossils and then the rocks came to be classified in terms of the relations of the extinct forms of the modern ones, and it came to be recognized that each well defined group of formations represents a well defined episode in the history of the earth. Gradually the fossils of the earth were found to belong to three great assemblages, and the rocks containing them to three great systems. The first and oldest of these rock systems, as shown by its position beneath the others and by the wide divergence of the organic types from those of to-day, is called Paleozoic; the second, which occupies an intermediate position and which includes organic types approaching those of the present, though their minor characters are distinctive, is called Mesozoic; and the third, which occurs above both the others and in which the forms approach those of to-day, is called Cenozoic. There is thus a fundamental classification of the fossiliferous rocks of the earth, based wholly on the earth's life history and therefore purely biotic, which seems to be applicable throughout the world.

Within each great assemblage of fossils and each system of rocks there are sometimes several groups of fossils and of rocky strata which maintain their distinctive characters over wide areas; and names, taken generally from localities of typical development, but sometimes from the petrographic character of the strata, and again from the relations of the organic forms to those of the present, have been assigned to these groups. Early observation within limited areas and accepted dogma led to the belief that each of these groups of strata with its contained fossils records a definite period in the history of the earth, and that these periods were separated by cataclysms or catastrophes of worldwide extent, now represented by breaks in the succession of the strata, or unconformities. This belief, born of dogma and nurtured on local sentiment, is fading away as distant parts of the earth are becoming known. It is now recognized that the groups are not always separated by unconformities, and that while certain of them are continuous throughout given continent they are not universal throughout the several continents. It is recognized in consequence that the groups do not represent definitely limited periods in the development of the earth as a whole, but only episodes in the development of considerable parts of the earth; and so, while it is admitted that the division of geologic strata into groups characterized by certain assemblages of fossils and certain characters of the strata is only partly natural and partly arbitrary, the classification into groups is generally retained in the interests of convenience and of uniformity in nomenclature.

The great groups of rocks which are made up of strata or beds of limestone, shale, sandstone, or other material are often similar through considerable thicknesses or over considerable areas in which the fossils are frequently distinctive. These subordinate series of strata are limited sometimes by unconformities, but more frequently by changes in structure or composition; and while the assemblage of fossils—or fauna—of each may be distinctive, individual fossils generally run up and down into the adjacent series of the same group. These subordinate divisions are usually called formations; and, just as in the infancy of geology the groups were regarded as of world-wide extent, so in the youth of the science the formation was, through association of ideas, supposed to stretch from point to point in the continent, or even from continent to continent. This pernicious notion survived long, but has at last fallen before the array of facts gathered from many lands, and it is now considered that each formation represents the relations of a definite set of rock-forming agencies acting throughout a definitely limited period of time within a more or less definitely limited area which may be called a geologic province; it is recognized that the organisms whose remains are entombed in the rocks selected habitats determined by the same natural conditions that determined the operation of the rock-forming agencies, that they sometimes were either destroyed or greatly multiplied by, but more frequently migrated with, such changes in conditions, and that there is accordingly a relation between rock structure and fossil contents; and thus it is considered that the formations only represent epochs in the history of localities within the continent.

The rocks of Northeastern Iowa have been the subject of study by Owen, Hall, Whitney, Worthen, White, Whitfield, Calvin, Barris, Norton, Webster, and others; and the formations have been classified and named in accordance with gradually enlarging views of geologic taxonomy. In general, the arrangement and nomenclature thus developed is retained. Unimportant changes only have been made in two or three cases for reasons set forth fully in other pages.

SECTION V.—THE PRODUCTS OF ROCK DECAY.

The rock is the popular emblem of strength and permanence; but to the wise student it is the symbol of impotence and evanescence.

In the ultimate classification, the subject-matter of the science of of the earth is divided into processes and products. The processes are the physical forces, and the products the tangible results of the operation of these forces; the processes are causes, and the products effects; the processes include the molecular motions among gases, liquids, and solids together with the molar motions dependent thereon, and the products include aggregations of matter determined by these motions.

The rock is one of the products of geologic process; it is unmade as easily as and more quickly than it is made; and the rock, like the organism, like the planet, like the stellar system, like the cosmos, is never stable but ever changing, and always represents some stage in an endless cycle of aggregation and segregation, construction and destruction.

The exposed rock surface is beaten by the raindrops, strained by unequal expansion and contraction resulting from change of temperature, rent asunder by the freezing of water within its pores, cleft by the insinuating rootlets of plants, and bruised by its own dislodged particles during storms; and so it is mechanically disintegrated. Some of the mineral compounds in the exposed rock surface are attacked by the oxygen of the air and the hydrogen of the waters, some are more energetically attacked by the carbonic acid of impermeating air and infiltrating water, and nearly all are yet more powerfully attacked by the acids employed by living plants or set free in the decay of dead plants; and so the rocks are chemically decomposed. Thus by the combined mechanical disintegration and chemic decomposition the rock surface is perpetually destroyed and its materials carried away.

The exposed rock surface may be smooth and bright—but if so the rock is in its youth as a part of the external earth. The rock surface may be rough with pits and wrinkles and hoary with lichens—and if so it is a patriarch, for the pits and wrinkles are the points of attack by air and water, and the rootlets of the lichens are sapping its substance. The rock may be buttressed, pillared, and bound with massive cornices like the temple of a Titan—and if so it is a senile weakling, much of its body is already gone and the buttresses, pillars, and cornices are rapidly going.

A master in geology has taught that the high mountain is the young mountain; for the destructive processes of earth-making are always at work, and the mountain that rears its head high must be either newly grown or yet growing, else they would have robbed it of its crown and even carried its body into the sea. And, in a like manner, it may be said that the hard rock surface is a new surface; for the rock destroying agencies are ever operative and quickly destroy the hard rocks and bury them beneath their own débris. The débris formed by rock destruction is soil. So the new mountains are high, and the new continents and provinces are rocky; while the old mountains are low, and the old continents and provinces are soil covered.

The agents of rock destruction are not equally energetic everywhere: In the tropics generally the rainfall is great, and where vegetation grows luxuriantly and decays rapidly they are indefatigable; in the temperate zones they are more sluggish; and toward the poles, where the rainfall is slight and vegetation sparse, they are indolent. In general the activity of the processes and the volume of their products diminish as latitude increases.

Again, it is near sea level that the rivers move with least rapidity and that vegetation is most luxuriant, and in consequence that rock destruction most exceeds rock removal. On table-lands and low mountains the streams are more energetic and the vegetation less luxuriant, and there rock destruction and removal of rock débris are more fairly balanced; while upon high mountains and along sharp crests where the rivers are most active and vegetation absent, the rock removing agencies are most industrious and ever await the tardier agencies of rock destruction. So, in general, the volume of disintegrated rock and soil decreases as the altitude increases.

In every country the rock terranes long exposed to the action of the elements are buried beneath a mantle of their own débris. The Blue Grass region of Kentucky is famous by reason of the soil derived from the decomposition of the subjacent limestone formation. At Washington the Piedmont gneiss is disintegrated, sometimes to a depth of more than 100 feet, or many feet below tide level. As shown by Russell, the depth of decay of these gneisses and the associated limestones, sandstones, and shales of the Appalachian mountains increases notably southward. The excavations for the St. Gothard tunnel prove that the rocks of the Alps are disintegrated to a depth of fully 1,000 feet; and the extensive plains of equatorial Brazil represent the product of rock destruction apparently extending to hundreds of feet in depth over hundreds of thousands of square miles.

A considerable part of the United States is floored with a sheet of glacial drift. Beyond the drift limit there are considerable areas of alluvium formed by rivers and small streams, of lacustral deposits formed in lakes now drained or evaporated, of torrential deposits upon mountain slopes; there are restricted areas covered by wind-blown dust and sand; there is an absolutely great though relatively small area of bare rock, particularly among the new or growing mountains and plateaus of the west; but the balance and greater part of the national domain is mantled by the products of the decomposition of the rocks in place.

Within the southernmost limits of the glaciated tract there is an isolated area which the ice-plow failed to touch—the driftless area of Wisconsin and three contiguous States; and this area, like the territory beyond the ice limit, is mantled by the products of local rock decay. This area extends into Northeastern Iowa.

Despite its extent and its accessibility, the superficial mantle of rock débris has received comparatively little attention; it was too common to inspire the enthusiasm of research in the local student, and like the drift of a generation past was by many regarded only as an annoying obstacle to investigation of the underlying rocks.

Yet within recent years many American chemists and geologists have found it a worthy subject of study. Hunt has well elucidated the conditions of its origin, and has seen within it a record of chemic activity varying through the ages with changes in atmospheric condition and climate; Pumpelly has seen within it a possible source of vast æolic deposits; Julien has ably set forth the influence of the humus acids in decomposing rocks and producing soils, and has, like Hunt, seen within the products a record of variable activity in rock destruction and of considerable changes in the climate of the earth during the geologic periods; Hilgard, Shaler, and others have investigated the products of rock decay as the most important source of soils; Chamberlin and Salisbury have made a classic study of the origin and physical composition of the residuary clays and loams of a definite territory; and Russell has recently summarized the work of his predecessors, pointed out that the products of rock decay vary in volume with the latitude, and inferred that they represent secularly constant activity in the rock-destroying processes. The local characteristics of the extensive mantle of rock débris within this country have also been set forth by a score of geologists in half the States of the Union.

Perhaps because of its universality in many lands and its prevalence in nearly all, the product of rock decay has no commonly accepted appellation. Pumpelly indeed groups the phenomena as "residuary products of a secular disintegration;"[1] Chamberlin and Salisbury combine them as "residuary products;"[2] and Russell speaks of "residual clay," "residual deposits," "residua," etc.,[3] but the expressions are manifestly employed as descriptive terms rather than specific appellations. Broadhead designates such material as "local drift,"[4] and Kinahan applies the term "meteoric drift;"[5] but these expressions, too, are employed rather in a descriptive than in a denotative way, and moreover they are misleading in that, where typically developed, the materials are not drifted. Many varieties of rock débris indeed have descriptive names—"adobe," "gumbo" (applied to disintegrated Cretaceous and Tertiary shales as well as to a Pleistocene deposit), etc., are common terms in this country; "terra rossa" is equally well known in southern Europe; "regur" is the common name of a prevailing soil, and "laterite" the accepted designation for a peculiar ferruginous phase of the prevailing product of rock decay in peninsular India; and the "black earth" of Ukraine and "chernojem" of the Ural region are well known; but the group into which these phenomena fall is singularly nameless, alike among the students and the tillers of the earth.

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[1] Am. Jour. Sci., 3d ser., vol. 17, p. 135.

[2] Sixth Ann. Rep. U. S. Geol. Survey, 1885, p. 239.

[3] U. S. Geol. Survey, Bull. 52, pp. 13, 23, and elsewhere.

[4] Geol. Surv., Mo., 1874, pp. 64, 98, and elsewhere.

[5] Jour. of the Royal Geol. Soc. of Ireland, 2d ser., vol. 4, part 3, pp. 115-121.

The product of modern river action is everywhere recognized by some form of its classic appellation, alluvium; the distinctive but ever varying deposit first studied on the banks of the Rhine has come to be known in all civilized lands by its original provincial name, loess; the assemblage of glacial deposits is everywhere known by the simple Anglo-Saxon designation, drift, and only less widely by its provincial British synonym, till; the foundation upon which all these categories of superficial deposits rest is universally recognized as rock, and a score of subordinate divisions are named by every schoolboy; yet the most extensive category of superficial deposits, of the phenomena lying nearest to man, is without a general name though many of its subdivisions are named—for here civilized man has imitated the savage, who names the members of a class but feels no need of a name for the class itself.

It is the more singular that the widespread products of rock decay should remain without distinctive appellation since at one period in the growth of geologic science such a designation was proposed and found its way into geologic literature. Early in the present century J. André De Luc clearly discriminated, first, the solid rocks of the earth and the unconsolidated materials by which these rocks are mantled, and, second (*a*), the immediate products of rock decay in situ and (*b*) the débris transported and redeposited by streams. For the former portion of the superficial mantle he adopted the provincial designation for "earth" in Holland and northern Germany ("geest"[1]), and for the transported materials of all kinds he adopted the term "alluvium."[2] Soon after, De Luc's term came into use by geologists in this country; and by two of the foremost among them, Amos Eaton and T. Romeyn Beck, the unconsolidated mantle of superficial deposits was divided into the proper unmodified soil, called geest, and that which has been conveyed from a distance by water and exists in thick beds, called alluvium.[3] Both Eaton and Beck pointed out that in extent and volume the geest far exceeds alluvium. But they lived in an age of speculation; the alluvial deposits offered an attractive subject for reflection and the thoughts of domestic and foreign geologists were concentrated upon them; cataclysms and deluges were in all men's mouths and minds, and before the pendulum of current thought had swung to mid position there came the glacial theory to once more distract attention from an inherently important subject; and the simple taxonomy and definite nomenclature of the pioneer geologists were forgotten in the race for knowledge concerning other and subordinate classes of deposits.

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[1] Abrégé Geologique, Paris, 1816, p. 121.

[2] Ibid., p. 112.

[3] Geol. Survey of the County of Albany, 1820, p. 31; Cf. Geol. and Agl. Survey, Rensselaer County, 1822, p. 23.

The provincial term adopted by De Luc and introduced into American literature by Eaton and Beck is in itself meaningless, and is thus an unobjectionable denotative term; it meets a manifest need of the tongue; it has never been supplanted; it has a definite place in literature, and it seems well to restore it.

SECTION VI.—GLACIAL GEOLOGY.

GLACIAL DEPOSITS IN GENERAL.

The most startling and inherently incredible and so the most distasteful conception ever forced upon the tardy credence of the cautious student of earth lore is that involved in the glacial theory. The conception of the lifting of continents from the bosom of the ocean is a grand one—but the continents exist and tell their own story; the conception that ocean waters washed over every acre of land where now forests grow, birds nest, and beasts roam is not a ready one, but it is easily grasped when the waters are observed in the act of forming just such deposits as those of which the land is built; the conception of the uplifting of great mountain chains is a sublime one—but the mountains rise in serried ranges above the clouds and by their own grandeur prepare the mind for its acceptance; the conception of the building of great volcanic cones and the outpouring of lava sheets hundreds of feet in thickness and thousands of miles in extent is stupendous—but Etna and Stromboli and Mauna Loa illustrate and vivify it; the conception of the moderate cataclysm with which the modern geologist is content—the swallowing up of islands, the sudden encroachment of the sea, or the shattering of rocks by earthquakes—is grasped with difficulty by the landman whose first formed and longest maintained induction is that of the absolute stability of the earth—but the memory of Krakatoa and of the far-reaching earthquakes of Lisbon, New Madrid, and Charleston lingers in every mind as the seed from which even this distasteful conception springs. So, throughout the entire domain of dynamic geology, save in one small portion, the conception grows out of visible phenomena through a mental process common to all men, and the phenomena illustrate and exemplify the conception, not only in kind but in degree; but the essential idea of the glacial theory is that of a continuous sheet of ice, hundreds or thousands of feet in thickness and hundreds of thousands of square miles in extent, creeping sluggishly over hill and valley, lowland and plateau, even mountain and lake, from a polar source toward a tropical sun; and the conditions of climate and of the congelation of water in so vast volume, and the magnitude of the process and its products, utterly transcend the experience of civilized man. The continental ice sheet is barely illustrated by the pigmy glaciers now living in the Alps, the Himalayas, and the northern Rockies; and it is inadequately exemplified by the little known ice field of central Greenland, which has been explored only since the conception became current among geologists. No other conception in the science of the earth is so difficult to grasp, and none other so inherently improbable, as that involved in the glacial theory.

Many years ago a few Swiss naturalists, born in the shadow of the glacier-ridden Alps and bred on their rugged foothills, became interested in the vernal shrinking and autumnal expansion of the glaciers about their mountain-girt home. Best known among these naturalists was the illustrious Agassiz.

These early observations upon the seasonal changes in volume of the glaciers were gradually extended from glacier to glacier, and then to historical records of greater changes covering long periods of years, and it was found that the historical record of glacial oscillation is corroborated and supplemented by an almost equally legible physical record found in striæ, ice-polished bowlders, and morainic accumulations many yards beyond the present termini of the glaciers. After familiarizing themselves with this physical record, traced by the ice itself upon rocks and surfaces, the naturalists slowly and cautiously extended their observations down the gorges occupied by the glaciers of to-day, and finally into the broader valleys into which the gorges embouch; step by step the unmistakable trail of the glacier was followed down the gorge, over the hillside, across the lowland, and from side to side of the broad valley; and as the ice record was deciphered, its significance gradually dawned upon its readers: and the glacial theory was conceived.

The handful of Swiss naturalists encountered strong and long continued opposition in framing and promulgating their startling theory. First and most bitter was that of their own prejudice and of the conservative habit of the trained scientific mind; but the phenomena upon which their induction was based only multiplied with prolonged study, and the broad field of speculation, fertilized albeit by a novel idea, failed to produce any alternative hypothesis. Then when the theory was made public it found hearers and readers alike incredulous, sometimes bitterly opposed, and the armament of antagonism, the shafts of sarcasm, the denunciations of dogma, and the weightier weapons of careful scientific scrutiny were directed against the theory; but the excellence and completeness of illustration, the lucidity and evident fairness of the presentation, and the ingenuous sincerity of statement convinced some, while others who entered the Vale of Chamouni to scoff and defeat, went forth to laud and defend the new doctrine. Next, as the naturalists scattered among distant lands and found ice records successively further and further beyond the reach of living glaciers, opposition to the conception was found at every step; but in most regions it was impossible to gainsay the fact that the glacial theory explained a wide range of phenomena which no other hypothesis was competent to explain; converts were made among fair minded students wherever the phenomena were well displayed and carefully studied; and as the adherents of the theory increased in number, the opposition weakened and finally gave way save in a few regions of peculiar situation. So the glacial theory came into full being.

In the United States, investigation of the superficial deposits was stimulated by the promulgation of the glacial theory, and a score of geologists were soon searching for striæ like those found at the termini of the Scandinavian glaciers, bowlders like those dropped from the Himalayan glaciers, moraines like those cumbering the gorges below the living glaciers of the Swiss Alps. The search was stimulated by the presence and inspiration of the leader of the Swiss naturalists; and ice records were quickly found throughout New England, in New York, New Jersey, and northern Pennsylvania, and soon after beyond the Alleghanies, in Ohio, Indiana, Michigan, Wisconsin, and other interior States. The discoveries were not made by one or a few possibly prejudiced advocates of the startling hypothesis, but by the ablest and most conservative geologists of the land, Dana, Hall, Newberry, Lesley, Cook, W. B. Rogers, and a dozen younger men. These men saw in the glacial theory a rational explanation of previously puzzling phenomena, and accepted it first as a working hypothesis but in time, as the evidence in its favor was accumulated and was corroborated by continued work, as a fundamental and important part of geologic doctrine. The second generation of geologists followed their leaders, and to-day there is no competent geologist in the United States who does not hold to the hypothesis of one or more Pleistocene ice sheets of continental extent.

The principal phenomena which can be explained only by the glacial theory fall into three categories, viz, (1) deposits, (2) the surface forms assumed by deposits, and (3) the features of rock surfaces commonly (though not always) covered by such deposits.

The deposits ascribed to glacial agency exhibit distinctive features in (*a*) materials, (*b*) condition of materials, and (*c*) structure and texture; and these features, while maintaining distinctive character, vary from one country to another, from one type of surface to another, and sometimes in the same country and type of surface from one terrane to another.

Classed with respect to dimensions, the materials of glacial deposits comprise bowlders and other transported rock masses (sometimes of enormous dimensions), cobblestones, coarse and fine gravel, sand, and a variety of finely comminuted rock débris and earths, commonly grouped under the designation "clay." But careful examination shows that the variously designated dimensions represent a continuous and unbroken series; that the finest particles graduate into the coarser particles in the so-called clay; that the coarser particles of the so-called clay are inseparable from the finest sand; that the coarse sand runs without break into fine gravel; that the coarse gravel is only arbitrarily separable from the pebbles, which in turn run into cobbles; and that no natural line lies between the cobbles and the bowlders. Convenience demands that the materials of glacial deposits shall be classed by dimensions, but it should be borne constantly in mind that the classification is primarily that of laymen which has been ingrafted upon geology, and that it is purely arbitrary.

Classed with respect to petrography, the materials of glacial deposits commonly represent all rocks of the region in which the deposits are found and sometimes those of contiguous regions. In general the larger component particles or masses are (*a*) those of the more obdurate rocks, or (*b*) those corresponding to the rocks of the nearest terranes, except that quartz is commonly found in the form of sand, which is the most stable mechanical condition of that crystalline or granular siliceous rock. In general the finer component particles are similar to those of little obdurate terranes commonly found in the vicinity though sometimes at considerable distances.

The coarser component particles and masses of glacial deposits are sometimes sharply angular, as are rocks freshly broken from original ledges; but they are more commonly subangular, and frequently crushed and battered as if by slowly applied pressure; and many of the bowlders, cobbles, and smaller pebbles are ground, striated, and polished upon one or more sides. The finer materials, too, are sometime found to exhibit like markings under the microscope.

The finest materials, including the impalpable rock particles commonly called clay in bulk, are frequently found by the simplest chemic examination to be unoxidized, and so in a chemically unstable condition under the ordinary conditions of deposition and the prevailing state of weathering of superficial deposits. Thus, in regions in which calcareous rocks abound, the glacial deposits taken from a few feet beneath the surface may effervesce as freely under acid as do deeper lying limestone ledges.

The typical glacial deposit is a confused mass of bowlders, cobble stones, pebbles, gravel, sand, and finer débris intimately commingled and without definite proportions and arrangement; the proportions of particles and masses of the different dimensions, and the dimensions of all particles and masses varying from place to place with various local conditions which are frequently ascertainable; and the texture is commonly firm and compact below the reach of weathering. In less typical cases and in those of hybrid deposits, more or less definite stratification and assortment of materials by dimensions or density is sometimes displayed.

In dimensions and stratigraphic character of materials, in the prevailing subangular forms, in the striation and faceting of the bowlders, cobbles, and pebbles, and in structure and texture the deposits of the upper Mississippi Valley, northern Europe, and other regions which have been ascribed to glacial action are essentially similar to those observed in process of deposition by the glaciers of the Alps, the northern Cordillera, the southern Alps of New Zealand, the Himalayas, and the Scandinavian highlands; and in all these features they are unlike the deposits of the winds, of running waters, of lake shores and bottoms, of the waves and currents of the ocean, of the tuff-forming or sinter-depositing spring, of the volcanic lava stream or lapilli shower, of the accumulation of organic matter through the operation of vital processes, or indeed of any other conceivable agents. The slight and nonessential differences between the deposits of broad plains ascribed to glacial agency and those observed in process of deposition by local glaciers are evidently due solely to difference in local conditions of deposition.

A wide variety of surface forms are exhibited by deposits which have been ascribed to glacial action. The prevailing types of form are (*a*) irregular hills or knobs associated with ponds or basins, both commonly arranged in lines transverse to that in which the ice is supposed to have moved; (*b*) ridges and elongated hills, either isolated or in lines arranged parallel to the direction in which the ice is supposed to have moved; (*c*) comparatively flat plains lying between the transverse belts of knobs and basins; and (*d*) broad, gently undulating plains. These forms are widely diverse and each is strongly distinctive where well developed; but comparative study of a large number of examples shows that they represent extremes of a series, or, rather, the limits of a congeries: that the rugose belts made up of knobs and basins sometimes grade into the comparatively flat plains by which they are separated on the one hand, or into longitudinal ridges with intermediate plains on the other hand; that the longitudinal ridges sometimes merge not only with the rounded knobs but also with the widespreading and gently undulating plains; that the widespreading plains can be discriminated only arbitrarily from the narrower plains between the belts of knobs and basins; and so that the strongly individualized types of surface displayed by deposits ascribed to glacial agency represent local and eccentric development of a generally intermediate type. Accordingly, while such surface forms may be classified for convenience by special and restricted characteristics, while they are invariably so classified by laymen, and while that classification has been ingrafted upon geology, it must ever be borne in mind that, like the common classification of the deposits into bowlders, pebbles, sand, and clay, it is purely arbitrary and the forms only represent an unbroken plexus.

Now, the belts of knobs and basins traversing deposits which have been ascribed to glacial action are identical with the terminal moraines heaped up at the snouts of living glaciers in the Alps and in every other region in which they are found; and they are unlike the surface forms produced by wind action, by water carving, by the action of waves and currents along shores, by the outflow of lava or the expulsion of lapilli, by any process of deformation of the earth's strata or surface, or indeed by any other process known to geologic science. Again, the comparatively smooth plains between the belts of knobs and basins are similar to those formed by living glaciers during each recession of their endless cycles of seasonal and secular oscillations; and they are unlike plains fashioned by the winds or waters, whether flowing or undulating, or by other active geologic processes. Moreover, the longitudinal ridges and elongated hills find a parallel in the longitudinal ridging of the surface sometimes exhibited by the intermorainic plains beyond the extremities of living glaciers; and they are unlike the forms produced by the work of winds, waters, or other geologic agencies. Finally, the broad, gently undulating plains are molded into forms similar to those manifestly produced by living glaciers; and they are unlike the plains produced by either eolic or aqueous deposition or by degradation, or by any other geologic process.

So the various yet related and always distinctive surface forms assumed by deposits necessarily ascribed to glacial action are fully explained by the glacial theory, and are inexplicable upon any other hypothesis which the mind of man has thus far conceived.

The distinctive forms assumed by rock surfaces upon which deposits ascribed to glacial action lie may be grouped as major and minor—the former being of such magnitude as to constitute topographic or even geographic features, while the latter are simple markings upon the rocks.

The major features include, in montanic regions, steep-sided and round-bottomed gorges and valleys, distinguished by U-shaped profiles as compared with the V-shaped profiles displayed by water carving; again, in plain regions, smooth surfaces and gently rounded forms little affected by unequal obduracy of the rocks and without the angular forms invariably developed by water carving; and, sometimes, in montanic and plain regions alike, both rounded bosses and ridges and soft contoured depressions, often converted into lakes. The forms vary greatly in dimensions: the gently undulating and soft contoured plains may be thousands of square miles in extent, as in the Rainy Lake region of Canada and in adjacent territory; the soft contoured and water filled basins may be hundreds and often thousands of miles in extent, as in the great American lakes of the Laurentian drainage system; and the rounded bosses may be swelled into plateaus hundreds of miles in extent if not into vast territories, like the Laurentian highlands of Canada; but from these enormous dimensions they run down in unbroken succession to *platte* a rod across, to pondlets which the rabbit might leap or the curlew wade, and to tiny knobs a span in height and a stride in width. And the broader plains, the wider and deeper basins, the larger bosses, as well as the sides and bottoms of the U-shaped troughs, are thus made up of myriads of lesser. smooth surfaced elevations and depressions exhibiting in endless repetition the exact form and expression of the larger features. Nearly everywhere the rock surfaces overspread by deposits ascribed to glacial agency (and some not so overspread) are beautifully molded in rounded forms of graceful contour, ever varying as to dimensions and endlessly repeated as to features.

The minor features of sub-surface associated with deposits ascribed to glacial agency are longitudinal groovings, flutings, parallel striæ, and glass-like polish, together with occasional irregular scratches, transverse cracks in lunoid shapes, and several other erratic forms. The finely striated and polished surfaces beneath glacial deposits are sometimes of such extent that whole city blocks are built upon them as in Minneapolis; the extensive plain of characteristic contour constituting the Rainy Lake region is similarly marked for miles and scores of miles of territory from which the commonly associated deposits have been removed if they were ever formed; and although there are great tracts—the greatest known being Northeastern Iowa—in which few of these minor marks of ice-work occur, and in which the deposits ascribed to glacial action are without the usual sub-surface, extended observations in many lands indicate that by far the greater part of such deposits lie upon surfaces thus marked.

The U-shaped gorges of montanic regions not now occupied by glaciers are similar to those of all glacier-ridden tracts thus far explored and in which the glaciers are observed to be engaged in the process of forming and perpetuating the characteristic profile; and they are unlike the gorges produced by water carving or by any other known geologic process. So, too, the smoothly molded plains, the soft contoured basins, and the rounded knobs associated with deposits ascribed to glacial action are similar in kind with those produced by living glaciers; and they are unlike the forms developed by any other geologic process. In like manner the grooving, the fluting, the striæ and polish, and the irregular scratches and lunoid cracks associated with such deposits are similar to those found beneath every living glacier thus far carefully studied and observed to be produced by its grinding; and they are utterly unlike surfaces formed—or indeed not quickly obliterated and destroyed—by any other known agency of the entire range of nature.

So the rock surfaces found associated with deposits inexplicable save on the glacial theory and with surface forms only explicable on that theory are themselves consistent with the same theory and with no other ever evolved from the brain of the student.

The phenomena of the deposits, the surface forms, and the subsurface marking of northern United States and of several other countries have been under careful observation for a generation; the observers have multiplied and the observations have been repeated, verified, tested, and recorded in maps, pamphlets, volumes, and great tomes until the literature forms a large library ; yet every observation has been found consistent with the hypothesis promulgated by the Swiss naturalists, and with no other.

During the generation, and especially during the decade elapsed since the study of Northeastern Iowa was practically completed, the results of glacial study have run chiefly in the direction of differentiation; and to-day the ice deposits, the ice-fashioned surface features, and the ice-molded rock surfaces of America and of wide areas in Canada have been classified by local peculiarities and by local conditions of genesis. Moreover, the deposits and surface forms created by the schmelzwasser—the waters derived from the melting glaciers—have been studied, differentiated, and similarly classified by local peculiarities and conditions of genesis. Still more, the puzzling progeny of the miscegenation of ice and water have been studied with care in America and Canada; these aqueoglacial deposits, too, have been differentiated and classified with respect to each other and with respect to the legitimate offspring of both progenitors. Foremost among the students of these phenomena in America stands Chamberlin; and a score of able contemporaries have contributed materially to the solution of the problems presented by the deposits.

The great drift sheet—the ground moraine of the continental ice sheet stretching from the Atlantic to the Rockies, and from Hudson Bay to the mouth of the Ohio—has been studied in every state of its vast extent by the official geologists of the various States, by many professional geologists and by a score of amateurs, and latterly by a trained force of Federal geologists. It has been ascertained through these researches that the drift sheet varies in materials from place to place: Commonly in New England and New York it is exceptionally stony, and few of its bowlders, cobbles, and pebbles are far transported; in some parts of New England it grades horizontally into stratified beds of aqueous or aqueoglacial origin, and in parts of New York it grades upward into similar deposits; in the interior basin east of the Mississippi River it is only moderately supplied with bowlders, some of which are far traveled though others are not many miles removed from their parent ledges, and here and there the influence of water operating in connection with ice is indicated by the structure of the deposit; west of the Mississippi in the interior basin bowlders are exceptionally scant in numbers though sometimes notable in size, and are unusually far removed from their original homes; and in the axis of the entire basin on both sides of the Mississippi the drift sheet frequently merges toward its southern margin into stratified deposits in the making of which water evidently played a part.

It has been ascertained, too, that the drift sheet is frequently divisible: In northeastern United States a lower sheet of bowlder clay, distinguished from the upper by firmer texture, distinct coloration, and various evidences of greater antiquity, is often detected beneath the principal bed of drift; in the interior basin on both sides of the Mississippi an older drift sheet is frequently found which is evidently continuous over large areas and is sometimes separated from the newer sheet by an ancient soil, with remains of a luxuriant arborescent flora; toward the southern drift margin in the interior basin the older drift sheet is frequently found at the surface or overlain by aqueous or aqueoglacial deposits, the upper drift sheet failing there; and it thus appears that there are at least two widespread sheets of drift, sometimes discriminated only with difficulty yet sometimes quite distinct, and that on the Atlantic slope the upper and newer overlaps the margin of the older, while in the interior basin the later falls far short of the earlier.

It has been ascertained, also, that the surface forms exhibited by the glacial deposits vary in systematic fashion: Along the axis of Long Island, across New Jersey, over the Appalachians in a reentrant curve crossing the Pennsylvania-New York boundary, through southern Ohio and Indiana, diagonally across Illinois and Wisconsin in a series of great loops, through Minnesota in a sinuous course of smaller loops and into Iowa in the largest of the loops, and thence through the Dakotas and across the southwestern plains of the Saskatchewan to the bases of the Rocky Mountains in Canada, there has been traced a line of knobs and basins and transverse ridges like the terminal moraines of the living glaciers—a line sometimes narrow and low, but sometimes expanding into a labyrinth of lesser lines and rising into ranges which have been dignified as mountains. This great terminal moraine marks the southernmost border of the drift on the Atlantic Slope but falls far short of it in the interior basin, and appears in some places, though not in all, to mark the margin of the upper and later drift sheet. Within the great terminal moraine other and lesser morainic ridges, generally transverse but sometimes parallel to the direction of ice flow, occur in many localities. In central Massachusetts and central New York original bosses of drift, called at first "lenticular hills" and more recently "drumlins," abound; and a few similar elevations occur in central

Wisconsin and elsewhere. Here and there the surface of the drift plain is longitudinally ridged; and between the moraines, the drumlins, and the ridges, and in part outside of the great moraine in the interior basin, the drift assumes a gently undulating surface and forms a vast plain varying in the value of the relief from place to place with the configuration of bedrock, but always exhibiting graceful profiles and contours.

It has been ascertained, as well, that, while ever varying in direction, the markings upon the rocks bearing the glacial deposit fall into a definite system: In New England the prevailing direction is southeastward and south-southeastward, with a marked tendency to diverge toward the directions of local valleys; in New York and Pennsylvania the striæ point in southerly directions; farther westward the rock scorings become more variable in direction, but, in general, run transverse to the terminal moraine in lines diverging and radiating from the axes of the many lobes which the moraine outlines. In the Dakotas the prevailing directions are southwesterly and toward the more regular morainic margin of the drift; beyond the British boundary the directions diverge more and more to the westward until an opposing, but thus far little known, series running down from the Rockies is encountered. About the shores of Hudson Bay the prevailing directions are westerly; on Hudson Strait the directions are northwesterly and finally northerly; and in parts of Labrador easterly directions are assumed.

Moreover, it has been ascertained that the deposits and connected configuration are unlike on opposite sides of the transverse continental divide separating the south-flowing waters from those of the Laurentian and Hudsonian drainage: On the southern side of the divide and near the crest the phenomena are distinctively glacial, and duplicate (with certain differences in degree) those exhibited at the termini of the living glaciers; and down the southerly slopes the traces of flowing water gradually appear and increase until the ice record is finally obliterated. But on the northern side of the divide the deposits generally exhibit more or less abundant traces of the conjoined action of ice and standing or sluggishly moving waters, and from place to place and from horizon to horizon, there appear deposits and surface forms such as are created only by standing or sluggish waters.

Still further it has been ascertained that the receding ice sheet was replaced by standing waters over immense areas: Dana has described the terraces of New England and shown that they represent a period when the lower lands were flooded; Shaler has traced shore terraces and littoral deposits superimposed upon glacial deposits along the coast and about the coastal islands of northeastern New England up to altitudes of hundreds of feet; Upham has developed the shore lines and described the deposits of a vast lake, ice bound on the north, in the valley of the northern Red River; Claypole has discovered a series of similar but smaller lake deposits and lake shores in northern Ohio; and a series of shore lines of surprising extent surrounding the entire region of the Great Lakes, and telling of the time when all these immense water bodies were united in a mediterranean sea, have been traced through many hundreds of miles, and described in detail by Gilbert and Spencer.

Finally, it has been ascertained, largely from the testimony of the terraces and shore lines superimposed upon the drift, that during the epoch of ice the land was depressed in the north, so that divides were shifted, the declivity of drainage ways changed, the fresh-water lakes at the retreating ice front enlarged, and ocean waters spread over enormous areas in Canada and limited areas in northeastern United States, which now rise far beyond the reach of the tides.

Yet, despite the differentiation of ideas concerning the glacial phenomena of a considerable part of the North American continent, and despite the refined classification of the deposits, the glacial theory imported by Agassiz weaves the tangled woof of otherwise inexplicable phenomena into a single close and consistent web.

The readiness with which the glacial theory was accepted by the geologists of all lands was determined with singular definiteness by their surroundings. To the earth student in the tropics the theory was a monstrous and functionless creature of distorted imagination; to the student of strata arranged in consecutive beds and only embarrassed by the annoying cover of rudely arranged débris concealing them, it was a needless and burdensome addition to scientific doctrine; and to the radical uniformitarian whose opinions were tinctured by antagonism to an injurious but decadent catastrophism, it was an unsavory resurrection. Even among the most liberal and advanced students of superficial deposits in the northern lands there were differences of opinion growing out of too restricted interpretation of local phenomena. This diversity of interpretation was exhibited nowhere more strikingly than between America and Canada. The American geologists studied deposits, surface forms, and rock markings created by ice alone or by ice and running waters which were similar to the products of living glaciers, and so quickly became radical glacialists; but the Canadian geologists studied just as attentively a hybrid deposit north of the continental divide commonly concealed beneath later deposits of inland lakes or encroaching ocean, at first seldom seeing the deeply buried rock scorings, and were the most pertinacious among the opponents of the glacial theory. It is only within a decade, and with the rapid extension and wide differentiation of ideas concerning glacioaqueous and aqueoglacial deposits, and with the enforced recognition of the aqueous agencies on one hand and of the action of glacier ice on the other, and so with enlarged conceptions upon both sides, that the long-standing differences of opinion have practically disappeared. To-day the American geologist admits the submergence of vast areas in Canada during the ice invasion and recognizes the aqueous or aqueo-glacial origin of widespread deposits and surfaces; to-day the Canadian geologist admits that much of America was not submerged but was ground by a continent-wide sheet of land ice; and the current doctrine on either side of the Great Lakes is that which best explains the local phenomena and is at the same time consistent with the phenomena of the neighboring country; to-day the water of Canada and the ice of America are wedded as firmly as they were when their wonderful progeny came into being.

THE LOESS.

GENERAL FEATURES OF THE LOESS.

A quarter of a century ago Sir Charles Lyell, the leading geologist of his generation, wrote:

> Some skillful geologists, peculiarly well acquainted with the physical geography of Europe, have styled the loess the most difficult geological problem, although belonging to the period of existing land-shells, and the highest and newest by position of all the great formations.

Even before that time the loess was recognized as a problem by American as well as European geologists; and a problem it has remained almost until to-day. The rival "theories of the earth" of the last century were tested first by dozens, then by scores, and finally by hundreds of patient students in many lands, and the measures of validity and falsity in each were ascertained; hundreds of investigators at work in all civilized countries gradually developed and set forth the nature and origin of the rocky strata constituting the visible crust of the earth; a score of American geologists and paleontologists, headed by such men as Mitchell, McClure, the Rogers brothers, and the veteran Hall, made out the order, succession, and relation of the strata of a considerable part of the North American continent; a dozen followers of the illustrious Swiss naturalist Agassiz seized upon his glacial theory and through it classified the principal Pleistocene deposits of the United States and illumined one of the darkest episodes in the physical history of the earth; the science of geology was conceived, came into tangible being, and took a leading rank among the branches of human knowledge; yet an essential element was lacking. The Cyclopean hieroglyphics of the record of world building were interpreted so fully that the one lost character was unnoticed by many; the mystery of the past was illumined so fully that the one dark spot was commonly overlooked; and every conspicuous phenomenon of geology had its explanation save one—the loess. So, for a generation, the cautious geologist questioned whether the loess was a product of the winds of the heavens, the waters of the ocean, the rivers and lakes of the land, the ice of the North, or even the volcanoes by which the crust of the earth is rent; and there were not wanting students to appeal to all of these agents as its parent.

Loess was first recognized and first came into prominence among geologists in the valley of the Rhine, and the early students adopted for it the name by which it was known among the German peasantry. Later it was found in other parts of Europe. During his "second visit," in 1846, Lyell recognized it along the banks of the lower Mississippi; still later Pumpelly discovered and subsequently von Richthofen described in detail the deposit as accumulated in unequaled volume in Mongolia; and a generation ago the geologists of every civilized country north of the fortieth parallel were quietly considering or openly discussing this mysterious product of unknown geologic process.

It was an early fiction, by which the progress of exact knowledge was retarded, that loess is everywhere uniform in composition and alike in structural characteristics, i. e., consisting of certain definite proportions of silica, carbonate of lime, alumina, iron, etc., and charged with nodules of carbonate of lime called loess-kindchen, ramified by branching calcareous tubules, and standing long in vertical faces where cleft by streams or cut by man. For years samples of all puzzling superficial deposits from new localities were cast into crucibles, tested by reagents, and identified with or discriminated from loess by the proportion of silica, lime, and alumina. So the term "true loess" came into current use and stood for a certain combination of minerals; to it was referred all river alluvium, all lacustrine sediments, and particularly all glacial deposits of this composition that the analyst chanced to stumble upon; and the literature of geology came to be burdened with meaningless analyses as uniform and simple as if all were fresh from the same shop. It was long before students realized that the peculiar features of the loess depend largely upon the mechanical condition of the component materials, and that the materials themselves are exceedingly variable.

The macroscopic characters of the deposit are moderately constant: (1) It is commonly fine, homogeneous, free from pebbles or other adventitious matter, and either massive or so obscurely stratified that the bedding planes are inconspicuous; (2) it commonly contains unoxidized carbonate of lime in such quantity as to effervesce freely under acid; (3) it frequently contains nodules and minute ramifying tubules of carbonate of lime; (4) in many regions it contains abundant shells of land and fresh-water mollusca; (5) it is commonly so friable that it may be removed with a spade or impressed with the fingers, yet it resists weathering and erosion in a remarkable manner, standing for years in vertical faces and developing steeper erosion slopes than any other formation except the more obdurate clastic or crystalline rocks.

Its microscopic characters are much less constant: It is commonly a mass of indiscriminately commingled grains of quartz and a great variety of other rocks, of ever-varying size and degree of rounding by attrition; but in some localities and certain strata the materials are coarser and graduate into sand, while in other localities and certain other strata they are finer and more uniform and pass into silt or mud.

It is still more variable in mineral composition: The leading component is generally quartz; but in some localities and in certain horizons there is a considerable element of carbonate of lime, or carbonate of lime and magnesia, in the form of rounded particles evidently formed by the breaking up and trituration of limestone and dolomite; in other localities and other strata minute clayey particles predominate, and the mass exhibits the physical characteristics of clay or loam; and there are as many other mineralogic phases exhibited by the deposit as there are distinct rock masses in its vicinity.

Even the homogeneous and massive structural characteristic frequently fails: Toward its base, where the texture is frequently either silty or sandy, it may be regularly bedded or finely laminated; at higher horizons the deposit may appear massive and homogeneous when freshly exposed, and may be uniform chemically and mineralogically and apparently so structurally, yet on weathering may exhibit a definite stratification due to inequality of wetness in contiguous layers; at nearly all horizons the loess-kindchen display a disposition to form in planes which simulate and evidently represent bedding planes; the molluscan remains are seldom uniformly distributed, but commonly accumulated in beds of distinctive appearance, so that the experienced collector is able even from a distant view to at once select the fruitful and avoid the barren portions of a large exposure; in no considerable outcrop is the deposit alike at base and summit; and in rare cases (at least in the Mississippi Valley) pebbles and bowlders of erratic materials are found within it.

In short, while loess is one of the most distinctive deposits of the entire clastic series, and while it is easily and in most cases certainly identified by student and layman alike, there is probably no single characteristic of structure or composition that can be considered constant. Moreover, its distribution is as variable and anomalous as its other qualities: In the valley of the Rhine, in the Lower Mississippi Valley, and in many other regions it is confined to the vicinity of large rivers; in Mongolia it lines extensive basins bounded by wandering mountain off-shoots from the main Himalayan system;

along the Missouri River it commonly caps the river bluffs and veneers the lower slopes of the adjacent uplands, dying out in a feather edge a few miles inland; while in Northeastern Iowa it is best developed on the highest eminences and frequently forms outlying ridges and bosses rising sharply from the upland drift plain.

Despite the variability in its composition and structure, and despite the peculiarity in its distribution, loess possesses one characteristic which is nearly if not quite universal and which measures its value to man: Its chemic composition may imitate that of alluvium, drift, or rock; its materials may be identical with those of granite, limestone, sandstone, shale, or several or all of these combined; but the materials are so comminuted and so assorted as to render the mass friable and porous. So it absorbs the water of the freshet like a sponge and holds it for midsummer drought, and during the drought the waters are brought up by capillarity to nourish the plants at the surface; it yields to the plow like cheese to the knife, and there is neither bed rock nor bowlder to intercept the roots of annual plant or sturdy tree, and the rootlets penetrate to astounding depths through the porous mass and gather sustenance from the finely-pulverized rock débris and the imprisoned waters; the water and air circulate freely, and the acids of plant decomposition follow them and render soil and subsoil alike fit for plant food. So the loess of the Rhine is famed for its vineyards; the loess of Mongolia supports a pastoral population in a region which without it would be desert; the loess of the plains adjacent to the Missouri River brings agricultural and pomological prizes in plenty to a region in which the pioneer feared to settle by reason of the limited rainfall; and in Northeastern Iowa the formation may be mapped by its fruitful vineyards and orchards, and by the capacious barns and commodious farmhouses built upon it. To "the farmer, who feedeth all," the loess is one of the most beneficent among the gifts of the earth.

The loess was first recognized in Iowa, on the Missouri River, at Council Bluffs, by Owen, and characterized as "siliceous marl." Its presence was supposed to prove that "the waters of the Missouri, many hundred miles from their embouchure, have been pent up into vast lake-like expansions, at the bottom of which a fine lacustrine sediment collected, subsequent to the drift period, entombing not only fresh-water species of mollusca, but a still greater number of terrestrial *Helicidæ* which frequented its shores."[1]

Subsequently the official geologists of Missouri examined the southern continuation of the same deposit, and from its accumulation in the vicinity of rivers and its peculiar habit of erosion, called

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[1] Geol. Surv. Iowa, Wisconsin and Minnesota, 1852, p. 132.

it the "Bluff deposit." Still later White reexamined the deposit along the Missouri in western Iowa, adopted the name applied to it by the Missouri geologists, and ascribed it to deposition of materials derived from the Tertiary and Cretaceous strata of the upper Missouri in a lake formed immediately after the close of the glacial epoch;[1] but he did not recognize the deposit along the Mississippi or indeed anywhere east of the Mississippi-Missouri watershed.[2] In 1878 Todd examined once more the deposit in the southwestern part of Iowa, and pointed out that its structure and distribution are inconsistent with the eolic theory of origin.[3] Even before this date Pratt recognized the deposit on the Mississippi at Davenport, described it in some detail, enumerated its fossils, and set forth its relations to the ancient soil of the forest bed and the subjacent drift sheet;[4] and a few years later, Witter found the same deposit at Muscatine and published lists of its fossils, vertebrate and invertebrate. Call, too, studied it about Des Moines, where it is locally overlain by glacial deposits, and interpreted the testimony of the depauperate shells among its fossils as to the temperature of the period of its deposition.

Meantime the study of Northeastern Iowa herein recorded was commenced. In 1878 the structural relations of the loess in Dubuque County were set forth at some length, though the deposit was not certainly identified;[5] and it was soon after pointed out that the materials represent the mud of a Pleistocene glacier, and that they were accumulated either within ice-bound lakes or in cañons excavated in the ice sheet, as illustrated in detail on other pages.[6] Subsequently Chamberlin and Salisbury subjected the materials of the loess found in southwestern Wisconsin and contiguous parts of Iowa and Illinois to rigorous miscroscopic examination, and showed definitively that its composition varies in different localities with that of the associated glacial drift, and that both composition and distribution "point to glacial silt as the parent formation of the loess" in the upper Mississippi Valley.[7] Still more recently Shimek[8] and Webster[9] about Iowa City, and Witter about Muscatine, have examined the loess and have thrown much light on its various phenomena, and particularly upon the fauna of the deposit.

Three phases of the loess, each quite distinct in structural relations, generally distinct in relations to rivers and other features of

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[1] Geol. Surv. Iowa, 1870, vol. 1, p. 104 et seq.

[2] Ibid., p. 709.

[3] Proceedings Amer. Assoc. for Adv. Sci., vol. 27, pp. 231-239.

[4] Proc. Davenport Acad. Sci., 1876, vol. 1, pp. 96-99.

[5] Proc. Amer. Assoc. for Adv. Sci., vol. 27, p. 198.

[6] Proc. Iowa Acad. Sci., 1879, vol. 1, part 1, p. 13; Am. Jour. Sci., 3d series, 1882, vol. 24, pp. 221-223.

[7] Sixth Ann. Rep. Geol. Surv., 1885, p. 305.

[8] Amer. Geol., 1888, vol. 1, pp. 149-152.

[9] Amer. Naturalist, 1888, vol. 22, p. 408 et seq.; Bull. Lab. Nat. Hist. of the State University of Iowa, 1890, vol. 1, p. 200.

the topography, and moderately distinct in composition and structure and in external features depending upon these conditions, are found in Northeastern Iowa.

The most extensively developed of these is the northern phase, which occupies the driftless area and its southwestern flanks, extending from the Mississippi westward to the headwaters of the Turkey, Crane, Volga, and North Maquoketa rivers, to the Maquoketa in northern Jones County, about to the divide between the Maquoketa and the Wapsipinnicon in eastern Johnson and northern Clinton Counties, and thence to the tip of "Cromwell's Nose" in the extreme eastern part of the territory.

The second phase is that of the river bluffs and paha, which is irregularly distributed in patches and belts over a still larger area lying southwest of the first and extending thence to the Iowa-Cedar divide in Marshall and Tama Counties, just across the Iowa River in northern Iowa and Johnson Counties, and thence about to a line connecting the great elbow of the Cedar with the mouth of the Wapsipinnicon.

The third or southern phase lies south of the second, and extends from the southwestern corner of the territory to the Mississippi in Scott and Muscatine counties.

The three areas are indefinitely separated, and, along the Mississippi, the three phases of the deposit blend.

SPECIFIC FEATURES OF THE LOESS.

In Northeastern Iowa the loess is the most conspicuous and noteworthy among the Pleistocene deposits, not only by reason of the interesting chapter in Pleistocene history recorded within it, but by reason of striking external features as well.

(1) The first feature impressed upon casual observer and careful student alike, is its nearly universal forest covering in a region of prevailing prairie land.

In much of eastern Iowa the primeval forest still stands intact or else remains in belts and patches left when the fields were cleared and which yet mark the original forest boundary; and generally the irregularly sinuous boundary of forest and prairie land coincides exactly with the boundary between loess and drift. Hardwood forests of half a dozen oaks, a cherry, two walnuts, several hickories, two or three species each of ash, elm, and maple, with abundant aspens and lindens and rarer birches in the north and sycamores in the south, grow luxuriantly to the very verge of the scarp of loess overlooking the lowlying drift plain; at the base of the scarp the forests fail almost as suddenly and completely as along the land lines marking the limits of cleared farms in the once wooded States east of the Mississippi; and over the bowlder-dotted drift plain, within gunshot of the forest margin, the verdant sod is carpeted with luxuriant grasses, but supports no tree larger than the crab-apple on the uplands and the willow in the sloughs, no perennial bush larger than the hazel in scattered thickets, no shrub larger than the "red root" or "prairie tea" (*Ceanothus americanus*). Not always, it is true, is the demarcation so distinct; but this is the prevailing relation.

To illustrate the relation between loess and woodland the primeval forest and swamp map, forming Pl. XXII compiled from the plats of original land surveys on file in the U. S. General Land Office, has been introduced. It should be observed that this map is somewhat inconsistent in different portions, partly because the surveys covered a period of twenty-seven years (1838 to 1864, inclusive), within which considerable changes in forest distribution occurred, and partly because the ideas of the surveyors as to the definition of woodland varied widely—e. g., in the generally wooded area near the Mississippi the "oak openings" and "burr oaks" (or tracts of prairie land interspersed with scattered oak trees and hazel thickets) were classed as prairie, while in the broader prairie lands in the western and northwestern counties the hazel thickets of the uplands and the willow copses along the water ways were dignified as forests. It should be observed, too, that in the north, where the relation between wooded loess and woodless drift is most definite, the alluvial bottoms of the streams are commonly sparsely wooded and have been classed as woodland; and also that in the extreme south the usual relation frequently fails, since there not only are the alluvial bottoms commonly wooded but the slopes of the ravines as well, while the loess-veneered divides, which consist of unmodified drift to within a yard of the surface, are commonly woodless. Yet, despite the inconsistencies in original mapping, and despite the local idiosyncrasies in forest distribution, a significant relation between loess sheeting and forest covering appears: north of the Iowa River there is no considerable loess area that is not wooded in whole or in large part; most of the smaller loess tracts are wooded; and in the majority of cases the loess boundary and woodland boundary coincide within the limits of error in mapping.

The same relation is exhibited as well by the present as by the primeval products of the soil. The loess lends itself readily to arboriculture and horticulture, while the drift does so slowly and stubbornly if at all; the loess area is the land of the fruit and the vine, and the drift area of the cereal; the loess everywhere produces luxuriantly the deep-rooted perennials, while the prevailing products of the drift are short-rooted annuals. This difference in product is manifestly due to difference in texture of soil and subsoil in the two terranes.

Elsewhere inequality in rainfall may determine the boundary between prairie and forest; in other regions the prairie fires set annually by the aborigines may have determined the limits of grassland and woodland ; but here both of these causes combined were so far less potent factors in determining plant growth than difference in soil texture that their effects are masked if not completely eclipsed. So, in Northeastern Iowa the limits of the loess are commonly defined and its province is accentuated by the forest, while the monotony of the drift plain was increased in early days by the interminable carpet of uniform grass.

(2) Another external feature of the loess which can not fail to impress casual observer and careful student alike is its distinctive minor topography. Whatever may be the character of the subterrane, whatever the relation of surface to base-level, whatever the altitude or latitude, the loess of the larger areas is laid open by a labyrinth of Lilliputian ravines ever branching from the water ways toward the water partings in wide-spreading dentritic systems, while the bounding hills and divides are steep and narrow ; and in the land of the paha the loess slopes gently down to the drift in easy curves perhaps unmarked by modern erosion, and the horizon is an undulating profile of graceful swells, merging at their extremities or blending with the plain at their bases. The configuration of the broader loess areas long invaded by erosion and that of the unscarred ridges and paha is indeed unlike, yet both are distinctive and afford some of the most conspicuous external features of the territory.

(3) Although the loess of Northeastern Iowa is in some degree variable in composition, there is a certain uniformity in the materials of which it is composed: In the north it is indeed rich in clay and poor in lime, and rich in iron and poor in comminuted silica ; and the wealth in clay and iron and the poverty in lime and siliceous matter decrease from north to south and increase from the drift margin toward the interior of the driftless area. It is true that the loess of the river ridges and paha is much richer both in lime and comminuted silica, and much poorer both in clay and iron than the northern loess and thus approaches the normal type of the deposit ; and also that the degree of approximation to the normal varies in a general way with latitude, culminating in the south and on the Mississippi River. It is equally true that the southern loess is generally rich in both clay and lime and poor in silica and iron, thus departing from the normal type, but in a direction different from the departure of the northern loess ; and, moreover, that those departures from the normal vary from place to place and from horizon to horizon at each locality and at some points, notably on the Mississippi River, become insignificant—the loess at Muscatine simulating closely the ideal type of literature and nature. Yet the local variations in composition only reflect parallel variations in composition of locally associated deposits and local terranes.

Thus, toward the Mississippi River the northern loess approaches the composition of the subjacent geest and consists largely of identical materials; toward the western part of the driftless area it approaches in composition the immediately subjacent glacial deposit, and its wealth in clay and iron is shared with the drift which, along the loess margin, contains an exceptionally large element of local residua; the loess of the paha and river ridges rests upon a drift sheet made up largely of far traveled and finely ground rock débris, and the local variations in composition of the drift are faithfully reflected in its materials; toward the south the loess of the river ridges frequently crowns crags and crests of limestone, and here it is commonly calcareous in an exceptional degree; while the southern loess rests upon and generally grades into an exceptionally calcareous drift sheet representing long glacial grinding of sublocal limestone terranes, and plainly partakes of the same character; and in those southern localities in which the loess lies near or beyond the southern limit of the upper drift sheet, it contains a notable element of finely comminuted dark clay, evidently derived immediately from the "gumbo" which forms the superior member of the earlier glacial deposits of the Mississippi Valley toward the latitude of the Missouri and the Ohio.

Yet the composition of the various phases of the deposit is not uniformly related to that of the subterranes. Generally in the northwestern and central portions of the territory, where the relations of loess and upper drift sheet are most intimate, the difference in composition between the two deposits is chiefly one of comminution; the drift is an assemblage of far traveled bowlders, cobbles and pebbles, and both local and erratic gravel and sand, incorporated with an abundant matrix of finer rock débris; while the loess is an assemblage of sand grains and rock débris scarcely finer though more uniform than the finest found in the drift, together with rare gravel grains and pebbles; indeed, if the materials of the loess were magnified a hundredfold or a thousandfold, they would simulate those common to the drift both in size and in petrographic character. In the driftless area, over the limestone crags of the southeast, and beyond the margin of the upper drift sheet on the other hand, the relations of loess to drift are less intimate, and the former deposit is manifestly a hybrid, its composition representing two elements, one of which is identical with that of the more northern phase and so approaches that of the upper drift sheet, while the second consists of local materials; and these elements are intermixed in ever-varying proportions.

The various peculiarities in composition of the loess of Northeastern Iowa are thus consistent with the hypothesis that it was essentially coeval with and largely derived from the upper drift sheet.

(4) The structure of the loess of Northeastern Iowa varies from

place to place and from horizon to horizon in each locality; yet the range in variation is limited, and certain structural features are common to all localities and all horizons: In the north the deposit is commonly massive and moderately homogeneous from surface soil to a basal bed of pebbles or sand, and indications of stratification are usually obscure or absent; in the river ridges and paha the deposit is less homogeneous, commonly more or less definitely stratified, and frequently interrupted by sheets of sand; in the typical locality at Muscatine the deposit is massive and homogeneous above but commonly becomes stratified and sometimes interbedded with sand in its lower portion; while in the southwest the deposit is generally massive, seldom stratified, and usually grades imperceptibly into a drift sheet. Yet in all localities the materials are finely comminuted; in all localities the fineness of comminution culminates above and diminishes toward the base; in all localities save in the southwest the materials are either stratified in part or in entirety or else graduate into stratified deposits, and in the southwest they pass into a manifestly aqueoglacial deposit. Thus the constant structural characters are consistent, and the variable characters not inconsistent, with the view that the loess is a water deposit.

(5) The stratigraphic relations of the loess of Northeastern Iowa are variable; yet in all parts of its area it passes definitely into other Pleistocene deposits of known genesis: In the north it grades either into an evidently water-laid pebble bed or into stratified sand; in the middle latitudes it commonly passes into stratified and evidently water-laid sand; and in the south it grades either into a peculiarly assorted but veritable glacial deposit evidently modified by contemporaneous aqueous action, or into water-laid sand. So the stratigraphic relations, apart from the structural features, ally the formation in Northeastern Iowa with water-laid deposits and indicate a certain community of origin between its finely comminuted materials and the coarser aqueoglacial materials at its base.

(6) The fauna of the loess is as variable as its other characters: In the extreme north it is unfossiliferous; in the middle latitudes it contains land shells, frequently depauperate and thus indicating enfeebled condition of the species such as results from unfavorable environment; in the south it contains remains of land snails and land animals, both generally moisture-loving, a few water snails and still fewer river mussels, the latter of subarctic facies; these molluscan remains generally represent species now living in the same vicinity, but the mammalian species are extinct or removed to distant parts of the continent. So, although variable, the testimony of the fossils is consistent in indicating that the conditions attending the deposition of the loess of Northeastern Iowa were those of swamps about which land snails congregated and herbivorous land animals foraged; that the waters were so shoal that no fishes and few mus-

sels invaded them; and that the climate was arctic in the south, still more inhospitable in middle latitudes, and destructive of all life in the north. Thus the faunal features indicate that the loess of northeastern Iowa dates its origin in a period of glacial cold.

(7) The hypsographic distribution of the loess of Northeastern Iowa is variable and apparently inconsistent: Within the driftless area it forms an essentially continuous mantle, thickest in depressions and thinnest over divides, and thus simulates aqueous deposits in general; along the margin of the driftless area and in the river ridges and paha generally the deposit seeks eminences and crowns the highest crests and summits, and thus forms the most elevated deposit of the territory; while in the south it usually avoids eminences and forms a mantle much as in the driftless area. If the deposit be viewed by itself this behavior appears inconsistent, and the tendencies governing the hypsographic distribution appear antagonistic; but the structure is essentially identical at high levels and at low; in so far as observation is possible, it appears that the structure lines are unbroken from the eminence to the adjacent lowland; and the observed relation to subterranes in hundreds of exposures at all altitudes indicates that the main body of the deposit in each of its principal areas is a practically continuous mantle, thickening toward the crests or on the slopes of eminences, thinning toward lowlands, and over the lowlands thinning most on divides; and that each minor area, howsoever completely isolated, is a miniature similitude of the greater areas. In short, the hypsographic distribution of the deposit, considered either with or without reference to the structure, is consistent with the view that the mass forms a discontinuous and complex mantle of sediments laid down within basins whose original boundaries usually rose higher than the present eminences of the region but are now completely obliterated.

(8) The geographic distribution of the loess of Northeastern Iowa is exceedingly complex in entirety and widely variable in detail: In the northeast there is a practically continuous area of considerable magnitude within which the deposit is accumulated in variable thickness; along the margin of this area spurs and fingers extend from the main body in a definite and consistent direction, sometimes for many miles; in the region of the river ridges and paha the deposit commonly assumes the form of such spurs and fingers, but they are greatly elongated and sometimes quite isolated, and moreover are curiously related to the rivers and extend in definite and everywhere consistent directions; and in the south the deposit occupies a considerable though discontinuous area, the main body being broken chiefly by alluvium-flanked water ways; and the present distribution is proved by the surface conditions of the loess and of the contiguous drift plains to coincide closely with the original distribution. The geographic distribution is as curious as complex, and

considered by itself might be wholly incomprehensible; but considered in connection with other features of the deposit it is consistent with the view that the loess was laid down in two considerable water-bodies and a series of elongated lakes and sluggish rivers trending in accordant directions, and that the shores of lakes and banks of rivers rose above the level of the present surface and are no longer in existence.

(9) The petralogic[1] distribution of the loess in different parts of the territory is diverse: In the extreme northeast it rests upon or grades into the geest of the driftless area, or perchance conceals crags of naked Paleozoic rock; along the margin of the driftless area it reposes alike upon the newer and older drift sheets, and by its basal pebble bed passes into the former, which commonly thins as it thickens; among the river ridges it commonly rests upon, and by its basal sand bed grades into, the newer drift sheet which thins and sometimes disappears as it thickens, particularly when it mantles knobs and ridges of Paleozoic rocks; among the smaller paha it rests upon and passes into locally thickened glacial drift of the newer sheet; and in the south it rests upon and grades into the aqueoglacial phase of the newer drift sheet. So, in its petralogic relation, the loess is evidently connected in some degree with the residuary clays of the northeast and much more intimately connected with the glacial drift of the ice-plowed portion of the territory.

In short, the composition, the structure, the stratigraphic conditions, the fossil remains of the fauna, the hypsographic attitude, the geographic distribution, and the petralogic relations of the loess exhibit certain diversities and anomalies when viewed separately; yet when viewed collectively the anomalies disappear and the phenomena fall into definite relation and blend in a harmonious whole, and the several specific features of the deposit testify individually and collectively to its origin. The various phenomena are partly unique, all are complexly related, and some might be inexplicable considered by themselves; but the entire assemblage is consistent with the view that the deposit represents the finer grist of the ice mill laid down in ice-bound lakes and gorges as the Pleistocene glacier shrunk by surface melting and retreated northward; and they are inconsistent with any other hypothesis that the ingenuity of a half hundred geologists has been able to devise within a score of years of constant study.

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[1] Petralogy has been orally proposed by Powell as a designation of that branch of geologic science dealing with rock-masses and their relations when considered as units. It is equivalent to the "structural geology" of some, but not all, writers upon such subjects. The same term was sometimes used in the infancy of geology to denote the physiography of rocks and minerals (Cf. Petralogy, a Treatise on Rocks, by J. Pinkerton; London, 1811).

It was an early fallacy that the loess is everywhere identical in composition. It is not proposed to fall into the parallel fallacy that the loess is everywhere identical in genesis or even in age; for the time has gone by for deductive speculation concerning world-wide problems in earth history. A local problem has been solved by the inductive method, and the origin of the loess within a restricted area has been determined. As time flies and similar solutions are reached for other local problems, the local solutions may be combined, and the origin of the loess of the Rhine, the Danube, the Hoang Ho, the Amazon, the Missouri, and the Lower Mississippi may be clearly set forth; but thus far the local solution is of only local application.

CHAPTER III.

THE INDURATED ROCKS.

While the study herein recorded and the purpose of the record relate primarily to the Pleistocene deposits, certain relations between them and the underlying indurated formations are so intimate and essential that Pleistocene history can not be read without some knowledge of the antecedent history. So a summary of the indurated formations of Northeastern Iowa, a map (Pl. XXIII[1]), showing their areal distribution, a description of the deformations by which they are affected, a brief review of the history recorded within them, and an account of their ante-Pleistocene surface configuration, are introduced.[2]

SECTION I.—THE FORMATIONS AND TERRANES.

THE ROCKVILLE CONGLOMERATE.

The formation to which this designation is applied consists either of a dark brown puddingstone of well worn quartz pebbles in a matrix of earthy limonite, or of obscurely stratified ferruginous sandstone. It is destitute of definite bedding and other constant structural characteristics, is found in only a few scattered bodies of limited extent, is seldom seen in contact with older formations, and is not known to be fossiliferous.

The most extensive body known occurs half a mile west of Rockville, Delaware County. It crowns one of the salients separated by the narrow gorge of the North Maquoketa from the Niagara upland which extends thence nearly to the Mississippi River. This miniature plateau, like others about the margin of the driftless area, is irregularly knobbed, and the knobs are somewhat rounded by glacial action and transformed into tors (or roches moutonnées); and between the knobs it is overlain by a thin sheet of sandy drift containing bowlders 3 to 5 feet in diameter, while bowlders of equal size are scattered over the tors. The conglomerate is exposed only in

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[1] In pocket at end of volume.

[2] Free use has been made of the official reports of Owen, Hall, and White, and of all other publications relating to the geology of the territory, in the preparation of this chapter.

artificial cuttings, which are now talus-covered; but large blocks of the rock yet lie scattered about the abandoned quarry and in the village, where they were once used as building material. While the pebbles are predominantly quartz, rounded or subangular fragments of chert are not rare, and now and then rounded pebbles of limestone and granitoid rocks occur; and the coarser sand-grains correspond in material with the larger pebbles. The mass is commonly quite friable and of brilliant shades of red and yellow when freshly exposed; but it quickly alters to brown and becomes as firm as the subjacent limestone on weathering.

Isolated exposures of a conglomerate of rounded quartz pebbles imbedded in a matrix of impure limonite occur occasionally in the extreme northern part of the State, e. g., in the NE. ¼ of Sec. 11, T. 100 N., R. 12 W. (2 miles northeast of Foreston), and over several hilltops in the vicinity. Similar conglomerates form a considerable element in the drift of northeastern Howard and western Winneshiek counties.

Another outcrop of pebbly ferruginous sandstone occurs 3 miles northeast of Oxford in Jones County; but the exposures are even less satisfactory than at Rockville, and the abundance of sand in the matrix suggests that it represents an outlier of Carboniferous sandstone rather than the pebbly conglomerate.

Pebbles, and even bowlders of considerable size, undistinguishable lithologically from the Rockville conglomerate, occur in the drift in many localities; and in Delaware and Dubuque counties there is occasionally found, overlying the Niagara limestone and beneath the older drift sheet, an irregular deposit of pebbly ferruginous clay or sand more or less closely approaching the Rockville conglomerate in composition and appearance, indicating that considerable bodies of this peculiar formation existed during ante-Pleistocene times, and that they were generally broken up by the action of the ice and their materials either intermingled and distributed with the drift, or redeposited (sometimes with little admixture of foreign matter) in neighboring depressions.

In the absence of fossils it is impossible accurately to determine the age of the formation, but a rough approximation may be made. The rather unsatisfactory exposures at Rockville indicate that it lies unconformably upon the Niagara limestone, and moreover, that it is made up in part of materials (chert and limestone pebbles) derived from the breaking up of that formation; and it must accordingly be much newer than the Niagara. At the same time the materials were not only accumulated but evidently cemented so firmly as to form obdurate drift bowlders before the first ice invasion, and so the formation must be much older than the earliest Pleistocene.

A still closer approximation may be made by comparison with related deposits of neighboring regions. Lithologically the Rockville deposits resemble somewhat the brown sandstones of the extensive Carboniferous outliers in Scott, Muscatine, and Johnson Counties described in a later paragraph, but differ from them in greater coarseness, in the predominance of clay over sand in the matrix, and in the presence of granitoid rocks, apparently derived from far to the northward, among the pebbles. They more closely resemble conglomerates found by Worthen in many localities in Illinois—e. g., in Hancock County, where it "exactly resembles the conglomerate of southern Illinois which we regard as of Tertiary age;"[1] in Pike County, where it forms a "bed of clean yellow flint gravel partially cemented by the oxide of iron into a ferruginous conglomerate;"[2] in Fulton County where again it "exactly resembles the bed at Metropolis, * * * on the Ohio River, which has usually been referred to the Tertiary period;"[3] and in Tazewell County, where it sometimes exhibits stratification "similar to that of beach deposits," and in one case reaches a thickness of 9 or 10 feet;[4] but Worthen's descriptions imply that in no case does the Illinois conglomerate include erratic materials. The occurrence of Tertiary shark teeth is indeed mentioned in the same connection, yet they seem never to have been found imbedded within the deposits; and the conglomerates of these counties are tentatively regarded as of Tertiary age only on the ground of lithologic resemblance to the Tertiary conglomerates of southern Illinois.[5] Similar conglomerates were observed by Worthen and his associates in the form of drift bowlders in various parts of the State. Thus the distribution of the Illinois conglomerate appears to correspond with the distribution of that found in Iowa, though the composition appears to differ in that the former deposit contains no presumptively Archean materials.

Lithologically similar deposits of Cretaceous age have been observed by N. H. Winchell and his collaborators at many localities in Minnesota—e. g., in Blue Earth County, as laminated clay imbedded in cavities of the Shakopee limestone;[6] in Le Sueur County, where like character and relations hold;[7] in Goodhue County, as "gray pottery clay, * * * having undulating beds of fine sand," and, "a continuous belt of iron-stone or clay iron-stone about three-quarters of an inch thick," and ferruginous sandstone beds yielding angiospermous leaves belonging to the species *Salix proteæfolio, Aralia radiata,* etc;[8] in Dakota County, as shale or clay;[9] and elsewhere. White has noted the occurrence of Cretaceous fossils in considerable number in the drift of Howard and Fayette Counties, Iowa, and inferred from

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[1] Geological Survey of Illinois, 1866, vol 1, p. 330.

[2] Ibid., 1870, vol. 4, p. 37.

[3] Ibid., p. 91.

[4] Ibid., p. 197.

[5] Ibid., vol. 1, pp. 41, 422.

[6] Geol. of Minn., final rep., vol. 1, p. 432, et seq.

[7] Ibid., p. 639.

[8] Ibid., vol. 2, final report, pp. 43-45.

[9] Ibid., p. 84.

them and from associated fragments of strata that Cretaceous deposits formerly extended eastward well toward, if not quite to, the Mississippi River;[1] and he observed that "in western and northwestern Iowa the Cretaceous sandstones are found to contain beds of siliceous pebbles scarcely cemented together at all,"[2] the pebbles being siliceous, but never granitoid, and the whole evidently resembling the Cretaceous outliers of Minnesota, and also corresponding closely with the Rockville conglomerate, save in the presence of granitoid materials.

In a previous publication[3] the undisturbed Rockville conglomerate was united with the ferruginous stratum at the base of the glacial drift containing pebbles of quartz, chert, and northern crystallines; and the series was regarded as probably of glacial origin "because, first, it contains pebbles of the Archean rocks which must have been brought from a distance of from 200 to 400 miles, * * * and because, second, it occurs at various levels and is unstratified."[4] It is noteworthy, however, that the proportion of erratic pebbles within it is very much less than in the overlying glacial deposits, either of the upper drift sheet or of the lower.

On reviewing certain phenomena of Scott, Muscatine, and Johnson Counties, Iowa, described on a subsequent page, and those of the several localities in Illinois, the southeastern counties of Minnesota, and the northern counties of Iowa mentioned by White, in connection with those exhibited by the Rockville conglomerate in situ in Delaware County, certain inferences appear: (1) The Rockville conglomerate and the Cretaceous deposits lying to the northward can not represent outliers of the Coal Measures (though the small deposit of ferruginous sandstone in Jones County may), because they are unlike the Coal Measure sandstone in composition—the Coal Measure outliers are without granitoid pebbles, and even quartz pebbles are rare, while quartz is abundant and granitoid rocks not uncommon in the conglomerate at Rockville and more northerly points; (2) there is no evidence of extensive submergence of Northeastern Iowa and contiguous country during the Tertiary, and so the Rockville conglomerate can not be equivalent to the Tertiaries of southern Illinois, whatever may its relations to the lithologically similar conglomerates of the northern part of that State; (3) the fossiliferous outliers in Minnesota and the scattered fossils and associated rocks in Iowa show that, during Cretaceous time, the Paleozoic formations of Northeastern Iowa and the southeastern part of Minnesota were submerged nearly or quite to the Mississippi, and there is therefore no inherent improbability in ascribing the deposition of the Rockville conglomerate to the Cretaceous submergence; (4) the materials of the Rockville conglomerate are essentially identical with those of the outliers

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[1] Proc. Am. Assoc. Adv. Sci., 1873, vol. 21, pp. 187-92.

[2] Geol. of Iowa, 1870, vol. 1, p. 84.

[3] Notes on the Geol. of a part of the Miss. Val., Geol. Mag., second series, 1879, vol. 6, pp. 553-561, 412-420.

[4] Ibid., p. 417.

in eastern Minnesota which contain Cretaceous fossils; (5) the outliers in Minnesota prove that the Cretaceous sea extended northward into and that its waves washed the region of crystalline rocks west of the Great Lakes, so that crystalline pebbles may easily have been swept thence southward for many hundred miles; and (6) the conclusion that the Rockville conglomerate was laid down during the Cretaceous, accords with its relations to the Paleozoic rocks below, and to the Pleistocene deposits above. On the whole it is safe to provisionally refer the Rockville conglomerate to the Cretaceous, and to more doubtfully correlate it with the Nishnabotany sandstone of southwestern Iowa,[1] and (at least approximately) with the Fort Dodge gypsum of western-central Iowa.[2]

The Rockville deposits are evidently littoral and largely of local origin in Iowa, as are their probable correlatives in Illinois; though in Minnesota clays and shales, probably laid down in deeper waters, sometimes overlie similar conglomerates.

So the conglomerates at Rockville and near Foreston tell of the incursion of the Cretaceous sea upon an old land surface, and mark approximately the easternmost extension of the waters in which so vast beds of sediments were laid down toward the later-born Rocky Mountains. But the relations of these outliers to the rocks upon which they rest and to the Paleozoic formations of the upper Mississippi generally, as well as the lithologic character of the Cretaceous deposits of the upper Missouri, indicate that the eastern shore of the Cretaceous sea was not an important source of sediments; indeed the waves appear to have swept up to the water's edge as much and as coarse material as the rivers carried down.

THE COAL MEASURES.

The Iowa-Missouri coal basin barely extends into the territory studied; yet rocks of the same age occupy a considerable area within it.

About the western boundary of Grundy County and in northern Marshall County there is a body of coarse brown ferruginous sandstone or fine conglomerate, frequently containing plant impressions and occasionally seams and local pockets of coal. These sandstones are well exposed at Steamboat Rock, Eldora, and Gifford, just west of the Grundy County line, and between Liscomb and Conrad, in northern Marshall County. Other but less noteworthy exposures occur in the upland northeast of Marshall. The rather friable strata suffered severely during the ice period, and their débris forms a conspicuous element in the drift of Marshall, Tama, and Poweshiek Counties.

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[1] White, Geology of Iowa, 1870, vol. 1, p. 289.

[2] McGee, Report Tenth Census, 1884, vol. 10, p. 258.

The plateau in eastern Iowa and northern Johnson Counties, into which the Iowa River turns to form its great elbow, is generally capped beneath the Pleistocene mantle by a similar brown ferruginous sandstone. This sandstone is well exposed in Sec. 21, T. 81 N., R. 9 W., near Höhe Amana, in a quarry which has yielded much of the building stone employed in the seven villages of the communistic society of Amana. It is friable when first extracted, but hardens on exposure to the weather and forms a moderately strong and durable building material. The sand is chiefly rounded quartz grains of variable size imbedded in a matrix of clay and decayed particles of limestone, now cemented by ferric oxide; and rounded quartz pebbles up to an inch or more in diameter occur rarely either in bedding planes or disseminated. The bedding is irregular and inconstant. Lesser exposures occur at several points on the north side of the river near Amana, also 4 to 8 miles farther eastward, and again a few feet above the Cedar Valley limestone near the summits of the bluffs on the north side of the Iowa River at the great elbow eight miles north of Iowa City. Irregularly stratified gray and brown sandstones, yielding impressions of Carboniferous plants, also occur in a water-carved depression in the Cedar Valley limestone mid-height of the bluffs in the northern part of Iowa City. These and other exposures along the Iowa River represent a completely insulated outlier (perhaps divided into lesser islands by erosion) far beyond the general boundary of the Coal Measures of the Iowa-Missouri Basin.

A more extensive outlier occurs in the plateau forming the northern bluffs of the Mississippi in southern Muscatine and Scott Counties. In the city of Muscatine a sixty-foot cliff of irregularly stratified gray or brownish sandstone, containing remarkably large and symmetric spheroidal concretions[1] and one or more discontinuous coal seams, overlooks the Mississippi, while in the northern part of the city the Cedar Valley limestones rise to a much higher level, indicating that the arenaceous strata rest unconformably upon them. Three miles northeast of Muscatine the sandstones contain an intercalated bed of clay, used in the manufacture of pottery; and a mile further up the river the sandstones are coarse in grain and brown in color, like those of Amana. Farther eastward the material becomes finer and less ferruginous, as in a quarry near Buffalo, and also in the Goetsch quarry, Davenport, where it is uniformly fine, imperfectly cemented, and light buff or white in color. The coal seams of this outlier are of sufficient extent and thickness for profitable working. In the Goetsch quarry in Davenport the sandstone reposes unconformably upon the Cedar Valley limestones; and both here and in Johnson County beds of sand and silt, sometimes con-

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[1] Described by Hall, Geol. Surv., Iowa, 1858, vol. 1, p. 276.

taining fossils and thin seams of coal, supposed to be Carboniferous, occur in irregular lenticular masses, intercalated within the limestones in such manner as to indicate that they were originally deposited in caverns and crevices of the eroded Devonian strata.

Even as far north as Clinton such an intercalation of sediments in an ancient cavern in the Niagara limestone has recently been brought to light by Farnsworth, but is considered much newer than the Carboniferous.[1]

These singular intercalations were examined by Hall in 1857, and were referred to the Carboniferous on the basis of the contained fossils ("a large *Euomphalus*, distinct from any known in the surrounding rock, and very similar to a Carboniferous form," and "*fish teeth* of Carboniferous character.")[2] More recently some of the Johnson County phenomena have been observed by Webster, who follows Hall in ascribing the intercalations to deposition of Carboniferous materials in caverns and channels formed during the Devonian, and synchronizes them with certain remarkable potholes in the Cedar Valley limestone near Iowa City.[3] Farnsworth considers the intercalations at Clinton and elsewhere Pleistocene; while N. H. Winchell, who has examined similar phenomena in eastern Minnesota, suggests that all are Cretaceous.[4] Pliocene or Pleistocene bones (*Bison latifrons* (*?*) and *Megalonyx jeffersoni*) have been exhumed from a somewhat similar crevice in the Galena limestone not far from Dubuque, in Jo Daviess County, Illinois.[5] The materials accumulated within this crevice, like those of the lead-bearing caverns and fissures generally, appear, however, to be subaerial, and the fossils represent a land fauna; and accordingly the fissure deposits of the Galena terrane must be separated from the cavern deposits of the Cedar Valley and Niagara terranes. The unmistakably ante-Pleistocene caverns have been attentively examined at Davenport by Barris, who finds them variable in filling, some being packed with sand or pebbly sandstone probably of Carboniferous age, others with tenacious blue clay also probably Carboniferous, while still others, excavated in the basal portions of the Cedar Valley ("Helderberg") limestone are filled with fossiliferous shale of newer Devonian ("Hamilton") age.[6]

So far as it extends, the paleontologic evidence as to the period of cave formation and filling is decisive and proves that the intercalations were accumulated during the Carboniferous and Devonian; for the gasteropod and fish remains are of Paleozoic aspect, the coaly

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[1] Am. Geol., 1888, vol. 2, pp. 331-334.

[2] Geol. Surv. Iowa, 1858, vol. 1, pt. 1, pp. 130, 131.

[3] Am. Nat., 1888, vol. 22, pp. 408-414.

[4] Am. Geol., 1888, vol. 2, p. 333.

[5] Leidy, Contributions to the Extinct Vertebrate Fauna of the western Territories, U. S. Geol. and Geog. Surv. Terr., vol. 1, 1873, p. 255.

[6] Proc. Davenport Acad. Sci., 1880, vol. 2, p. 264.

layers are unlike anything found in the Cretaceous or other post-Paleozoic strata of the territory, and Barris's Devonian fauna is abundant and characteristic; but the various caverns appear to represent different periods.

The physical evidence is indecisive. It is true that the filling of fissures alike in the Cedar Valley and Niagara limestones indicates that these formations were so long subjected to erosion that the general surface was brought to something near its present condition before the incursion of the waters whose sediments and animal relics are preserved in the intercalated beds; but the same is true also of the Coal Measure outliers, which were evidently laid down upon a greatly eroded limestone surface—indeed the common surface of sandstone outliers and limestone subterrane appears to have suffered less from post-Paleozoic erosion than did the pre-Carboniferous limestone surface before the outliers were laid down. Moreover, most of the intercalations occur in the vicinity of the Carboniferous outliers in a region known to have been submerged during Carboniferous time. Yet there was a long period of erosion after the post-Carboniferous uplift followed by the Cretaceous submergence, another long period of post-Cretaceous erosion followed by the Pleistocene flooding, and perhaps other alternations of condition; and during any of these, certain caverns may have been formed and filled.

The northeasternmost outlier of the series thus far brought to light is a circumscribed one in southeastern Jones County, in Sec. 13, T. 83 N., R. 1 W., and apparently extending into a contiguous section. It is dark brown sandstone with a few obscure plant impressions not certainly identifiable but resembling characteristic Carboniferous forms.

The Coal Measures of the Iowa-Missouri basin proper are separable into three divisions, viz: Upper, middle, and lower, only the last named being rich in coal; and it appears to be the lower that extends into Northeastern Iowa. It is mainly composed of shales, clays, and friable sandstones, with occasional thin layers of impure limestone and a number of valuable beds of coal. Farther westward the strata are uniform and the materials predominantly fine, while in Marshall, Jasper, and Poweshiek Counties the bedding is generally irregular and sandstones predominate. Farther southward and southwestward the horizontality of the beds is apparently disturbed by a series of low parallel undulations coincident in direction with the principal water ways, the water ways certainly in some cases, and probably in all, following the anticlinals; and this system of undulations extends into Northeastern Iowa, being represented by the anticlinal followed by the Skunk River in the extreme southwestern corner and by a half dozen others in the central part of the territory.

The equivalence of the isolated outliers with the main body of the Lower Coal Measures of the Missouri-Iowa basin has been demonstrated through paleontology and identification of coal seams by Hall, White, and others. Both of the official geologists were of opinion that the principal outliers on the Iowa and Mississippi Rivers were laid down in circumscribed basins completely cut off from the Carboniferous sea. Whether this be true, or whether the outliers are remnants of once continuous deposits, the materials are certainly littoral, and so mark approximately the northeasternmost shore line of the later Paleozoic ocean; and here, as in the case of the Cretaceous, both stratigraphic relations and lithologic characters indicate that the land to the northeast of this ocean stood low and furnished little material for the vast body of sediments stretching hundreds of miles westward, southward, and southeastward. Chamberlin's "Isle of Wisconsin" was not an important source of either Cretaceous or Carboniferous sediments.

THE SUBCARBONIFEROUS FORMATIONS.

The St. Louis Limestone.—No exposures of this formation are known within the territory; but it probably forms the subterrane beneath the Skunk River in the extreme southwestern corner, since it is exposed well toward the summits of the bluffs near Pella, 10 miles below, and near Ames, 40 miles above. Observations outside the territory indicate that the formation is made up of three divisions: The uppermost of these consists mainly of moderately pure limestone, sometimes brecciated or concretionary, sometimes regularly bedded, compact, homogeneous, and brittle, with a conchoidal fracture, commonly bearing a bed of clay at the summit; the middle division is a regularly bedded firm, homogeneous and hard freestone of quartz sand, sparingly distributed through a calcareous matrix; while the lowest division is a compact, homogeneous, regularly bedded dolomite, sometimes stylolitic or suture-jointed.

The Keokuk Limestone.—No outcrops of this formation are known in the territory. It probably exists in the southern part of Johnson and Iowa Counties beneath the Pleistocene deposits, though it may not extend so far north. Farther southward it comprises two members, the upper being an irregular mass of shaly clacareo-siliceous strata abounding in geodes, while the lower consists of a compact grayish or bluish limestone, generally regularly bedded, with shaly partings.

The Burlington Limestone.—This formation, like the last, gives no exposures in Northeastern Iowa and may not exist within the territory; but since it outcrops in some thickness along the English River just beyond the limits of Johnson County it probably extends into that and perhaps other counties. At its type locality, 40 miles south of Muscatine, it is made up of three well marked beds. The uppermost consists mainly of light gray, whitish, or buff, regularly bedded, compact limestone of approximate purity, with occasional clayey or shaly partings, commonly growing siliceous, cherty, and irregular toward the top; the middle member is predominantly siliceous though generally shaly, and is seldom regularly bedded; and the basal division is pure limestone, yellowish or grayish in color, regularly bedded medially, but cherty and heteromorphic both above and below.

The Kinderhook Limestone.—The best exposures of this formation occur along the Iowa River between Marshall and Tama, and on the headwaters of Wolf Creek, near Conrad. It consists of regularly but heavily bedded limestones, sometimes magnesian, and frequently oolitic. The limestone layers are sometimes parted by beds of shale or clay. A lenticular parting of such material, exposed a few years ago at the extensive quarries of Le Grand, was found filled with beautifully preserved crinoids of many genera and species, and yielded some of the richest crinoid collections known to science. It was completely exhausted within a few months; but fortunately a large part of the material passed under the eyes, and a considerable part into the hands, of Wachsmuth and his associate Springer, the foremost authorities on crinoids; and it is now under examination.

These four Subcarboniferous formations of Iowa are commonly concealed by drift, and are known only from a few widely separated outcrops; they have been discriminated by the official geologists of the State on paleontologic grounds alone; and little is known of their physical relations. In a general way it is known (1) that they are predominantly shaly in the southeast, and predominantly calcareous in the northwest (e. g., the Kinderhook is almost wholly shale at Burlington and almost wholly limestone at Marshall, Iowa Falls, and Humboldt); (2) that the two medial formations, or at least the fossils upon which they have been founded, extend but a little way northwest of the Mississippi River and are not found in the northwestern part of the Subcarboniferous terrane; (3) that the series probably thickens and the terrane certainly widens to the northwestward; and (4) that there are no indications of unconformity between the formations in any of the quarries and cliffs in which they are exposed. It is probable that they represent collectively a continuous series of deposits, and that the dying out of the Keokuk and Burlington faunas northwestward expresses some change in condition which is otherwise expressed by the diminution of argillaceous sediments in the same direction.

It is significant that the deposits of these formations are either limestones or fine shales, and so apparently off-shore deposits. It is equally significant that, while there is no marked unconformity between the St. Louis limestones and shales and the superjacent Coal Measures in central Iowa, and while these great groups of rocks, like the individual formations, thus appear to represent continuous deposition, yet on the Iowa River in Marshall County the latter overlaps the earlier formations and reposes unconformably upon the oldest of the four, the three newer being entirely absent. And it is significant, too, that while the shore deposits of the later Carboniferous sea are preserved in great outliers and overlaps, those of the earlier have completely disappeared. These significant relations elucidate in some measure the Paleozoic history of the territory

THE DEVONIAN FORMATIONS.

The Hackberry Shale.—The best exposure of this formation occurs half a mile west of Rockford, Floyd County. It here consists of dark shale or clay abounding in well preserved fossils belonging to a characteristic fauna. Other exposures occur at the village of Hackberry, 7 miles northwest of Rockford, and another at Rudd is described by Webster.[1] These shales and clays were no doubt extensively distributed over the western part of the territory during preglacial times, but they suffered greatly under the ice-plow, which moved most energetically in that region, and were either broken up to furnish materials for the drift of Floyd, Butler, and perhaps other counties, or concealed beneath the prevailing Pleistocene mantle of the prairies.

The formation was specifically designated "Rockford Shales," by Calvin, in 1878,[2] and again in 1883,[3] and was described by Webster under the same designation within a year;[4] but since the geographic element of this designation was preoccupied in the "Rockford Goniatite Beds" or "Rockford Limestone," of Meek and Worthen,[5] at Rockford, Indiana, it must be abandoned. The formation has been designated "Lime Creek," by different geologists from the stream on which it is typically developed, but the name just applied by Webster, "Hackberry,"[6] is preferable.

The Cedar Valley Limestone.—This formation is the most extensively distributed within the territory, and it is at the same time the most widely diverse in lithologic, paleontologic, and structural characters. Thirteen distinct lithologic phases have been enumerated elsewhere,[7] and, as will appear later, the paleontology is equally diverse. It consists predominantly of limestones, ranging from pure to argillaceous, dolomitic, or perhaps carbonaceous; sometimes it is regularly divided by smooth bedding planes, again it is massive, elsewhere finely laminated, and frequently brecciated in a peculiar manner; sometimes the strata are horizontal, but elsewhere they are

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[1] Proc. Davenport Acad. of Sci., 1889, vol. 5, part 1, p. 101.

[2] Bull. U. S. Geol. Surv. of the Terr., vol. 4, p. 725; Am. Jour. Sci., 3d ser., vol. 15, p. 460.

[3] Am. Jour. Sci., 3d ser., vol. 25, p. 432.

[4] Proc. Dav. Acad. of Sci., 1889, vol. 5, part 1, p. 100 et seq.

[5] Am. Jour. Sci., 2d ser., 1861, vol. 32, p. 167 et seq.

[6] Am. Nat., 1889, vol. 23, p. 242.

[7] Report Tenth Census, 1884, vol. 10, pp. 261-263.

CONTACT BETWEEN DEVONIAN AND SILURIAN LIMESTONES, FAYETTE.

locally inclined to every point of the compass and at all angles up to 10° or 15°; and sometimes the mass is so richly fossiliferous that well preserved fossils may be collected by the bushel, while again it is quite destitute of fossils over wide areas. The thickness of the formation can only be estimated roughly, and the extent of the terrane can not accurately be determined by reason of the heavy mantle of drift, particularly in the southwest.

The contact between the Cedar Valley limestone and the superjacent shales is nowhere well exhibited; neither is the contact between the Devonian formations and the overlying Subcarboniferous anywhere clearly exposed; and the outliers of the Coal Measures repose unconformably upon and fill cavities within the limestones at the known points of contact in Johnson, Muscatine, and Scott Counties. The contact with the subjacent Niagara limestone is exposed at two points, viz, in the northwestern part of Fayette, and in the left bluffs of the Wapsipinnicon between Central City and Paris. The former contact is exhibited in the accompanying illustration reproduced from a photograph (Pl. XXIV), and in the general section, showing the relations of the brecciated and nonbrecciated limestone, forming Fig. 14. The formations appear scarcely conformable on careful examination, though the unconformity is inconspicuous and perhaps fictitious; for the heavy ledge of magnesian limestone (number 5 of the section; mid-height of the rock face in Pl. XXIV) appears to agree lithologically rather with the Niagara than the Cedar Valley, yet the immediately subjacent ledge of dolomite feathers out to the left, so that while the heavy ledge may represent shoaling waters of the earlier epoch, it is equally probable that it represent rearrangement and redeposition of the Niagara dolomite consequent upon submergence after subaerial exposure.

In the contact on the Wapsipinnicon the succession (as observed and described by Prof. Wm. H. Norton, of Cornell College, Mount Vernon) is as follows:

		Feet.
Cedar Valley	Brecciated limestone	1
	Slope	45
	Saccharoidal limestone	2.4
	Slope	3.8
	Variable limestone	7.4
Undetermined	Variable layers of limestone	4.8
Niagara	Buff vesicular dolomite	16.3
	Slope to river level	10

Here again there is no decided unconformity and no perceptible discordance in bedding, but only an intermediate stratum which might represent a passage bed, though it is probably significant of the general discontinuity indicated by the broader relations among among the formations.

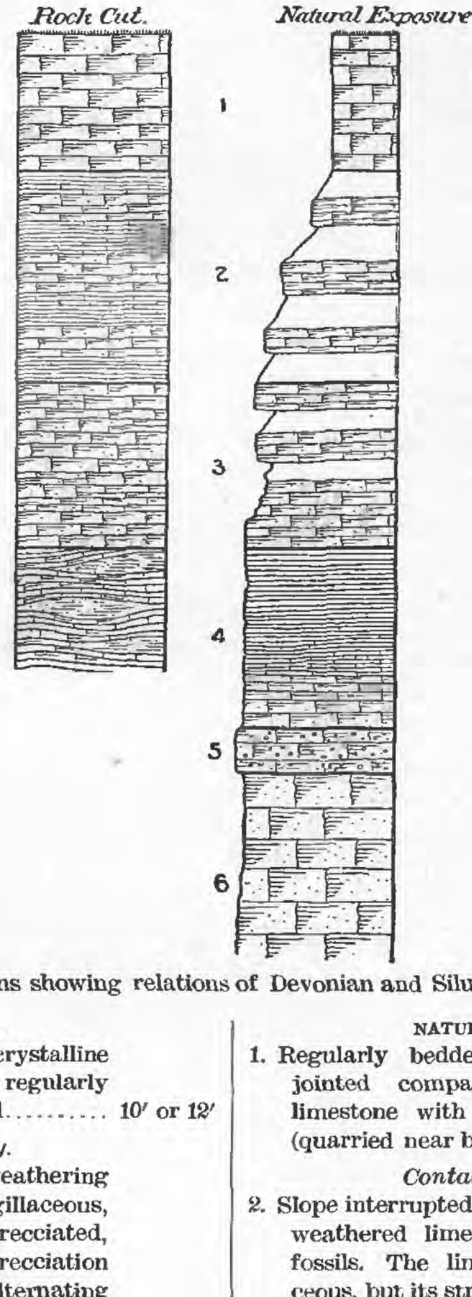

FIG. 14.—Juxtaposed sections showing relations of Devonian and Silurian formations at Fayette.

ROCK CUT.

1. Slightly argillaceous subcrystalline limestone, fossiliferous, regularly bedded, uniformly jointed.......... 10′ or 12′

Conformity.

2. Variable beds of rapidly weathering limestone, somewhat argillaceous, and either laminated or brecciated, the lamination and brecciation being best displayed in alternating layers. The laminated portions are poorly fossiliferous.................. 15′ ±

No marked unconformity.

3. Argillaceous limestone, extensively brecciated. The fragments are finely laminated, as are the few nonbrecciated portions. Rare fossils alike in fragments and matrix .... 12′ ±

Apparent unconformity.

4. Heterogeneous whitish limestone, generally argillaceous and laminated, sometimes magnesian and massive or heavy bedded, such portions being commonly lenticular with inclosing laminæ; unfossiliferous........... 10′ ±

NATURAL EXPOSURE.

1. Regularly bedded and uniformly jointed compact subcrystalline limestone with occasional fossils (quarried near by)................... 12′ ±

Contact not exposed.

2. Slope interrupted by ledges of much weathered limestone, yielding no fossils. The limestone is argillaceous, but its structure does not appear in the imperfect exposures.... 15′ or 18′

Contact not well exposed.

3. Much weathered argillaceous limestone forming a steep slope, inconspicuously brecciated, the fragments and at least part of the matrix being laminated..................... 10′ or 12′

Contact not exposed.

4. Thin bedded or laminated argillaceous limestone, exhibiting moderately regular bedding below, but becoming shaly above; unfossiliferous above, poorly fossiliferous below... 12′ or 14′

Unconformity?

5. Heterogeneous, silty and cherty brown magnesian limestone in a single ledge.......................... 3′

Conformity?

6. Heavily bedded, light brown magnesian limestone with fossil casts..... 12′ ±

The Devonian limestones of Iowa were first studied and described, and were correlated with the Hamilton, Corniferous, and Onondaga formations of New York, by Owen, in 1850.[1] His nomenclature varied, and he evidently sought to apply a descriptive and connotative designation to the formation, rather than a specific denotative name; and the nearest approaches to a specific name are, "Limestones of Cedar Valley,"[2] and "Formations of Cedar Valley."[3]

In 1858, Hall referred certain "gray and yellow sandstones, with shaly admixtures and shaly partings, which exist at numerous points on the Mississippi River below Davenport," associated with the Devonian limestone, to the Chemung;[4] and at the same time he referred the limestones themselves to the Hamilton and the Upper Helderberg,[5] and certain laminated shaly limestones underlying the latter to the Onondaga.[6] In 1860, White recognized the general equivalency but denied the exact contemporaneity of the former beds with the Chemung as developed in New York;[7] a year later, Meek and Worthen referred at least a part of the same beds, which they designated Kinderhook,[8] to the Carboniferous; Worthen retained the same classification in 1868;[9] and in 1870, White referred all the Devonian strata of Iowa to the Hamilton.[10] Subsequently, Hall and Whitfield reinvestigated the Devonian rocks of the northern part of the State, and correlated the shale occurring at Rockford and Hackberry and certain beds at Cedar Falls with the Chemung, the limestones at Waterloo with the Upper Helderberg, the white limestone at Raymond with the Schoharie, and the limestones and shales at Independence and Waverly with the Hamilton.[11] After a study of the rocks and fossils extending over several years, Calvin, in 1878, called attention to the tripartition of the Iowa Devonian into the shales exposed on Lime Creek, the great limestone series, and a dark shale found beneath the limestones at Independence and elsewhere; but he followed White in referring the three divisions to a single formation—the Hamilton.[12] In 1880, Barris pointed out that the Devonian strata at Davenport comprise a series of clearly differentiated beds with one or more unconformities; and that while one of the beds appears to correspond with the Hamilton of New York, the general affinities of the fauna of another seem to be with the fossils of the Corniferous or Upper Helderberg.[13] A few years later,

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[1] Report Geol. Surv. of Wisconsin, Iowa, and Minnesota, 1852, pp. 77-89.

[2] Op. cit., p. 81.

[3] Op. cit., legend of folding map.

[4] Geol. of Iowa, 1858, pt. 1, pp. 88-91.

[5] Ibid., pp. 81, 85

[6] Ibid., p. 76.

[7] Jour. Nat. Hist. Soc. of Boston, vol. 7, pp. 209-226.

[9] Am. Jour. Sci., 2d ser., 1861, vol. 32, pp. 173-228.

[8] Geol. Surv. of Illinois, vol. 1, p. 109.

[10] Geol. of Iowa, vol. 1, p. 187.

[11] 23 Regent's Report New York State Cabinet, 1873, pp. 223-226.

[12] Am. Jour. Sci., 3d ser., vol. 15, pp. 460-462; Bull. U. S. Geol. and Geog. Surv. Terr., vol. 4, p. 727 et seq.

[13] Proc. Dav. Acad. of Sci., vol. 2, pp. 261-269 and 282-288.

H. S. Williams, after an elaborate study of the Devonian fauna of the United States, concluded that the Lime Creek beds are "equivalents of the Chemung period deposits of the east;"[1] and subsequently that "the exact relation of the Lime Creek beds and other deposits of the west is not satisfactorily determined."[2] In the same year, Calvin correlated anew the Iowa and New York faunas, noted new discoveries which "would seem to indicate that the Lime Creek beds are equivalent to the New York Chemung," but conceded that "the mingling of Upper and Lower Devonian features in the Lime Creek fauna, and in all the Devonian fauna as well, leaves the question of exact equivalency still doubtful."[3]

Quite recently H. S. Williams has pointed out that "the relation of the Rockford (Lime Creek) shale fauna and that of the yellow sandstones of Muscatine * * * is with the fauna of the Ithaca group of New York and the east;"[4] and since, as long since shown by Calvin, the faunas of the summital and basal shales of the Iowa Devonian are substantially identical, this reference applies equally to the subjacent limestones with their large and locally variable faunas.

The "gray and yellow sandstones" associated with the limestones below Davenport and near the present village of Buffalo, referred to the Chemung by Hall in 1858, were supposed by him to be equivalent to the sandstones near Burlington which were in 1861 shown by Meek and Worthen to be Carboniferous and included in their Kinderhook formation;[5] and White, in 1870, accepting Hall's correlation of the Buffalo and Burlington sandstones as well as the determination of the age of the latter by Meek and Worthen, referred the sandstones of Muscatine County to the Carboniferous;[6] and Hall,[7] Williams,[8] and Calvin[9] accepted that reference. Recently, however, Calvin has reinvestigated the matter, ascertained that the characteristic fossil of the Buffalo sandstones, *Spirifera capax,* is but an internal cast of the characteristic fossil of the Hamilton, *Spirifera parryana,* showed that this fossil is associated with many other characteristic Devonian fossils and that the sandstones contain absolutely no Carboniferous remains, and thus demonstrated that these beds belong to the Devonian system and probably to the Hamilton formation.[10]

So the Devonian rocks of Iowa have been referred to the Kinderhook, Chemung, Ithaca, Schoharie, Hamilton, Corniferous, and Upper Helderberg; and even if the question be narrowed by excluding the

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[1] Am. Jour. Sci., 3d ser., 1883, vol. 25, p. 103. The "Lime Creek beds" are the Hackberry shales of foregoing pages.

[2] Ibid., p 311.

[3] Ibid., p. 436.

[4] Am. Geol., 1889, vol. 3, p. 233.

[5] Am. Jour. Sci., 2d ser., 1861, vol. 33, pp. 173-228.

[6] Geology of Iowa, 1870, vol. 1, p. 189.

[7] Report State Geologist of New York, 1882, Pl. 52 and description.

[8] Am. Jour. Sci., 3d ser., 1883, vol. 25, pp. 97-104.

[9] Notes on the geological formations of Iowa, 1885, p. 7.

[10] Bull. Lab. Nat. Hist. State Univ. of Iowa, 1888, pp. 7-18; Am. Geol., 1889. vol. 3, pp. 25-36.

Hackberry shales and the Independence shales, and by accepting Calvin's correction of the erroneous reference of the Buffalo sandstones, it remains true that parts or all of the limestone series have been referred to the Chemung, the Schoharie, the Hamilton, the Corniferous, and the Upper Helderberg. Yet the stratigraphic relations of the fossiliferous beds generally indicate continuous deposition, the only noteworthy unconformity being that recognized at Davenport by Barris.[1] It is therefore manifestly unwise to correlate either the limestones alone or the entire series of Devonian strata with any of the New York divisions; and while the shales may be discriminated on both lithologic and paleontologic grounds, it is not now possible (and perhaps it never will be possible) to separate the limestone series into distinct formations or into individualized beds of more than local value. They may accordingly be treated as a unit, and may take an individual name; and it seems expedient to recur to the designation originally proposed by Owen, and rechristen the entire series of calcareous Devonian sediments stretching from the Minnesota line to Muscatine County, in a belt 50 miles in average width, the *Cedar Valley limestone.*

Over a considerable portion of its terrane the Cedar Valley limestones are singularly brecciated at one or more horizons. The best exposure of the breccia is in a railway cutting 60 or 70 feet deep at Fayette, where the brecciated layers are interstratified with non-brecciated beds of somewhat greater aggregate volume, as illustrated in Fig. 14. Here as in other cases the breccia is made up of angular fragments of light drab or bluish argillaceous limestone of laminated structure ranging from a fraction of an inch to several inches in diameter, sometimes sparsely and sometimes abundantly imbedded in a matrix of similar limestone; and the intervening non-brecciated beds are also similar to the fragments, though usually exhibiting the laminated structure more distinctly. Both fragments and matrix are sometimes fossiliferous, and their fossils are identical. The brecciated beds are also, but less perfectly, exhibited in the cliffs of the Volga, in the northwestern part of the same village. The relations of the two exposures and of the brecciated and non-brecciated beds in each are shown in the juxtaposed sections forming Fig. 14. The character of the breccia is shown in Pl. XXV, which is a process reproduction of a photograph on the natural scale, and in Fig. 15, which is reproduced from a drawing, also natural size; and the manner in which the brecciated and non-brecciated portions merge is shown in Fig. 16, which is slightly reduced in scale.

The structure is exhibited over an immense area. Similar breccias occur occasionally in various parts of Fayette County, in Mitchell, Chickasaw, Buchanan, Benton, Iowa, Jackson, Cedar, and Muscatine

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[1] Proc. Dav. Acad. Sci., 1880, vol. 2, p. 265.

Counties, and have been noted as drift bowlders in all of these and in some other counties of Northeastern Iowa. The brecciation appears to be practically coextensive with the Cedar Valley terrane.

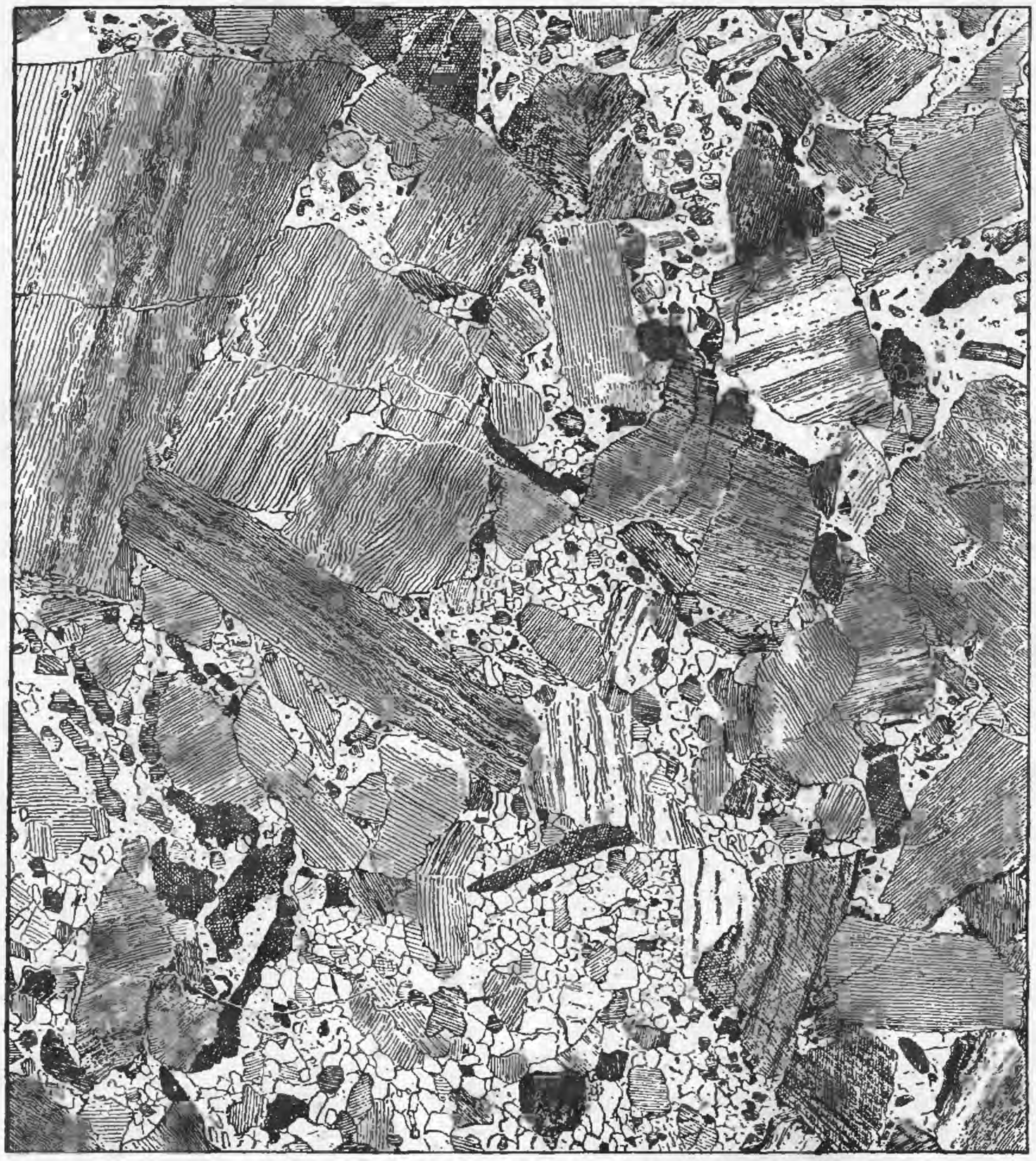
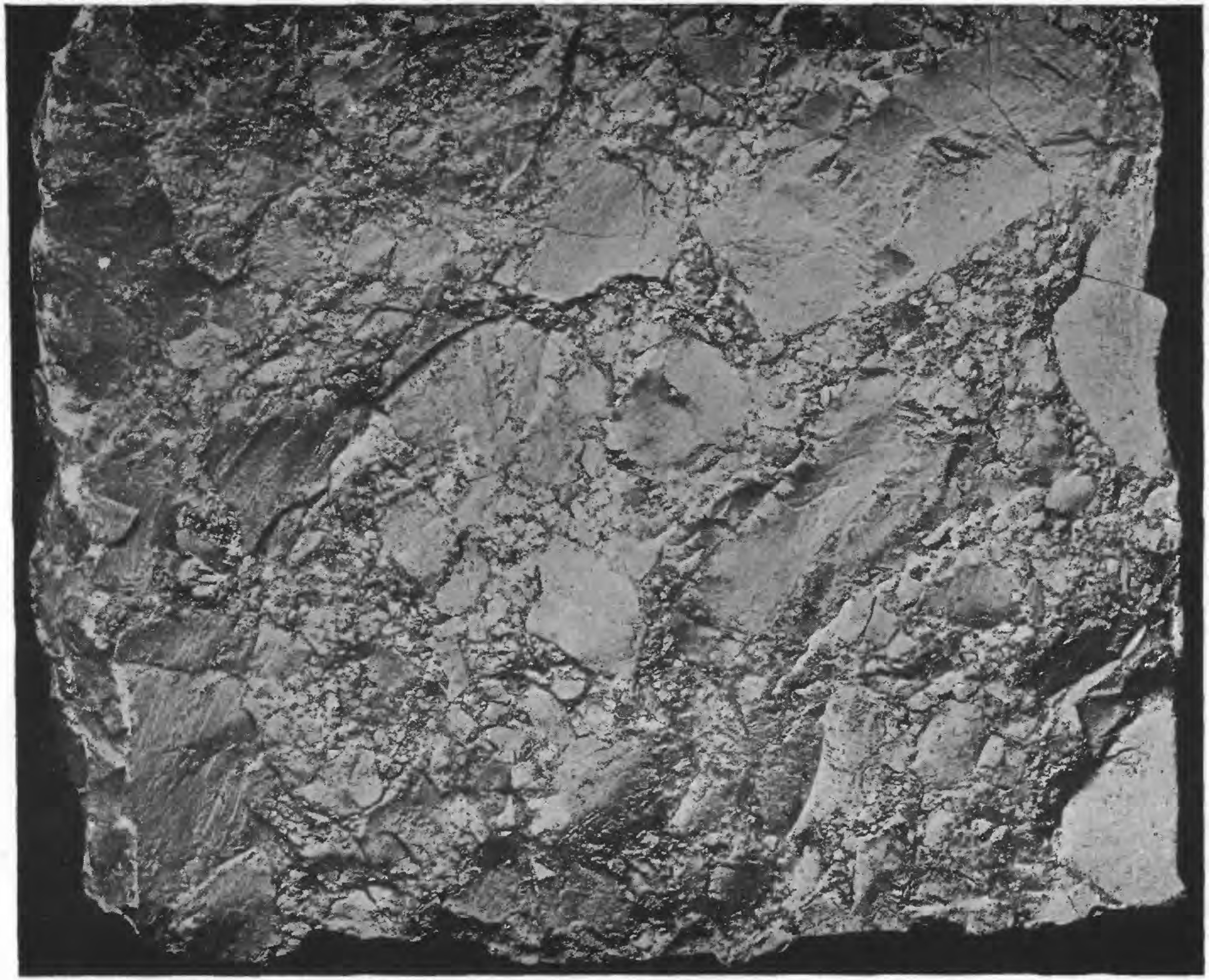


FIG. 15.—Devonian breccia. Natural size.

The Independence Shale.—This formation, named by Calvin in 1878,[1] is overlapped by the Cedar Valley limestone and probably has no natural outcrop. It is a dark carbonaceous shale, about 25 feet in maximum known thickness, characterized by an abundant and distinctive fauna closely allied to that of the Hackberry shale. It was first found in a shaft at Independence, and has since been brought to light at several localities in the Wapsipinnicon and Cedar valleys, notably at Marion and a few miles east of Toddville. Its

[1] Am. Jour. Sci., 3d ser., vol. 15, p. 460; and elsewhere.



DEVONIAN BRECCIA.

relation to the Cedar Valley limestones above and to the Niagara below are shown in the accompanying section, Fig. 17.

As a whole the Devonian rock-mass has a gentle southwestward inclination and thickens southwestward. Its terrane narrows and its mass apparently thins materially to the southeastward, yet its thickness at the Mississippi River, in Scott County, probably exceeds 400 feet;[1] and its thickness in the northern part of the terrane may

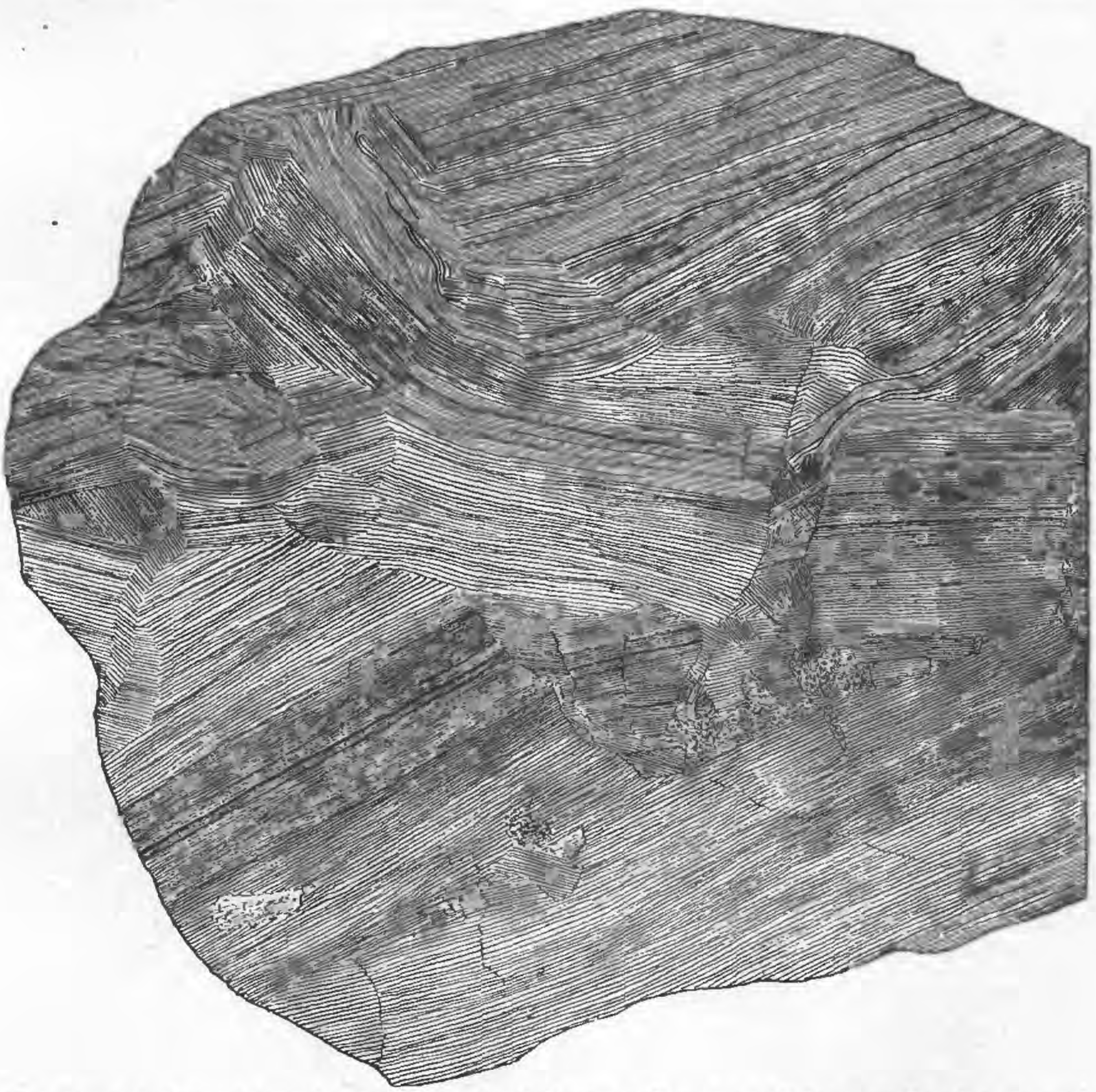


FIG. 16.—Relations of breccia to non-brecciated Devonian limestone, slightly smaller than natural size.

be roughly estimated at 300 to 600 feet. Neither the Hackberry shales nor the Independence shales are known in the south (unless the former are represented by the yellow sandstones at Buffalo); yet the great mass of the formation in the north consists of more or less pure limestones with some dolomites (the shales being relatively thin), while to the southward the limestones are argillaceous, shale-parted, and sometimes sandy, with some clean sandstones. So the mass as

[1] According to Tiffany, there are 390 feet of Corniferous and 80 feet of Lower Helderberg ("Le Claire") at Davenport. Am. Geol., 1889, vol. 3, p. 117.

a whole is predominantly calcareous in the north and largely argillaceous and arenaceous in the south—the distribution of mechanical and chemico-mechanical materials respectively agreeing with that exhibited by the Subcarboniferous formations.

The greater part of the Devonian strata are made up either of finely comminuted sediments or precipitates such as are commonly regarded as deep-water deposits. Yet the northeastern shore of the Devonian sea could not have been far away. No outliers like the conspicuous "mounds" of Niagara limestone occur beyond the principal terrane; none of its silicified fossils or rare cherty nodules have ever been found among the residuary materials of the driftless area, as are the residua of the Devonian and Carboniferous formations of central Kentucky upon the lower Silurian floor; there is not throughout the Silurian terranes of Iowa, Illinois, and Wisconsin, either an outlying Devonian knob or a residuary pebble, so far as known; and

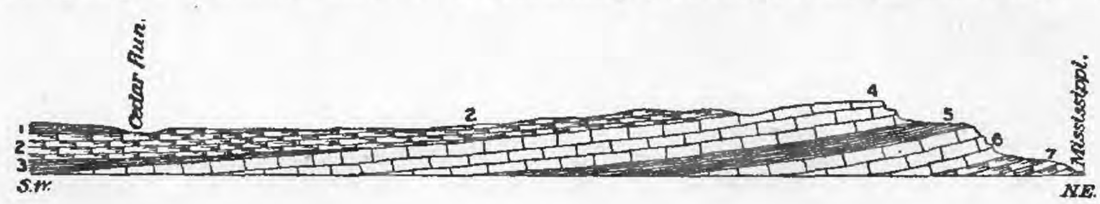


FIG. 17.—General stratigraphy of the Devonian and Silurian in Northeastern Iowa: (1) Hackberry shale; (2) Cedar Valley limestone; (3) Independence shale; (4) Niagara limestone; 5) Maquoketa shale; (6) Galena limestone; (7) Trenton limestone.

still more decisively, there is not a hill nor a valley in the region which exhibits form or relation certainly inherited from any newer terrane than the Niagara limestone. The greatly eroded Niagara has left its impress on every hill and valley of the region, but no topographic feature can be ascribed to the Devonian. Chamberlin has indeed hypothetically located the Devonian shore line near the present course of the Mississippi between Iowa and Wisconsin;[1] and while there are reasons for believing that the course of the Mississippi was not finally chosen until long after the post-Devonian elevation, it is probable that this location is approximately right.

From the general section forming Fig. 17, it will be seen that the southwestward inclination of the Devonian strata is less than that of the Niagara; that the lower division of the Devonian rock-mass laps but a little way upon the Niagara, and falls short of the deeper water limestones; that there is a hiatus between the Independence shale and the Niagara limestone, probably representing in part or in whole the Corniferous, the Schoharie, the Cauda Galli, the Oriskany sandstone, the Lower Helderberg, and the Salina series of New York, whose equivalents may exist (perhaps greatly attenuated) beneath the Independence shale farther to the southwestward; that the successive beds of the Cedar Valley limestone fail below, and thus that the Devonian and Silurian rocks are unconformable in a large way, despite the close accord in dip at the points of contact; and it will

[1] Geology of Wisconsin, 1883, vol. 1, pl. 3, pp. 202, 252, 253.

be remembered that there is a thin passage bed between these groups of rocks at Fayette. So the Devonian must have been ushered in by an epoch of high level of the land when the shore was far southwest of the present terrane; the land must have gradually sunk, and as the waves advanced, progressively newer and newer strata must have been laid down on the submerging land until the waves rolled well up the slopes of the "Isle of Wisconsin" and there stood long (perhaps with the slight oscillation indicated by the Davenport unconformity) before commencing more rapid recession. Yet even when the land stood highest the rivers from the northeast could have paid but scant tribute to the ocean; and when the land stood lowest and the waves rolled highest, too little mechanical detritus came down to replace the limy precipitates. It was only as the waves finally receded that the rivers cooperated with them to the extent of furnishing purely mechanical débris for the formation of the shales at the summit of the series.

Although the formations wrapped about the southwestern flanks of the "Isle of Wisconsin" are in general of progressively diminishing inclination from the upper Silurian up to the Carboniferous if not to the Cretaceous, it is a useful, even though farfetched, hypothesis that the Devonian was brought to an end by an uplifting of the continental nucleus toward the center rather than along its southern periphery. By this hypothesis (with its corollary concerning increased declivity) the transition from limestone to shale in the upper part of the Devonian rock-mass may be explained; by this hypothesis, too, the diversity in inclination of the southwesternmost Devonian strata and the overlying formations of the Subcarboniferous may be explained; and if the fresh-formed sediments upon the sloping flanks of the island be supposed to have settled slightly seaward down the prevailing slope and so slipped upon each other, then by this hypothesis also the widespread crumpling and buckling (described on a later page), of the Devonian strata and the extended development of the Devonian breccia may be explained.

THE NIAGARA LIMESTONE.

This limestone forms an extensive terrane, and its exposures are innumerable; and unlike the still more extensive Cedar Valley limestone, it is wonderfully consistent in composition and structure.

In the northern part of the territory, and in its northeasternmost exposures and outliers, the formation consists of brown, buff, yellowish, or cream-colored dolomite, heavy bedded or massive, and frequently charged abundantly with characteristic nodules of chert, either disseminated or accumulated in bedding planes. In the central part of the territory the dolomite is lighter in color, generally less magnesian and more thinly bedded, yet abounds in chert; and occasionally it becomes a pure limestone, either massive or irregularly bedded, gray, blue, or bluish white in color. In the southern and western parts of its terrane the rocks are predominantly magnesian but sometimes slightly argillaceous, and are generally regularly and thinly bedded, rarely with shaly partings; and chert is less prevalent than to the northeastward, though still frequently found.

Throughout its terrane the Niagara strata have the prevailing inclination to the southwestward characteristic of the formations of Northeastern Iowa and contiguous territory; and in general the dip is fairly uniform. In its central and southern portions the dip is interrupted only by a few low anticlinals and synclinals extending in northwesterly-southeasterly directions, and toward its northern limits the formation attenuates and the inclination diminishes until in eastern Howard County the smallest ante-Pleistocene, and even modern, drainage lines cut through it in all directions over an area of scores of square miles, and until wells penetrate the limestone to find an abundant water supply at the summit of the subjacent Maquoketa shales; but these departures from the low southwesterly dip are exceptional.

In the central part of the terrane, the Niagara reaches a considerable thickness, probably not less than 350 feet; but it thins rapidly to the northward. At Fayette its bluffs are only 100 feet high, and the entire formation is probably not more than 150 feet thick; at Fort Atkinson it appears to be little, if any, more than 75 feet in total thickness; two miles south of Florenceville, less than 50 feet intervene between the Cedar Valley limestone capping the bluffs and the Maquoketa shales cropping out on their slopes; at Foreston no more than 25 feet of the Niagara dolomite appears; and still farther northward, in Minnesota, but a single exposure of only a few feet in thickness is known.[1]

In 1852 Owen combined the Niagara with the Galena and Trenton limestones as the "Upper Magnesian limestone" or "St. Peter's Shell limestone."[2] Half a dozen years later Hall discovered an intervening formation—the Maquoketa shale—which he correlated with the Hudson River, of New York,[3] and, after disposing of the inferior portion of Owen's group, separated the superior dolomitic layers into the Niagara limestone (which he correlated with the formation of the same name in New York), and the Le Claire limestone (which he was disposed to regard as "establishing a distinct group.")[4] This division of the upper series of Iowa dolomites was not adopted by White when, in 1870, he correlated the entire series with the Niagara of New York;[5] but in subsequent publications Prof. W. H. Norton has maintained Hall's division of the dolomite series into the Niagara and the Le Claire.

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[1] Geology of Minnesota, Final Rep., 1884, vol. 1, p. 302.

[2] Geol. Surv. of Wisconsin, Iowa, and Minnesota, p. 19. Ibid., p. 71.

[3] Geol. Surv. of Iowa, 1858, vol. 1. p. 64.

[4] Ibid., p. 75.

[5] Geol. of Iowa, 1870, vol. 1, p. 182.

The correlation of the Iowa series with that of New York rests upon paleontology alone, though the general facies of its fauna allies it in some degree to the Clinton, and its prevailing fossil (*Pentamerus oblongus*) is as characteristic of the Iowa Niagara as of the New York Clinton.[1] Hall divided the series on the ground of both lithologic and paleontologic differences; but the paleontologic differences are the less important, for only one or two Le Claire fossils are peculiar to the beds to which the name was applied and but few Niagara species are not represented within it, while the Niagara dolomites are predominantly massive or heavy bedded, cherty but otherwise homogeneous, and quite destitute of argillaceous matter, and the Le Claire dolomites are obscurely laminated as at the type locality, distinctly and finely laminated as at Anamosa, or laminated and ripple-marked as at the Palisades on the Cedar near Mount Vernon, and everywhere poor in chert but charged with clay. In short, the Niagara and Le Claire, respectively, of Hall and Norton exhibit the commonly accepted features of deep-water and shoal-water deposits. No unconformity between the two phases is known; and indeed the change is in line with the gradual modification in lithologic aspect observed in tracing the upper Silurian dolomites from the great escarpment to the Devonian boundary along any section. So it is inexpedient to divide the series. The successive strata unquestionably represent continuous deposition with some change in conditions (probably due to gradual shoaling) which might easily have produced as decided a change in life as that indicated by the slightly diverse fauna of the base and summit; and while the series is probably not precisely equivalent to the New York formation from which it was named by Hall, common usage and consequent convenience prescribe the retention of that name.

Dolomites are less readily soluble in either pure or acidulated waters than nonmagnesian limestones; and the Niagara dolomites are generally impregnated with siliceous matter (frequently segregated as chert) by which their resistance to erosion is still further increased. Thus the Niagara has ever been an obdurate formation, and its rocks have resisted erosion more stubbornly by far than any others of the Mississippi Valley. Its cherty portions were especially obdurate, and are now marked by prominent knobs many miles within the glaciated area; but even the nonsiliceous portions of the formation are practically free from the caves and underground streams characteristic of limestone terranes generally, including that of the Trenton, a few miles northeastward. So it is that the Niagara strata not only stand in a prominent escarpment marking the northeastern boundary

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[1] Cf. Hall, Geol. of Iowa, 1858, vol. 1, p. 72; Whitney, Ibid., p. 366; Hall, Paleontology of New York, 1857, vol. 2, p. 81; 28th Regents' Report New York State Cabinet, 1879, p. 101, note; Am. Jour. Sci., 2d ser., 1848, vol. 5, p. 364, note.

of the formation, but have stood for untold ages in isolated outliers left 5, 10, even 50 miles behind in the secular recession of that cliff line. And so it was that the Niagara limestone became an impassable barrier for the Minnesota-Iowa lobe of the great ice-sheet; it gave a rugose surface, among whose irregular knobs and wandering ravines the ice became entangled, and its body rose as a great ridge, which partially deflected the mobile sheet and then crevassed it into rapidly melting seracs as its attenuated edge reached the crest.

The Niagara formation originally stretched northeastward far beyond the present course of the Mississippi, as indicated not only by its outliers but by the influence of its slowly receding escarpment upon the topography. Where the shore line of the Niagara ocean lay, and whence its sediments came, no man certainly knows.

THE MAQUOKETA SHALE.

The materials of this formation are mainly blue, green, and gray shales and clays, with occasional irregular and discontinuous beds of impure limestone—the limestone beds increasing in number and thickness, and the shales becoming progressively more calcareous to the southwestward. Its thickness ranges from perhaps 20 feet at its northernmost exposure near Lime Springs to about 125 feet on the Mississippi in eastern Jackson County. At Monticello the shales were found 110 feet thick in an artesian boring.

The materials of the formation are so little indurated that it quickly breaks down on weathering; and hence the terrane forms a long, narrow, and exceedingly sinuous belt of gentle slopes, from which the Niagara escarpment rises steeply and often precipitously. This zone of gentle slopes everywhere separates the rugged escarpment above from the stronger slopes assumed by the Galena dolomite below. It is a zone of abundant springs, for the waters permeate the porous Niagara limestone to, and flow out upon, the impervious shales; and it is a zone of landslips, for the slopes are burdened by débris from the escarpment above and invaded by the undermining of the cliffs below; but these and other characteristics are, in part, masked by the mantle of loess in the south, and of water-sorted drift in the north—for where the Niagara escarpment is high the ice-sheet terminated at its verge, and the ice-borne bowlders are perched upon the hill-tops, while only the finer glacial débris lies upon the lower slopes.

The formation was recognized by Hall, and correlated with the Hudson River deposits of New York in 1858.[1] Twelve years later, White reinvestigated its rocks and its fossils and concluded that they "leave no doubt as to the propriety of referring it to the same geological period as that at which the rocks at Cincinnati, Ohio, were formed; but, as a formation, it is regarded as distinct from

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[1] Geology of Iowa, part I, p. 64.

any other one of that group hitherto defined;"[1] and to the formation he applied the distinctive appellation yet retained. The formal abandonment of the Cincinnati group[2] affects neither the integrity of the formation nor the propriety of White's designation.[3]

The eastern boundary of the formation can not be delineated with exactitude, because its shales and clays thin out gradually, give no topographic expression, and are mantled by Pleistocene deposits; neither can the thickness of the formation be determined with exactitude from outcrops, for wherever the slopes are sufficiently steep to permit of measurement there the plastic clays have been compressed beneath the weight of the massive ledges of the superincumbent Niagara limestone, and the ledges have either settled unequally, leaving great ramifying fissures intersecting the hills in all directions but generally parallel with their faces, or fallen down and cumbered the slopes in huge, angular masses.

How far the waters of the Maquoketa ocean encroached upon the "Isle of Wisconsin" does not appear; but certainly it was continuous with that in which the Hudson River strata were laid down along the western flanks of the Paleozoic Atlantis, for the characteristic sediments and fossils of the epoch stretch across Illinois, Indiana, Ohio, Pennsylvania, and New York in constantly increasing strength.

THE GALENA LIMESTONE.

The greater part of this formation consists of heavy bedded or massive, buff, brown, and gray dolomite, somewhat vesicular or cavernous in texture; but its upper part is more argillaceous and regularly bedded, with shaly partings. Indeed, despite the wide difference in external appearance, the Maquoketa shale passes into the Galena by interbedding, by intergradation of materials, and by intermingling of faunas; the *Lingulæ* and associated Maquoketa brachiopods (rare or unknown in the limestone) abounding in the shaly intercalations within the Galena, and the "lead fossil" (*Receptaculites*) and associated gasteropods of the limestone (unknown in the shale) abounding equally in the intercalated ledges of limestone within the Maquoketa. The Galena dolomite is moderately constant in structure, texture, and composition, but it varies greatly in thickness, thinning northwestward from 250 or possibly 300 feet in Dubuque County to 20 feet or even less at the northern line of the State, beyond which it soon disappears. In Dubuque and Jackson Counties, it gives character to the topography only less decidedly than the

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[1] Geology of Iowa, 1871, vol. 1, p. 181.

[2] Proc. Cin. Soc. Nat. Hist.; Am. Jour. of Sci., 3d ser., vol 17, p. 484; Ann. Rep. Geol. Surv. of Indiana, 1878, p. 23.

[3] Since this was written, J. F. James has redescribed this formation, enumerated its fossils, discussed its relations, and urged that the name be abandoned for that of Cincinnati. Am. Geol., vol. 5, 1890, pp. 335-356.

Niagara, and the steep-sided cañons of the Mississippi and its tributaries are carved within it; but in Winneshiek County it has little topographic expression.

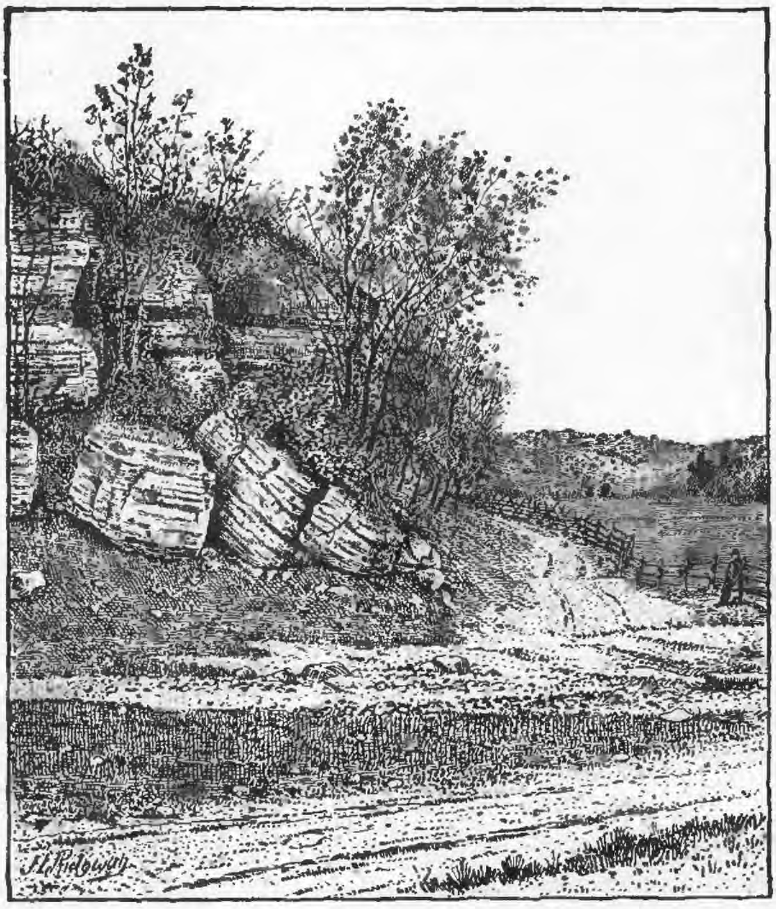


FIG. 18.—Truncated bluff of Galena limestone at Eagle Point (near Dubuque).

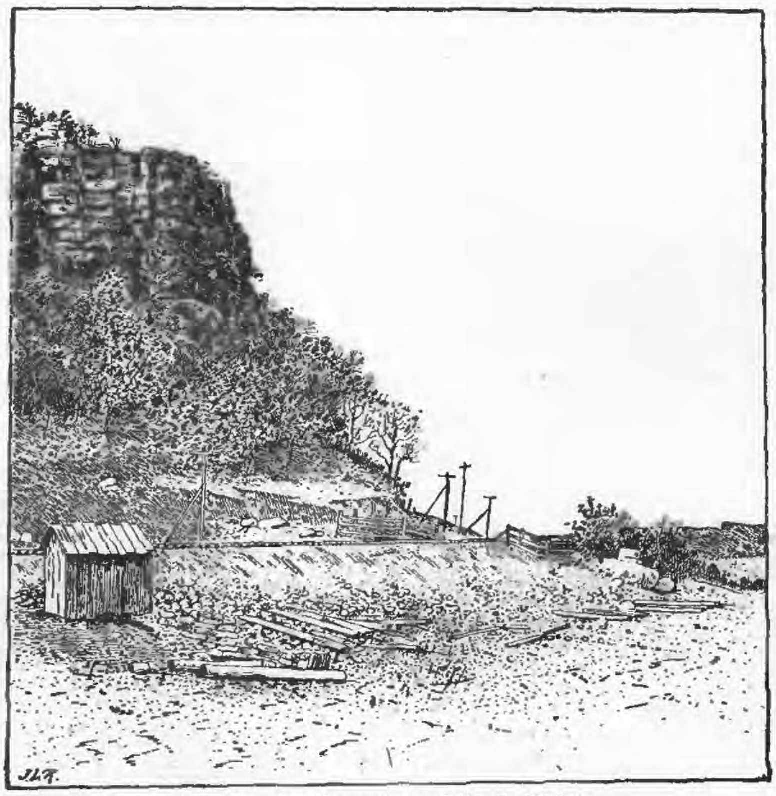
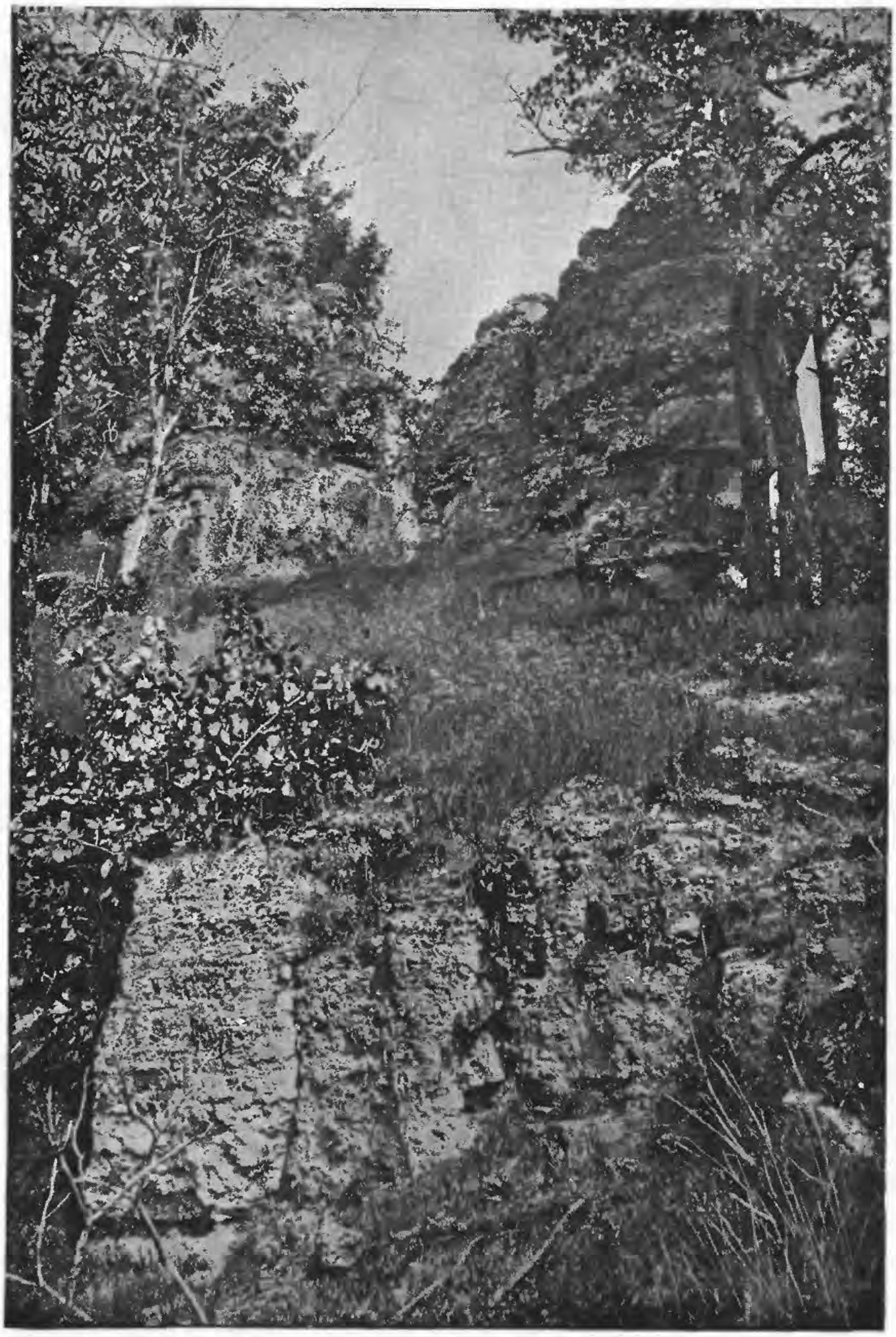


FIG. 19.—Another view of Eagle Point.



EROSION TOWERS OF TRENTON LIMESTONE, BUENA VISTA.

On both sides of the Mississippi the Galena strata are cleft by subterranean fissures and ramified by caverns. The roofs of the caverns are set and the walls fluted with snow-white stalactites, and their floors are studded with gray or creamy stalagmites; and some of the fissures and smaller caverns are filled with the cube-crystaled sulphide of lead (galenite or galena) from which the formation takes its name. Most of the limestone caverns of Dubuque and Jackson Counties, Iowa; Grant, La Fayette, and Iowa Counties, Wisconsin; and Jo Daviess County, Illinois, are in this formation. A few of these contain quantities of red residuary clay—typical "cave earth"—sometimes protected by the stalagmitic floor, from which a few undetermined mammalian and avian bones have been obtained; but in most caverns thus far explored the "cave earth" is either scanty and barren or has been removed by miners in search of lead ore, and any organic remains once entombed within it are lost or destroyed.

The formation was named by Hall in 1858.[1] It has since been provisionally correlated with the Utica of New York upon paleontologic grounds by Walcott.[2]

THE TRENTON LIMESTONE AND SHALE.

The richly fossiliferous limestones of this formation are moderately pure, heavily bedded, and nearly free from argillaceous matter in the southernmost exposures, where the mass is perhaps 75 feet in thickness; but northwestward the body thickens rapidly and becomes shaly, particularly in its upper portion—its thickness in northern Winneshiek County reaching not less than 250 and perhaps 350 feet, of which the lower two-thirds is generally argillaceous limestone with shaly intercalations, and the upper third a shale little firmer than that of the Maquoketa.

By reason of the thickening of the formation in the northern part of the territory, the limestone of the Trenton forms an escarpment more conspicuous than that of the attenuated Niagara limestone in the same latitude, though far less prominent than the same Niagara escarpment in the central and southern part of its extent. Neither is the escarpment so definitely and simply related to the water ways as that of the Niagara; for, after the manner of pure limestones, the Trenton has been attacked by acidulated waters during the vast period of ante-Pleistocene erosion, and its strata are penetrated and sometimes honeycombed by caverns formed by subterranean streams and its surface is pitted with sinks resulting from the collapse of cavern roofs; and here and there the divides expand into broad plateaus, undrained subaërially but well drained by streams perhaps 100 or 200 feet beneath the surface; and many brooks and even

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[1] Geology of Iowa, vol. 1, part 1, p. 60.

[2] Trans. Albany Inst., March 18, 1879.

goodly mill-streams are swallowed, sometimes to reappear a few miles below as mighty springs, but sometimes to be seen no more.

This Iowa formation was correlated by Hall and White with the Trenton limestone of New York on paleontologic grounds; and with the progress of research in intermediate States it has been found that the limestone and associated shales constitute an unbroken deep-sea deposit stretching from New York through Pennsylvania and Virginia, Ohio and Kentucky, Indiana and Michigan, Wisconsin and Illinois; and so the early induction from fossil evidence has been fully verified by later observation.

The Trenton is one of the most extensive formations of the United States; and just because of its vast extent, little is known of the geography of the Trenton epoch or of the source of the sediments of the Trenton formation.

THE ST. PETER SANDSTONE.

The greater part of this formation is literally a bed of quartzose sand, rather less than 100 feet thick, and coextensive with the Trenton limestone, upon which it reposes in Northeastern Iowa and contiguous territory. Commonly the sand is feebly or not at all cemented, and the mass is friable as the sands of the modern ocean beach; sometimes it exhibits the stratification and cross-lamination of original deposition, yet remains loose; again lithifaction has taken place about structure planes, and on the weathering of scarps and overhanging cliffs the structure is accentuated; and rarely the cementation is more general, and the rocks are massive. When this is the case the heavy beds are carved by erosion into the massive pilasters, colossal columns, buttressed façades, and endless varieties of fantastic forms pictured upon the cliff-faces of the upper Mississippi. Sometimes the sands are snow white, and under the summer sun dazzle the eyes of the beholder; again they are cream-tinted, or yellowish, or gray, or buff; sometimes dingy browns prevail; elsewhere reds appear in bands and irregular streaks and blotches; then blue-blacks and rich greens come in, and sometimes the stratification is marked off with a gaudy succession of all of these colors; and in the "Painted Rocks" near McGregor the cliffs are banded, mottled, and fancifully figured in harlequin coats of gorgeous red, brilliant yellow, dazzling white, deep blue, jet-black, vivid green, rich brown, and an endless variety of mixed tones and shades in an endless variety of patterns. Here the color-loving aborigines gathered, and their tumuli and temples crown the summits and their implements and weapons crowd the talus-flanked bases of the gorgeously painted walls; and here flock the pleasure-seeking whites to marvel at the glory of color, enjoy the grandeur and symmetry of form, and revel in the delicious cool of glens shaded by luxuriant foliage and tempered by refreshing springs. Toward the base of the formation the sands become calcareous, the colors fade, definite bedding supervenes, and a moderately distinct bed of arenaceous limestone forms one of its lower members.

The St. Peter is essentially a formation of the upper Mississippi Valley. It was named by Owen, after the river heading in Lake Traverse and embouching into the Mississippi just below the Falls of St. Anthony; and by reason of its poverty in fossils it has not been correlated with other rock masses in distant States and countries, but to-day maintains its individuality and retains its distinctive name, though that of the river it commemorates (the modern Minnesota) has been half forgotten—save by the geologist to whom the rocks are reminders of the original name of the river. Despite the strong individuality of the formation where characteristically developed, it is difficult in Northeastern Iowa to define its base; for it becomes calcareous in its lower portion, and there is (in the extreme northern part of the State at least) a moderately definite sheet of limestone intercalated between the principal mass of sandstone and a bed of slightly calcareous, but otherwise similar, sands below. In parts of Minnesota and Wisconsin both of these bodies are indeed set off from the St. Peter and given specific appellations; but in Iowa the differentiation of strata is nowhere sufficiently decided to find topographic expression, the various beds are alike practically unfossiliferous, and, south of Village Creek, or Yellow River at the farthest, stratigraphic distinction appears to fail completely. Even in southeastern Minnesota the distinction weakens, and the intercalated limestone bed—the Shakopee—gives no topographic feature.[1]

A sand bed so extensive must record interesting history; but thus far the record has not been fully deciphered, and no man knows how the St. Peter ocean was bounded nor whence came its vast mass of fine but silt-free and uniform sand.

THE ONEOTA LIMESTONE.

The bed of pure sand with calcareous intercalations below, designated the St. Peter, passes without unconformity into an arenaceous dolomite, bearing intercalations of sandstone in its upper portion. The dolomite is, in general, coarsely saccharoidal, frequently vesicular and cavernous, and generally buff, yellow, or light brown in color. To the tourist upon the Mississippi it is the most conspicuous among the formations of the bluffs; for, like the Niagara, it well resists erosion and weathering, and is carved by corrasion into the precipitous salients and mural scarps overlooking the great river from Clayton northward. Its thickness ranges from over 300 feet at the Minnesota line to something more than 200 at its southernmost exposure; yet despite its prominence in the river bluffs and its considerable thick-

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[1] Geological and Nat. Hist. Surv. Minnesota, Final Report, 1884, vol. 1, p. 220.

ness, the terrane is narrow and the outcrops almost confined to the cañon walls of the Mississippi, the Oneota, the Yellow, and their minor tributaries.

The magnesian and arenaceous limestone, to which the name is applied, is the principal member of the vaguely defined series of beds which Owen, in 1852, called the Lower Magnesian limestone. Owen's name was retained by Hall in 1858, and by White in 1870; but more recent studies, particularly in Minnesota and Wisconsin, have shown that the St. Peter, the Lower Magnesian of Owen, and the Potsdam, comprise a series of sandstones, shales, and magnesian limestones representing continuous sedimentation from the later part of the Cambrian well into the Silurian, which are indeed often locally distinct, but which, nevertheless, are found to merge by interbedding, by gradual transition of sediments, and by intermingling of faunas, when viewed in the large way. The Minnesota succession has been admirably worked out by N. H. Winchell,[1] and that of Wisconsin has been equally well elucidated by Chamberlin and his collaborators.[2] The formations recognized and the relations generally accepted by the geologists of both States are illustrated and both series correlated with the simpler Iowa series in the accompanying table:

Siluro-Cambrian formations of Minnesota, Wisconsin, and Iowa.

Wisconsin.				Minnesota.		Iowa.	
		Feet.			*Feet.*		*Feet.*
	1. St. Peter sandstone	0–212		1. St. Peter sandstone		St. Peter sandstone	90
Lower Magnesian limestone.	2. Willow River (limestone)	65–250		2. Shakopee limestone	20–40		
	3. New Richmond (sandstone)			3. White sandstone	0–40		
	4. Main body of limestone			4. "Main body of limestone"	75–175	Oneota limestone	200–300
Potsdam sandstone.	5. Madison sandstone	30	Saint Croix sandstone.	5. Jordan sandstone	75–100	Potsdam sandstone	300
	6. Mendota limestone	35		6. St. Lawrence limestone	0–30		
	7. Slightly calcareous sandstone	150		7. Sands and sandy shales	200–?		
	Shale	80		Dresbach sandstone			
	Fine quartzose sandstone			Shales			
	Coarse quartzose sandstone			Hinckley sandstone			

The correlation of the first six members appears definite and satisfactory, though none of the formations are uniform in composition and thickness throughout any considerable area in either State, nor were they probably synchronous in widely separated localities save

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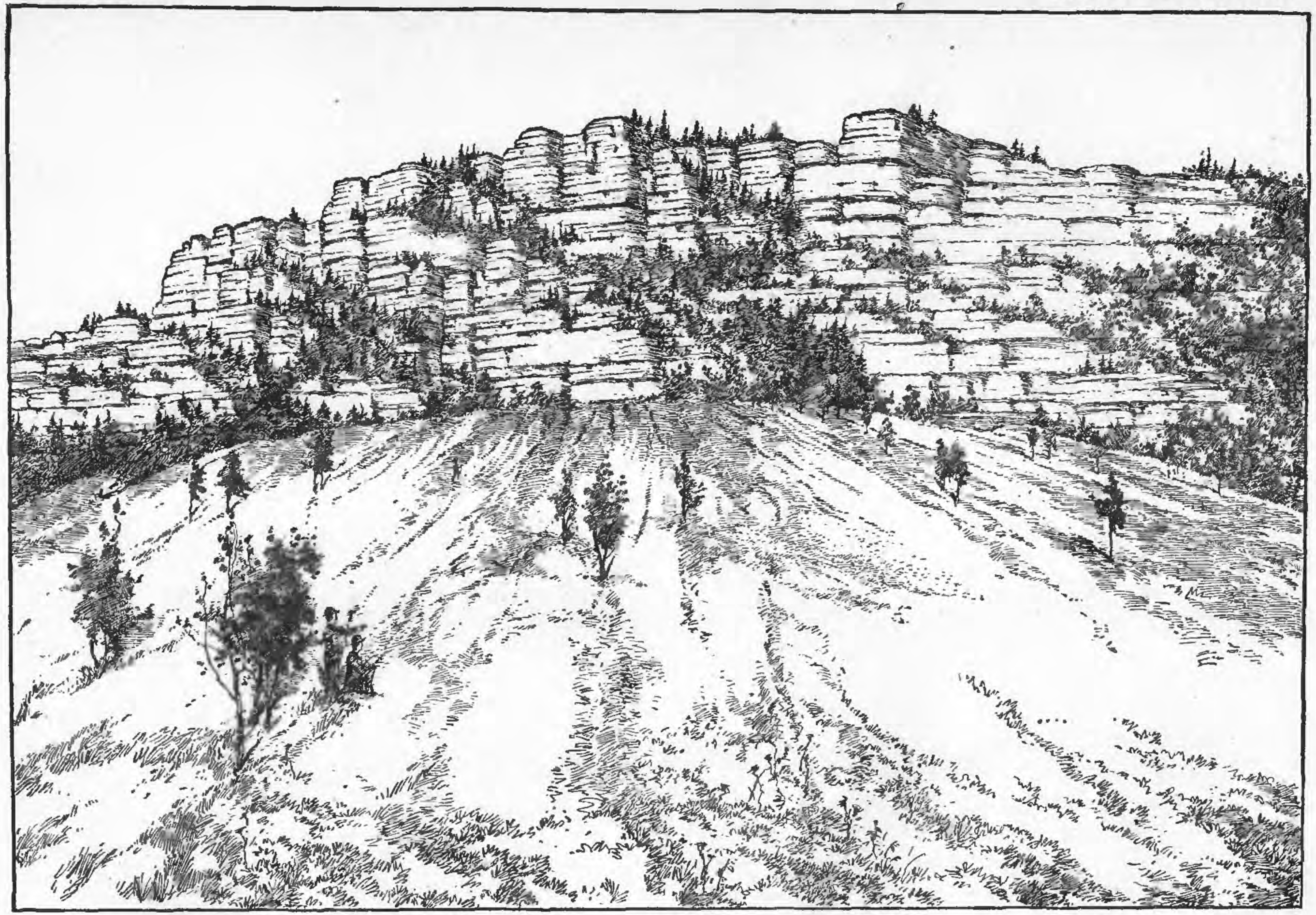
[1] Geol. Nat. Hist. Surv. Minnesota, Final Report, 1888, vol. 2, pp. 12-23.

[2] Chamberlin Geol. Wisconsin, 1883, vol. 1, pp. 119-144; Wooster, ibid., 1882, vol. 4, p. 106, and elsewhere; Irving, Am. Jour. Sci., 3d ser., 1875, vol. 9, pp. 440-443, and elsewhere.



TYPICAL CLIFFS OF ONEOTA LIMESTONE, IOWA BLUFF FROM THE EAST.

in a general way—the early Paleozoic continent rose and fell unequally, the early Paleozoic ocean shoaled and deepened alternately at each locality, and sandstones were formed here, shales there, and limestones elsewhere, in ever varying succession as the relation of land and water changed. In the lower part of the column, however, the conditions of deposition were still more inconstant, and the deposits recognized in the first two States respectively can not be correlated, nor can they be identified certainly in the alternating beds of sandstone and shale forming the part of the Potsdam exposed in Iowa.

Formation No. 4 of the table was designated the "Main body of limestone" by Irving,[1] and the same term with like definition is used by H. N. Winchell. This mass of dolomite constitutes the principal part of the Lower Magnesian limestone of Owen, and is the sole remnant of his vaguely defined series for which the name might with any degree of propriety be retained. But the definition and taxonomic value of the part are obviously unlike those of the whole; Owen's series has been abandoned by modern systemists; the term itself is objectionable in that its correlative element has been meaningless since the division of the original Upper Magnesian limestone into three formations, and in that the lithological element is not strictly applicable; and so the name of the river upon which the rock-mass finds its typical development, not only for Northeastern Iowa but for the country at large, may be applied to the formation. The three superior formations are, for reasons already stated and for present purposes only, combined under the name St. Peter; and the several inferior formations and beds are combined under the name Potsdam, by reason of the impossibility at present of definitely separating them from the rock-mass to which that appellation was long ago applied by Hall.

THE POTSDAM SANDSTONE.

Just as the St. Peter becomes calcareous, so the Oneota becomes arenaceous toward the base, and passes by interstratification into a great formation which is predominantly sandy, though divided here and there by calcareous or argillaceous beds. The limestones are magnesian, always more or less sandy, and generally heavy bedded or massive; the shales are imperfectly fissile, commonly calcareous, and sometimes richly fossiliferous, as at Lansing, where they are charged with fine specimens of *Dicellocephalus minnesotensis* and other characteristic upper Cambrian forms, while the predominant sandstones are generally friable or cemented only along bedding planes, like the sands of the St. Peter. Unlike the brilliant-hued St. Peter, the prevailing colors of the formation are somber browns and neutral grays, rarely running into bright yellows and still more rarely into rich reds.

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[1] Am. Jour. Sci., 3d ser., 1875, vol. 9, p. 442.

The Potsdam sandstone is a conspicuous element in the scenery of the Mississippi above McGregor and along the lower Oneota; for it forms walls, precipices, and salients, rising thrice the height of the spreading elms and giant cottonwoods clothing the river bottom at the bases of the bluffs, commonly capped and protected by the obdurate Oneota strata, and sculptured boldly in heavy arcades and wooded buttresses separating shadowy alcoves, as well as in rounded bosses and easy curves. The formation is indeed seen best in relief; for in plan it forms but a narrow ribbon skirting the waterway, and all its outcrops are cañon walls.

The Potsdam was correlated by Hall with the sandstone of northern New York bearing the same name. For the present it suffices to regard it a unit in Iowa, though in Wisconsin and Minnesota it comprises several divisions. It is the lower part of a series of calcareous and arenaceous strata beginning well down in the Cambrian and extending well up into the Silurian, yet representing practically continuous deposition throughout, so that the dividing plane between the lower Paleozoic groups of the taxonomist must be arbitrarily drawn in the upper Mississippi Valley.

The geography of the Potsdam epoch and the source of the Potsdam sediments largely remain to be made out by future research, though Chamberlin has made important contributions to knowledge of both subjects.

RÉSUMÉ.

In structural relation and thickness, the sixteen formations of the territory are as follows:

Stratigraphy of Northeastern Iowa.

			Feet.
Cretaceous (?)	Rockville conglomerate	Conglomerate	20
	Great unconformity.		
Carboniferous	Lower Coal Measures	Sandstone, shale, etc.	100
	Great but local unconformity.		
	St. Louis limestone	Limestone, shale, etc.	500
	Local unconformity (?).		
	Keokuk limestone and shale		
	Burlington limestone and shale		
	Kinderhook limestone		
	Unconformity (?).		
Devonian	Hackberry shale	Limestone, shale, etc.	450
	Cedar Valley limestone		
	Independence shale		
	Local (?) unconformity.		
Silurian	Niagara limestone	Cherty dolomite	350
	Unconformity (?).		
	Maquoketa shale	Limestone, dolomite, and shale.	450
	Galena limestone		
	Trenton limestone and shale		
	Unconformity (?).		
	St. Peter sandstone	Sandstone, shale, and dolomite.	700
	Oneota limestone		
Cambrian	Potsdam sandstone		

The several formations incline southwestward, the inclination diminishing progressively from the bottom to the top of the series; and there are certain subordinate departures from the original condition of approximate horizontality under which the deposits were laid down.

There are three known unconformities representing interruptions in deposition; three others may be postulated (between the Kinderhook and Hackberry, the Maquoketa and Niagara, and the Trenton and St. Peter, respectively) on the ground of sudden and decided transition in life and in character of sediments; and another is suggested (between the St. Louis and Keokuk) by a considerable break in faunal succession, though no evidence of interruption in deposition has been brought to light. All of these unconformities, known and supposed, are represented in other parts of the country by considerable series of deposits; and the latest is represented not only by the vast series of deposits constituting a whole geologic group (the Jura-Trias) but by the greatest unconformity of America as well. The two other known unconformities may justly be regarded as local and representing a period covered by continuous deposition somewhat further from the continental nucleus; and the same is true of the four suspected unconformities.

Grouping the formations by physical characters alone, the succession in stratigraphic order is as follows:

(1) A littoral conglomerate in isolated outliers of limited thickness, representing a heavy series of deposits some hundreds of miles westward.

(2) A great unconformity.

(3) A coarse littoral sandstone passing into off-shore shales, fine sandstones, and some limestones a few scores of miles southwestward.

(4) A notable unconformity, probably represented by continuous deposits further southward.

(5) A probably continuous series of limestones and shales with some fine sandstone nearly 500 feet thick (St. Louis to Kinderhook, inclusive), comprising a faunal and possibly a stratigraphic break.

(6) Perhaps an unconformity, probably represented farther southwestward by continuous deposits.

(7) A heavy bed of shaly and (rarely) sandy limestone, with a bed of shales at summit and a lesser one at base, the whole fully 450 feet in maximum thickness.

(8) An inconspicuous unconformity, probably represented by continuous deposition farther southwestward.

(9) A heavy bed of cherty dolomite, becoming argillaceous and almost shaly above, 350 feet in maximum thickness.

(10) Perhaps an unconformity.

(11) A series of shales, dolomites, and pure limestones representing continuous deposition and progressive increase in argillaceous matter and other sediments from base to summit (Maquoketa to Trenton, inclusive), 300 feet or more in mean thickness.

(12) Perhaps an unconformity, represented in the eastern part of the country by continuous deposition.

(13) A great series of conformable sandstones and dolomites with intercalated beds of shale (St. Peter to Potsdam, inclusive) over 700 feet in maximum thickness, representing continuous but variable deposition.

SECTION II.—THE DEFORMATIONS.

THE TYPES OF DEFORMATION.

The strata of Northeastern Iowa are deformed in three ways: (1) All have a gentle southwesterly dip diminishing from northeast to southwest, and diminishing also from the older to the newer formations; (2) the Cedar Valley limestones are frequently thrown into local flexures sometimes accompanied by inconspicuous faults, and the other formations are sometimes affected in the same manner but to a less degree; (3) all of the formations are affected by a series of low anticlinal and synclinal folds trending approximately parallel with the strike.

THE GENERAL INCLINATION.

The southwesterly inclination of the strata is fairly consistent throughout the territory. In the extreme northeast and in the formations below the Niagara, it averages about 15 feet per mile or 0°10′; in the Niagara limestone it is about 10 feet per mile or 0°6′; in the Cedar Valley limestones and associated shales it probably averages about 7 or 8 feet per mile or 0°5′; in the Subcarboniferous formations it is probably between 2 and 4 feet per mile; while the general dip of the limited extent of Coal Measures within the territory probably does not exceed a foot per mile, and the strata are sensibly horizontal save where affected by local undulations.

The directions of maximum inclination in the successive formations are orthogonal to the strikes, and hence vary somewhat in the different terranes: Thus the highest dip of the St. Peter (which is approximately uniform in thickness throughout its extent) is about S. 35° W.; that of the Oneota is more southerly, or about S. 40° W.; that of the Trenton is more southerly than either, or about S. 45° W.; that of the Maquoketa is roughly S. 40° W.; that of the Niagara is less southerly than any of the older formations, averaging about S. 30° W.; that of the Cedar Valley limestone may be roughly averaged at S. 40° to 45° W.; and that of the Subcarboniferous limestones is perhaps S. 50° W. on the average (the strike varying in different part of the outcrops and also in the different formations); but these inconsistencies are inconsiderable, and the mean inclination is is not far from S. 45° W.

This general inclination of the strata was determined by the conditions of growth of the nascent continent, and forms an intelligible record of these conditions and of the mode of growth.

THE IRREGULAR DEFORMATIONS.

Throughout its terrane the Cedar Valley strata are frequently flexed into low anticlinals, synclinals, and monoclinals. The dips range from almost nothing to 5° or 6°, in some case 10°, and rarely 15°. The axes of inclination are various, but generally coincide approximately with the strike. Inconsiderable faults are sometimes connected with these flexures. An example of the flexing with a fault associated is shown in Fig. 20.

The folds are every where of small amplitude, both vertical and horizontal. The anticlinals and synclinals are seldom more than 50 to 100 yards across, and a complete monoclinal flexure may be confined within 10 yards; and the vertical deformation seldom exceeds 10 feet. Yet these slight irregularities of structure are so widely distributed that, in the numberless exposures occurring in nearly all parts of the terrane, the strata are more frequently distorted than in the sensibly horizontal normal attitude. Whether these irregular deformations of the strata affect the formations below and formerly affected those above the rock-mass of which they are characteristic is uncertain; but certainly such deformations are never seen in the older Niagara limestone, nor are they at all common in the newer Subcarboniferous strata within Northeastern Iowa; and it is noteworthy that in some cases the distortion is evidently confined to a limited thickness of strata.

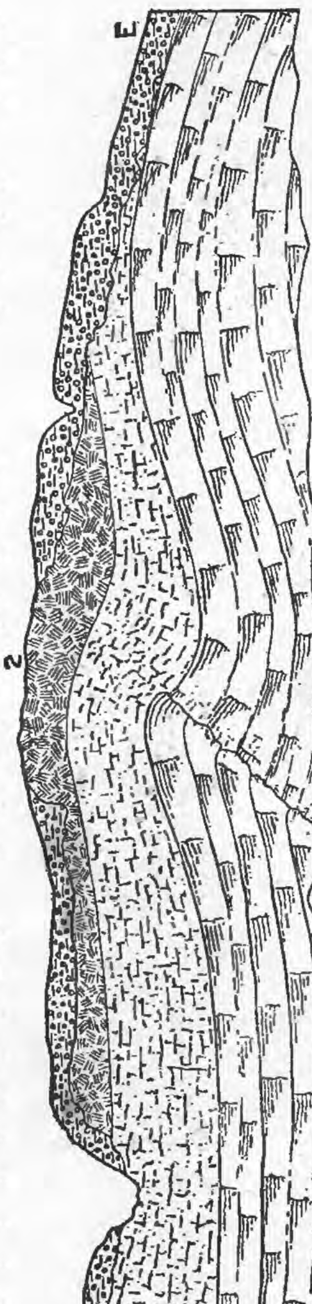

FIG. 20.—Fault and flexure in Devonian strata at Roberts's Ferry, Johnson County: (1) Glacial drift; (2) Brecciated limestone; (3) Irregularly bedded argillaceous limestone; (4) "State House quarry" rock—heavy bedded limestone made up largely of comminuted molluscan shells. Height of exposure 16 feet.

It has already been stated that throughout much of its terrane the Cedar Valley limestones are peculiarly brecciated. Now, it is significant that this brecciated condition of the Iowa rocks is confined to the beds and the belt affected by the irregular deformations. This association suggests that the phenomena are related; and since the brecciation was unquestionably coeval with deposition, the admission of such relation fixes the period of the irregular crumpling of the Cedar Valley limestones at about the close of the period of their own deposition; and the practical confinement of such crumpling to the Cedar Valley formation is corroborative of this inference.

THE REGULAR DEFORMATIONS.

The strata of eastern Iowa and contiguous territory are thrown into a series of anticlinals and synclinals, generally low, inconspicuous, and nearly parallel, but occasionally more prominent in size and form and divergent in direction. Most of them indeed are so low that their presence is detected only by comparison of altitudes at different points, by anomalies in outcrop, or by the topographic configuration determined by them.

(1) The northeasternmost undulation known is a gentle anticlinal seen in the Mississippi bluffs between McGregor and Clayton. It is 3 or 4 miles broad and so low that it serves only to arrest for half its width, and then proportionately increase, the normal southwesterly inclination of the strata. . Similar idiosyncracies of dip are perceptible thence northwestward to and beyond the Oneota River; at Myron the Trenton crops out well toward the hilltops, though the Niagara crowns the scarcely higher summits near Postville, only a few miles away; the Oneota limestone dips rapidly beneath the Trenton in the Oneota cañon near the mouth of Canoe River; and the peculiar elbow in the river at Decorah records an episode in the development of the superimposed waterways depending on undulations of the superimposing strata.

(2) The second observed undulation, which also is an anticlinal, coincides approximately with the divide between the Oneota and Turkey Rivers, in Winnishiek County. The unusual attitude of the strata here has led to curious misunderstanding of the structure by nearly all geologists who have visited the region. In 1858 Hall, deceived in part by the unusual character of the Niagara dolomite in the northeasternmost exposures, and in part by the exceptionally high dips on the flank of this anticlinal, referred the terrane forming the divide to the Galena instead of the Niagara, and consequently exaggerated the thickness and extent of the former;[1] Whitney, equally deceived by lithologic characters, confused further by the thinning of the Niagara northward, and impressed with the great

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[1] Geol. Surv. Iowa, 1856, vol. 1, pt. 1, map.

altitude of the supposed Galena formation in the Military Ridge, inferred that Turkey River follows a fault of 200 or 300 feet;[1] and in 1870, White, misled by the local inclination in the flanks of the arch, supposed that the exceptionally flat strata of western Winneshiek and eastern Howard Counties are exceptionally inclined.[2] The same anticlinal appears to extend far southeastward. It finds expression in the high inclination of the Trenton at Elkader; it appears to be marked by the course of the Mississippi at the root of "Cromwell's Nose" in southeastern Clayton and northern Dubuque Counties; and it finds still more definite expression in extreme northern Dubuque County, where the St. Peter sandstone reappears above the low-water level of the river for a few miles.

(3) Parallel with the second anticlinal lies a low synclinal, occupied in northeastern Fayette County by Turkey River. In Clayton County the river appears to diverge from the synclinal, and its axis is marked by the singularly long and narrow salient of the Niagara escarpment lying between the Turkey and the Volga at a less altitude than the plane connecting the Galena uplands on the headwaters of Pony Creek with the gentle slopes of the Maquoketa shale south of the Volga. Still further southeastward the axis of the synclinal is represented approximately by the Niagara escarpment in southern Clayton County, and by its isolated outliers, Sherrill's Mound and its neighbors, in northern Dubuque County; and in the same line lie Sinsinewa Mound in Wisconsin, and Council Hill and Scales Mound in Illinois.

(4) There is a persistent line of scarps and isolated mounds a few miles southwest of Dubuque (including Table Mound, Hog-back, and other locally noted eminences) which, standing alone, would not be regarded as significant; but in view of the general relation between such scarps and outliers and the prevailing structural deformation in the territory they may be interpreted as the axis of a gentle synclinal. It is along this line that the Niagara bluffs first approach the Mississippi River in extreme southeastern Dubuque County; and a series of elevations (including Pilot Knob) marks the continuation of the line many miles in Illinois.

(5) The next expression of the parallel corrugation of the territory is found in central Dubuque County, where the Maquoketa shales are brought to the surface almost to the headwaters of the Little Maquoketa River, and at a plane considerably higher than the summit of the same formation 10 miles down the stream; and the same uplift appears to be connected with the notable recession of the Niagara escarpment from the Mississippi about the Tête des Morts, in northern Jackson County.

(6) Parallel with these several corrugations occurs the most decided and conspicuous member of the series—the broad, low anticli-

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[1] Geol. Surv. Iowa, 1856, pt. 1, pp. 315-316.

[2] Geol. Surv. Iowa, 1870, vol. 1, p. 183.

nal extending from northern Buchanan County to the Mississippi in the northeastern corner of Clinton County. Its presence is first revealed by the detour in the Cedar Valley-Niagara boundary, near Oelwein. It next appears 5 miles southwest of Manchester. Here bituminous shales with an abundant supply of water have been reached in several wells at from 12 to 50 feet beneath the surface, according to elevation; fragments of this shale yielded no fossils but exhibited the lithologic characteristics of the Maquoketa, and can indeed represent no other formation. The summit of the shale here is between 975 and 1,000 feet above tide; while at Monticello, 15 miles distant and nearly in the line of the strike, the shale was reached in an artesian boring 440 to 465 feet lower. Ten miles southeast of Manchester the rather prominent bluffs of Niagara limestone overlooking the Maquoketa River in this part of its course suddenly fail and no rocks are exposed for some miles; and in this region of easily interpreted sculpture the sudden failure of the bluffs can only be ascribed to the presence of a little obdurate subterrane, such as the Maquoketa shale. The influence of the undulation is next perceived near Cascade, where wells drilled in Niagara limestone find an abundant supply of water in shale at a level little below that of the Maquoketa River, indicating that here, too, the strata are upheaved some hundred feet. There is then a hiatus for several miles, which is difficult of explanation save on the hypothesis that the anticlinal subsides; but an anticlinal of similar trend though of less height appears in southeastern Jackson and northeastern Clinton Counties. Its axis is here occupied by the principal branch of Elk River, which occupies a disproportionately broad valley; for its waters have cut through the Niagara limestone into the subjacent shales, and the limestone cliffs have been sapped and the valley thus widened during both preglacial and postglacial times. In the vicinity of Elk River the shales rise considerably above their level immediately west of Sabula; and on the Illinois side of the river the Galena limestone reappears, and according to Worthen rises fully 50 feet in the river bluffs.[1]

(7) A conspicuous deformation of the territory is thus described by White:

> A line of disturbance of the strata of this (Niagara) formation passes into Iowa in a direction almost corresponding with the direction of its trend; crossing the Mississippi River at Le Claire, and being last recognized in the valley of the Wapsipinnicon, about 3 miles west of Anamosa. This disturbance apparently partakes more of the nature of an abrupt fold than of a true fault, leaving the general dip of the strata on each side of its axis seemingly unchanged from what it would have been if the disturbance along that axis had not taken place. This disturbance seems confined to a very narrow area, for the strata, within less than a mile on each side of both the localities named, appear entirely undisturbed, although the angle of dip has reached, in some places, 28° with the horizon.[2]

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[1] Geol. Surv. Illinois, 1886, vol. 1, Plate 5.

[2] Geol. Surv. Iowa, 1870, vol. 1, p. 184.

No new data of note concerning this synclinal have been obtained; for between Le Claire and Anamosa the indurated formations are so deeply mantled by loess and drift as to preclude observation. The axis determined by White was by him supposed to be the only one coincident with the prevailing drainage; but it is approximately parallel with the gentler undulations both north and south.

(8) Notwithstanding the superposition of the Coal Measure outliers, the Cedar Valley strata, in the vicinity of Davenport, appear to rise in a low arch some miles broad. This arching is best displayed on the Illinois side of the Mississippi;[1] but it is also displayed on the Iowa side in the anomalous trend of the Cedar Valley-Niagara boundary in Scott, Cedar, and Linn Counties—particularly by the reentrant coinciding approximately with the course of Cedar River, and by the greater altitude of the Niagara outcrops at Cedar Bluffs and in the "Palisades" south of Mount Vernon than the plane of the formation-junction to the north, southeast, and southwest. This anticlinal is noteworthy in that it appears not to affect the Coal Measures.

Still farther southwestward, beyond the limits of Northeastern Iowa, there are a number of parallel undulations similar in character to the gentle anticlinals and synclinals of the northeastern counties.

(9) An anticlinal affecting the northeastern boundary of the Coal Measures appears to pass somewhat southwest of Grinnell and near Montezuma, and continuing southeastwardly is marked by a long spur of the Coal Measures extending almost to the Iowa River immediately below the mouth of the English. Beyond, it is represented by a Subcarboniferous salient at Washington; and it apparently intersects the Mississippi River a few miles below the mouth of the Iowa. In Illinois it finds expression in the Oquawka arch, depicted by Worthen in his section along the Mississippi.

(10) A parallel anticlinal brings the St. Louis limestone to the surface in the valley of Skunk River for many miles, probably from Ames, in Story County, to the southern part of Keokuk County; and still farther southeastward it finds expression in the exceptionally high altitude of the Subcarboniferous rocks in western Henry County.

(11) An inconspicuous synclinal appears to trend parallel with the Des Moines on the northeast in Mahaska, Wapello, Jefferson, and western Lee Counties, where it is represented by a line of productive coal mines at low altitudes.

(12) The Des Moines River unquestionably follows the crest or southwestern slope of a gentle anticlinal, by which the Subcarboniferous rocks are brought not only to the surface, but well up in the bounding bluffs from the central part of Marion County nearly to the extreme southeastern corner of the State.

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[1] Cf. Worthen, Geol. Surv. Illinois, 1866, vol. 1, Pl. v.

These undulations of eastern Iowa appear to fall into a wide-reaching system, extending far beyond the limits of the State.

In southwestern Wisconsin there is an anticlinal parallel with the Iowa system, and apparently continuous with that crossing the Mississippi about the mouth of Snymagil Creek, its course being indicated by the exposures of "Lower Magnesian limestones" mid-length of Grant and Platte Rivers in central Grant County, both east and west of Lancaster, and notably by the exposure of St. Peter sandstone in a well defined anticlinal ridge in the valley of the Pecatonica, 4 miles southeast of Darlington in Lafayette County; and there is some indication of extension still farther southeastward in the considerable exposures of St. Peter sandstone about the confluence of the Yellowstone with the Pecatonica, and below the mouth of Skinner Creek, in Green County. It is significant that the most conspicuous outliers of Niagara limestone in southwestern Wisconsin—the Platte Mounds—sustain just such relations to this anticlinal as do Sherrill's Mound and its neighbors to the anticlinal crossing the Mississippi near Dubuque. It is also significant that the strata of the lead region in southwestern Wisconsin are generally thrown into slight undulations, which are, according to Chamberlin, due initially to inequalities in deposition, and secondarily to subsequent corrugation along lines determined by the initial inequalities in deposition.[1]

A considerable share of these undulations are parallel with those already noted; and Chamberlin is of opinion that the distribution of ores in that noted mining region was determined by these structural irregularities.

Five principal axes of elevation of the strata in Illinois have been described by Worthen:

"The most northerly one crosses the north line of the State in Stephenson County, and intersects Rock River at Grand Detour, and the Illinois at Split Rock, between La Salle and Utica. This uplift brings the St. Peter's sandstone to the surface on Rock River, and the Lower Magnesian limestone on the Illinois. Its general trend is from north-northwest to south-southeast, and its extent southward beyond the Illinois has not yet been determined."[2]

It should be noted that not only is the uplift on Rock River described by Worthen almost exactly in the line of the anticlinal crossing the Mississippi near Sabula, but that the extension of the anticlinal well toward Rock River is proved by the exceptionally high altitude of the Trenton limestones between Sabula and Grand Detour.[3] Moreover, according to Shaw, "Rock River runs along this anticlinal axis."[4] It is noteworthy, too, that the uplift on the Illinois River near La Salle lies but a little way north of the pro-

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[1] Geol. of Wisconsin, 1882, vol 4, pp. 404-438.

[2] Geol. Surv. Illinois, 1866, vol. 1, p. 5.

[3] Geol. Map Illinois, Worthen, 1875.

[4] Geol. Surv. Illinois, 1873, vol. 5, p. 118.

longed axis of the Anamosa-Le Claire, or Wapsipinnicon, synclinal, which toward the Mississippi becomes almost a monoclinal. While the verity of Worthen's axis of disturbance may not be questioned, and is indeed sustained by Chamberlin's inferences from the behavior of the drainage,[1] it would seem probable that this axis is intersected by different members of the system of parallel undulations developed in Iowa, and that its most decided manifestations occur about the points of intersection.

The next deformation noted by Worthen "is at Cap au Gres, in Calhoun County. Here we find a dislocation of the strata and a downthrow of the beds on the south side of the axis of at least 1,000 feet. * * * This axis crosses the Illinois about 5 or 6 miles above its mouth in Jersey County" where it "forms an anticlinal axis, with a double line of bluffs separated by a narrow valley for a distance of 3 or 4 miles, when it again strikes the Mississippi by the eastern bend of the river and is lost in the river valley. Its trend is W. 10° N. by E. 10° S."[2] This dislocation was observed in Lincoln County, Missouri, by Potter, who found that "the main axis of this uplift seems to have been in a general direction of W. 30° N." "The amount of uplift * * * must have been about 400 feet."[3]

The next axis described by Worthen is "near the south line of St. Clair County, where the strata have been again dislocated, leaving the St. Louis limestone on the lower side of the axis inclining to the southwest at an angle of about 20°. The trend of this axis is from N. 20° W. to S. 20° E."[4]

Another dislocation, which would appear to be considered a branch of this, is noted at Salt Lick Point in Monroe County (opposite Platin Rock, Missouri), where it brings the Trenton limestone to the surface in a conspicuous line of bluffs. Its direction is not stated, but would appear to be approximately orthogonal to the river.

The most conspicuous axis of elevation in Illinois "brings the St. Peter's sandstone of the Lower Silurian above the surface at Baily's Landing on the west side of the Mississippi River, tilts up the Devonian limestones at the 'Bake Oven' and 'Bald Bluff,' in Jackson County, at an angle of about 25°, and after elevating the upper portion of the Subcarboniferous limestone above the surface entirely across the southern part of the State, finally crosses the Ohio in the vicinity of Shawneetown, and is lost beneath the Coal Measures of Kentucky."[5] Its axis on the Mississippi River is marked by the "Grand Tower," a conspicuous boss of Trenton limestone.

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[1] Geol. of Wisconsin, 1882, vol. 4, p. 426.

[2] Op. cit., p. 5, 6.

[3] Geol. Surv. Missouri, Preliminary Report on Iron Ores and Coal Fields, 1873, pp. 221, 222.

[4] Op. cit., p. 6. There is inherent evidence that the trend is erroneously recorded, perhaps through a misprint. Broadhead regards the southern extremity of this supposed axis as the continuation of that north of Platin Rock.

[5] Op. cit., p. 4.

The southernmost of the Illinois anticlinals crosses the Mississippi "at the 'Grand Chain,' in Alexander County. Here the Trenton limestone is again elevated, forming a dangerous reef of rocks, extending entirely across the river, and also a limestone bluff on the Illinois shore, about 70 feet in height. The trend of this axis appears to be from northwest to southeast, and it probably crosses the Ohio a few miles above Caledonia, in Pulaski County, where the St. Louis limestone forms a reef of rock known as the 'Grand Chain' entirely across the stream."[1] The same anticlinal was noted in Cape Girardeau County, Missouri, by Shumard.[2]

Additional undulations apparently belonging to the same system have been described in central Missouri. According to Meek, in Saline County "some 6 miles north of Arrow Rock, on the Missouri, there has been a local uplift, which has brought the Saccharoidal sandstone and the Trenton limestone, which are there overlain by the Devonian and Lower Carboniferous beds, above the surface of the river; though at Arrow Rock below, and at Cambridge about the same distance above, the Lower Carboniferous is again seen down at the waters edge, indicating a distinct north and south dip from this place."[3] Broadhead subsequently found that this anticlinal axis extends for some distance in an easterly direction, and that along its line there are also occasional irregular depressions and elevations;[4] and quite recently he has pointed out that from Cooper County to St. Charles the Missouri follows the strike of a monoclinal limiting the northern extension of the plateau.[5] Moreover, he locates a definite anticlinal parallel with the general system, extending from Augusta to the Mississippi near the mouth of the Meramec, and "well displayed near Columbia, St. Clair County, Illinois, where the Coal Measures rest on the upturned Lower Carboniferous."[6] It is not at all certain that the same anticlinal maintains unbroken continuity from Arrow Rock, in central Missouri, to Columbia, Illinois, but it is certain that the line is one of coincident crumpling and its extremities may safely be joined, at least for purposes of graphic illustration.

Still farther southwestward, undulations of somewhat similar though more pronounced character have recently been brought to light. According to Comstock,[7] the Paleozoic strata of southwestern Arkansas are thrown into a series of closely appressed anticlinals and synclinals of wonderful length and parallelism, extending about S. 28° W. Branner points out[8] that the system of east-west folds in

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[1] Op. cit., p. 7. Evidently in this as in some other cases the trend is erroneously stated in the text. As indicated by the map the trend of this axis from the "Grand Chain" in the Mississippi to the "Grand Chain" in the Ohio is a few degrees north of east.

[2] Geol. Surv. Missouri, 1855-'71, 1873, p. 275.

[3] Ibid., pp. 160, 177.

[4] Rept. Geology of Missouri, 1873-'74, p. 182.

[5] Am. Geol., 1889, vol. 3, p. 10.

[6] Ibid., p. 9.

[7] Ann. Rept., Geol. Surv. Arkansas, 1888, map, Pl. 2.

[8] Ibid., p. 30.

the rocks of the State south of the Boston Mountains and north of the Mesozoic border in the southwest "is one of the most marked features in the geology of Arkansas;" but he adds that the structure is complex and the trends of dislocation somewhat irregular. Thus, "in White and Faulkner Counties, the axes of these folds are very nearly east-west lines; at Little Rock the strike of the rocks is a little north of west and south of east, while further west the strike is, for the most part, about five degrees south of west and north of east. There are, of course, many local variations in the direction of these folds, some of them changing their bearing as much as thirty degrees in a distance of 5 miles."

In brief there are more than a score of known deformations of the strata of the Mississippi Valley which are singularly consistent in relation. They are grouped in the accompanying list, and depicted on the accompanying map, Pl. XXVIII.

Principal flexures of the Mississippi Valley.

1. Snymagil Anticlinal.
2. Turkey River Anticlinal.
3. Sherrill-Sinsinawa Synclinal.
4. Table Mound Synclinal.
5. Tête des Morts Anticlinal.
6. Maquoketa Anticlinal.
7. Wapsipinnicon Synclinal.
8. Cedar River Anticlinal.
9. Oquawka Anticlinal.
10. Skunk River Anticlinal.
11. Oskaloosa Synclinal.
12. Des Moines Anticlinal.
13. Grand Detour-La Salle Anticlinal.
14. Cap au Grès Anticlinal.
15. Carondelet Anticlinal.
16. Arrow Rock Anticlinal.
17. Platin Rock Anticlinal.
18. Grand Tower Anticlinal.
19. Grand Chain Anticlinal.
20. Big Fork Anticlinal.
21. Little Rock Flexure.

The deformations are not, however, equally well made out, nor are they equally important: The Snymagil anticlinal is fairly well established in Iowa, but its extension into Wisconsin is in part hypothetic, though there can be no doubt that the strata of Grant and La Fayette Counties, in Wisconsin, are corrugated in about the direction of this anticlinal; the Turkey River anticlinal is definite in Iowa, and may extend farther into Wisconsin than has been indicated; the Sherrill-Sinsinawa synclinal is well made out in southern Clayton and northern Dubuque Counties, though its northwestern extension in Iowa and its southeastern extension in Wisconsin and Illinois are not so well ascertained; the Table Mound synclinal and the Tête des Morts anticlinal are fairly determined throughout their course in Iowa and a little way into Illinois; the Maquoketa anticlinal is well determined toward its extremities in Iowa, though its central portion in this State and its extension in Illinois are in some measure hypothetic; the Wapsipinnicon synclinal is well determined at its northwestern and fairly well at its southeastern extremity in Iowa, though its central portion in Iowa and its extension in Illinois are inferred only; the Cedar River anticlinal is well made out in Cedar County and fairly well in its extension beyond the Mississippi, though there is some doubt as to continuity through Scott County; the Oquawka anticlinal is based upon inferences from geologic outcrops at nearly all points, and is accordingly largely hypothetic; the Skunk River anticlinal and the Oskaloosa synclinal rest upon similar but sounder bases; the Des Moines anticlinal is one of the most conspicuous features in southeastern Iowa, and its verity and continuity can not be questioned; the Grand Detour–La Salle anticlinal represents conjoined observation and inference by an able and conservative geologist, has been carefully measured and mapped at its southern extremity, and has been accepted by a still more cautious student;[1] the Cap au Grès anticlinal has been observed by all geologists who have studied that part of the Mississippi River, but the precise structure and trend are vaguely recorded; the verity of the Carondelet anticlinal can not be questioned, though its structure and direction are somewhat uncertain; the Arrow Rock anticlinal is well determined at several points, but its continuity has not been established; the Platin Rock anticlinal is well known on the Mississippi, in both Illinois and Missouri, though its direction is in some degree doubtful; the Grand Tower anticlinal is the most conspicuous feature of the geology of southern Illinois and its verity, its trend, and its general character are fairly established; the Grand Chain anticlinal is almost equally well known, not only in Illinois but in Missouri; the Big Fork anticlinal is but a single example of a large number of parallel corrugations concerning whose extent and importance there can be no doubt, though the trend may depart somewhat from that indicated; and the Little Rock flexure similarly represents a well ascertained and extensive system of corrugations. Even if all cases in the least degree hypothetic be thrown out, there still remain the large number of remarkable and singularly consistent corrugations represented by the full lines upon the map.

Collectively these corrugations exhibit several interesting and significant relations:

(1) In the north they are approximately parallel, or rather concentric; farther southward their axes diverge, but so slightly that if the system were as close as in the north approximate local parallelism would hold; while still farther southward the axes are more divergent and finally coincide approximately with the axes of Appalachian corrugation.

(2) While the undulations vary in magnitude, there is in a general way progressive increase in both vertical and horizontal amplitude (especially the former) from north to south.

(3) The closeness of appression is much greater in the south, where it is decided and akin to that of the Appalachians, than in the north,

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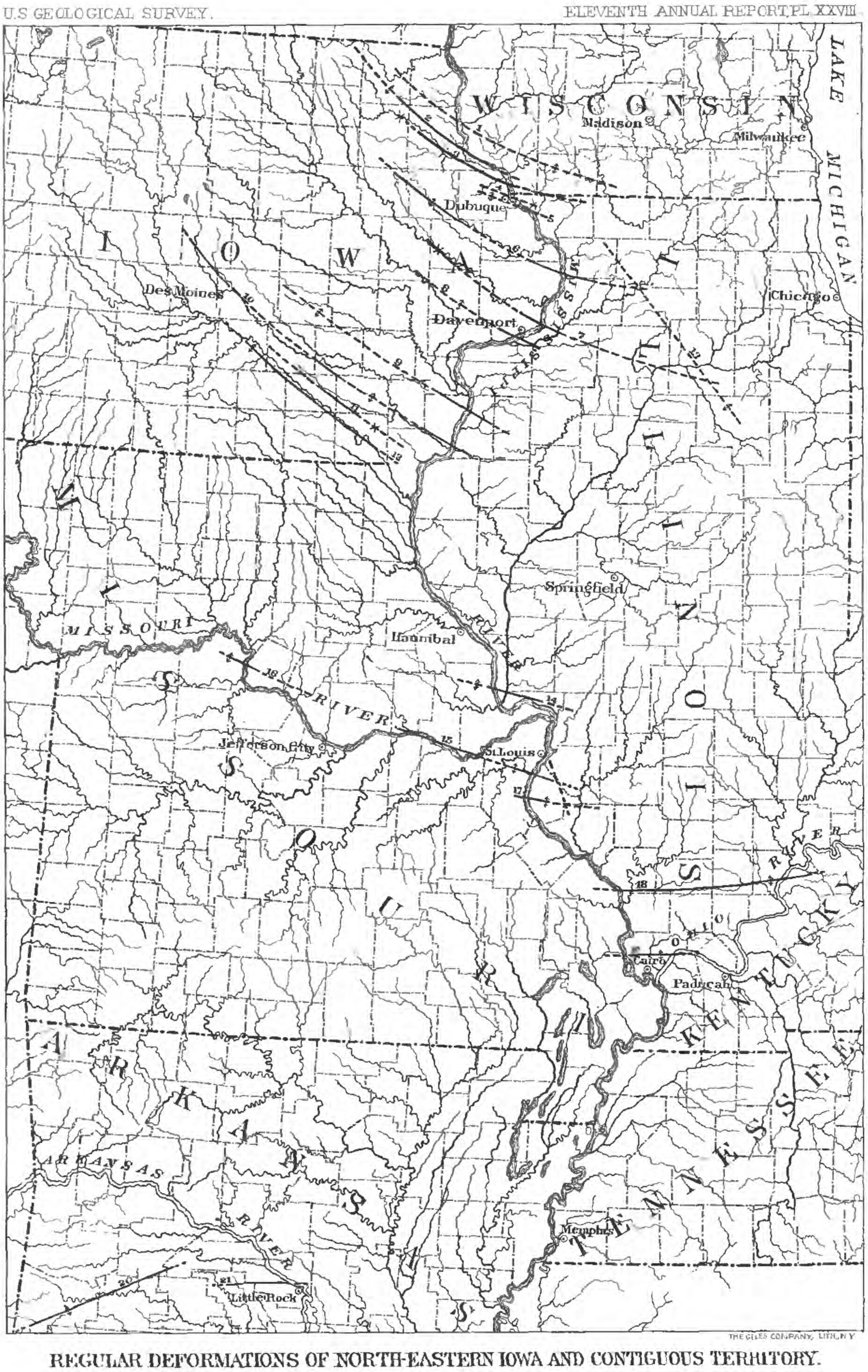
[1] Chamberlin, Geol. Surv. Wisconsin, 1882, vol. 4, Pl. VIII.



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REGULAR DEFORMATIONS OF NORTH-EASTERN IOWA AND CONTIGUOUS TERRITORY.

where it is inconspicuous; but not enough is yet known of the intermediate territory to determine whether the northern and southern conditions represent the extremes of a continuous series.

There is little evidence in the stratigraphy as to the contemporaneity of these undulations, or even as to the period of their origin; but the Cedar River anticlinal appears not to affect the Coal Measures at Davenport and Rock Island, while at La Salle, according to Worthen, the Coal Measures partook of the flexure of the subjacent strata.

The tract stretching from northern Iowa and southern Wisconsin to Arkansas is long and wide. Within it there are thousands of slight deformations not yet detected by the geologist, hundreds of minor deformations observed but not described, and dozens of conspicuous deformations whose descriptions are incomplete or buried in the mass of geologic literature. Of all of these, a score only have been so well observed and recorded that they may be mapped; yet although these few undulations distributed over a vast tract form a slender basis for generalization, they are worth assembling as a guide to future work; and their value is many times multiplied by the harmony among them and by their consonance with the history recorded in the formations they affect.

SECTION III.—THE PALEOZOIC HISTORY.

The several formations of Northeastern Iowa and contiguous territory, in themselves and in the deformations by which they are affected, record a history of continent growth which is worth reading. The greater part of this record has indeed been admirably interpreted by one of the foremost of American geologists in as charming a chapter as was ever contributed to the science of the earth;[1] but a briefer interpretation of the formations and the deformations as well, differing only in minor details from the first, may be offered to those who desire to read the running titles and chapter headings rather than the full pages so ably filled out by Chamberlin.

A half, or a third, or a quarter of the way from the beginning to the end of Paleozoic time, the "Isle of Wisconsin," the nucleus of a continent, peeped through ocean waters in what is now northern Wisconsin. To the northwest and to the northeast stretched long islands with which the nucleal "isle" was perhaps sometimes connected by narrow isthmuses; 1,500 miles to the eastward, the flanks of the Paleozoic Atlantis rose steeply; while the sea rolled between over all of what is now the Appalachian mountains, the eastern Mississippi Valley, and the valley of the St. Lawrence. The elongated islands stretching northwestward and northeastward, and the central isle at their junction as well, were low and their rivers short,

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[1] Geology of Wisconsin, 1883, vol. 1, pp. 45-300.

and they probably supplied less detritus for the building of new lands than the distant Atlantis; for the sheets of sediment stretch from the supposed flanks of the lost continent to the known flanks of the "Isle of Wisconsin:" the winding sheet of the ancient land was the swaddling cloth of the new.

Such was the geography of the middle Cambrian.

Toward the end of the Cambrian the "Isle of Wisconsin" rose higher above the waters, its rivers were lengthened and strengthened, and its rocks were beaten by the rains and swept by the rivers into the active ocean to be washed about by its waves and laid down alongshore as sands and offshore as finer sands, silts, and chemico-mechanical precipitates. But the island oscillated in its lifting, the shore alternately advanced and retreated, and so there were alternations of sands and silts and precipitates on every zone of its submerged slope; yet in general the deposits extended far in all directions from the continental nucleus, save that to the eastward they met and merged with the similar sands and silts and precipitates from Atlantis; and so the sandstones stretch (albeit far below the surface) from beyond the Appalachians to beyond the Mississippi.

Thus were laid down the 700 or more feet of sandstones with intercalations of shale and limestone running from the upper third of the Cambrian over the lower third of the Silurian.

The wide-stretching sand beds of the Lower Silurian and Upper Cambrian are striking; and the vast expanse of nearly pure quartz sand forming the St. Peter is wonderful.

Two of the great problems of geology are: First, the enormous extent and thickness of the sandstones of the geologic formations; and second, the great extent and continuity of the sand beds of the modern seashore. The problems are evidently related; and a rough solution is easy. The sediments of the sea result from the breaking up of older rocks which in the ultimate analysis are Archean granites and other crystallines; and although the minerals composing the rocks may be equally firm, yet on exposure to air and water the feldspar, mica and hornblende are disentegrated, decomposed, and either dissolved or reduced to impalpable silt, while the quartz crystals remain to be more gradually rounded by the action of the waters. While undergoing trituration, these materials are swept down to the sea and washed about by the waves; eventually they are assorted by the water, and the sands dropped about the seashore, while the dissolved minerals and the impalpable mud are carried far away to form deep sea precipitates and silts. This is the rough explanation of the phenomena of great sandbeds, and the ready solution of the problem.

But the rough solution is incomplete. The débris of the land is carried down to the sea in bowlders and pebbles as well as in finer condition. When the bowlders and pebbles are loosed by the torrents in the mountains they beat against one another and thrash the stream bottom in their course toward the sea; the masses are heavy and the blows are violent, and by each some rock is crushed and the rolling bowlders ever reduced in size. But as the bowlders become pebbles, and the pebbles become gravel, the blows are enfeebled until the masses are worn too small to effectively crush their neighbors, and as well (and this is essential) too small to be effectively crushed themselves—for the force of each blow is distributed over a number of pebbles, and each distributes its share among its neighbors, and the energy is expended in mass movement rather than in crushing. And as the pebbles are reduced, the occasional bowlder among them is handicapped in the struggle for perpetuity; for when the bowlder strikes the pebble its energy is distributed among many, while the energy with which each small pebble strikes the inert bowlder is largely expended in crushing; so, as the pebbles and gravel grains, and the smaller particles as well, are assorted and rubbed one over the other the bigger bear the brunt of the fray while the smaller are always protected by their companions, and so equality in size persists; and as they are still further reduced, the attrition diminishes and the crushing practically disappears, the grains protect each other, and the shifting of the mass does not prevent indefinite preservation of the individual grains.

But even yet the solution is incomplete. As the bowlders are gathered in the mountains, and as the cobblestones and gravel are swept forward by the currents and washed about by the waves, the complex minerals composing them are kept wet and in general the surface is thereby softened and disintegration thereby promoted. But when the grains of sand are reduced to homogeneous crystals of quartz the softening by chemically inert water becomes insignificant; and so (and this, too, is essential) the coating of water which was a destructive agent in the bowlder and larger pebble becomes a protective agent—the larger grains thrown against each other by the force of the waves are crushed by the impact, but the smaller are separated by a water cushion; and so the film of water by which each is surrounded tends to indefinitely perpetuate the smaller grains.

This seems to be the solution of the problem of the sand beds.

Now the dearth of silts and precipitates coeval with the preponderant sands of the Lower Silurian and Upper Cambrian about the flanks of the "Isle of Wisconsin" indicates that the formations are due to trituration of quartzose rather than the decomposition of compound rocks, and thus that the Algonkin quartzites formed a larger land than is commonly supposed.

After rearing her head above the waves until many hundreds if not thousands of feet of rocks were washed into the sea, the "Isle of Wisconsin" sank to the level of or quite beneath the waters, and with her the elongated northwestern islands went down until only their crests remained within reach of rains and range of rivers. At the same time Atlantis and his rivers became indolent, and for an eon only fine material was carried into the prevailing ocean, and silts and precipitates were swept from the shores of Atlantis even to and beyond the half-drowned western island. But there the precipitates were mingled with the fine silts from the northeastern and northwestern islands; the submerged land alternately heaved and sank, and so sometimes the silts and sometimes the precipitates prevailed; with each rise the shore deposits of the lower stage were broken up, and with each fall the same deposits were carried further on the land; but at last it rose until the land surface stood well above the water, the rain and rivers recommenced their work, and their silts prevailed greatly.

Thus were formed the deep-sea limestones and offshore shales of the Lower Silurian.

The eon of air and sunlight upon the young continent, and upon the gradual shrinking arms reaching northwestward and northeastward, was short. Atlas tired, and the earth sank into the waters; the rivers were cut off at their sources, and the rain beat bootlessly upon the waves and narrow lowlands. Nearly all over the erstwhile island were dropped precipitates carried from the distant Atlantis, mingled with the seashells, corals, and siliceous silts of the Niagara epoch; but the crests were only so far submerged as to cut-off the rivers, the corals built reefs in the shoal waters, and the waves alternately made and destroyed strata over a wide area; and even 300 miles southwestward the latest deposits were laminated and ripple-marked shales.

Thus the later Silurian period came and went.

Once more the nascent continent was lifted and became dry land; but its face was changed. When the land was young it lifted its head high above the waters, its slopes were steep, and its rivers quickly transferred its crown to the sea and formed a mantle about its flanks. Also, when its head first rose, the sun beat upon and warmed it, and the rocks expanded and rose still higher; yet, after a time, it was submerged and the central area was again chilled and shrunken, so that when it rose again it was broader and flatter than before, by reason of the truncation of the original crest, by reason of the mantle about its flanks, and by reason of the shrinking of its center. Now, the history of the first elevation was repeated during the second, again during the third, and once more during the fourth, and as many times as the land lifted above the ocean and was again submerged; and, as the island grew large after many heavings, the load to be lifted grew unequal in different parts—the ancient crystalline rocks of the center were heavier than the clastic rocks about the flanks, and whenever the land was lifted anew the flanks were lifted more than the center, and thus for another reason the island grew flatter. As the flattening of the center progressed, the annulus of steepest slopes enlarged, lying beyond the mean shore line of each successive period. So with every oscillation, a new mantle of deposits was formed about the flanks of the young land; these successive mantles were piled one over the other until they reached many hundreds of feet in thickness; and each was laid down upon the seawardly sloping surface of another, and each consisted of strata inclined toward the deeper waters. Thus it came about that on the resurrection of the land at the end of the Niagara period, a broad lowland plain received the rays of the sun and the breezes born of the sea, and the rivers of the plain were sluggish; the elongated islands to the northeast and northwest were shrunken; little coarse sand was swept into the ocean to mingle with the silts and precipitates which came largely from the young continent itself, though stretching out eastward to meet the similar silts and precipitates from Atlantis; but the slopes of the offshore sea bottom were steep. The sediments of the successive mantles wrapped about the young continent were dropped from the cold waters of deep ocean, and were long chilled by contact with the waters; yet by the end of the Silurian they were so deeply buried as to no longer feel the chill waters and to be heated by conduction from the earth's interior; and so the isogeotherms, or planes of equal temperature, rose from the former ocean floor into and through the lower sediments, and their temperature was greatly increased. As they were heated they expanded; a part of this expansion was vertical, and so the peripheral portions of the continent were elevated, not by the building up of successive sheets of sediment but by their own expansion; yet a considerable part of the expansion must have been horizontal and must have resulted in either mass or particle movement, or both combined; and, since the sheets of sediment rested on inclined surfaces and were themselves inclined, the movement of expansion must have taken the line of least resistance, and the expanding strata must have crept seaward, while the strata at some distance from the shore line must have been compressed horizontally, perhaps buckled and crumpled, and thrown into anticlinal and synclinal folds concentric with the shore, or elsewhere crushed and broken into fragments along the planes of least strength.

Such appears to be the history of the limestones and shales of the Devonian. As deposition went on the land first sank until each successive bed lapped upon the previous shore, and later rose slowly until each new bed fell short of its predecessor. The rising and falling were oscillatory at many stages, and at different stages the strata slipped upon each other and became crumpled along some lines and brecciated at some horizons.

Yet again the land sank, the waves encroached upon its flanks and took from the rivers sand, mud, and dissolved salts, and laid them down offshore in a 500-foot bed of limestones, shales, and rare sandstones. Atlantis was now low and perhaps contributed less to the broad ocean between the two lands than did the vigorously growing "Isle of Wisconsin;" the new land rose and fell alternately, and the silts and precipitates alternated, but it never rose in mountainous shore lines; the rivers were always sluggish, and their detritus was always fine.

Thus came into being the Subcarboniferous formations; and as they were finished the land lifted once more, still broader, still flatter, and still higher than ever before; and it lifted more on the west than on the east. America was well grown, and Atlantis senile.

Once more Atlas tired, and the land sank slowly; once more the waves advanced upon the flanks of the young continent and overwhelmed its eastern half; but on the west they only gathered sand and finer materials from the rivers and dropped the sand in shoals and within bays, and carried the silts and precipitates far offshore. But the earth-bearer was only gathering strength for his greatest effort. By successive throes he lifted the flanks of the continent in broad zones until the landward waters shoaled over hundreds of thousands of square miles; then the land was alternately lifted to become covered with tropical forests, and submerged to be wasted by the waves; and the forests of each episode of sun and air were transformed into the coal seams during the succeeding episode of storm and flood.

Thus the Coal Measures were formed; and the sands laid down in the shoals and within the bays on the southwestern slopes of the continental nucleus form isolated outliers and mark the farthest advance of the water upon the land.

The last episode in this long continued succession of alternate heavings and sinkings, and the closing event of the Paleozoic, was the most stupendous in the history of the continent. Atlas arose refreshed; the "Isle of Wisconsin" lifted far broader, far flatter, far higher than before; the wide ocean toward the east drained away, and left its bottom to form the eastern Mississippi Valley and the Appalachian Mountains; but defeated Neptune seized upon the enfeebled ancient continent in his retreat, and Atlantis was no more.

It was ages before the waters encroached again upon the broad land of America. The Ohio and the Mississippi busied themselves in making the beds in which they yet lie; the Appalachians were cut down well toward their present dimensions, sending thousands of feet if not vertical miles of solid rock into the sea through their swift-flowing rivers; and even in the low-lying Mississippi Valley, hundreds of feet of the Paleozoic sediments were removed from every square mile. This period of erosion was long—it stretched from the close of the Carboniferous over the Triassic and Jurassic periods and well into the Cretaceous. If the whole period of written history be represented by an inch, the post-glacial period must be represented by a foot, and this great erosion period by a furlong, a mile, or a league; perhaps even this measure is too moderate.

After the lifting of the great mountains of the west, the Wisconsin land—island no longer—sank for the last time, and the waters of the Cretaceous sea rolled over the plains of untold ages and encroached well upon the original continental nucleus, probably as far as the Mississippi River. But they remained not long; the soils were broken up and redeposited; the hilltops were swept into the valleys; some sand and a few pebbles were washed from the far north along its shores to mingle with the detritus of shorter travel; and then the waters retreated.

Thus the unimportant Cretaceous outliers were formed, and the land was once more lifted; the western mountains and plateaus were outlined; the waters drained away from the interior plains, and the sun and rain and rivers once more began their task of vivifying the land; and this task continued until the conquest of the Ice King.

SECTION IV.—THE ANTE-PLEISTOCENE SURFACE.

THE DRIFTLESS AREA.

Seen from the hurricane deck of the Mississippi packet, the driftless area is a series of knobs and salients divided by steep walled ravines: The knobs and salients are sometimes precipitous, sometimes rounded, and sometimes combined of precipitous faces and moderate slopes; the ravines may be here narrow and V-shaped, there wider and U-shaped, and elsewhere broad and flat bottomed; and the beholder is impressed with the amount of the relief and with the steepness of the slopes. Seen from one of its own commanding summits, the interior of the driftless area is a rather strongly undulating plain of soft contoured ridges, which are all water partings and of height proportional to the proximity of the streams; toward the larger rivers these water partings break up into minor ridges, and finally into spurs, salients, and perhaps isolated buttes, everywhere divided by ravines of which the depth and steepness may not be seen; and the beholder is impressed by the dependence of divides, salients, and buttes upon the waterways, and by the gentleness of the slopes. Could it be seen from a point in the air 5 or 10 miles above its own surface, the driftless area would stand forth in its true character as a plexus of polygonal hills, running into continuous uplands between the waterways, divided by a labyrinth of bifurcating, zigzag, wide-branching ravines; but the steepness of slope along the ravines and the gentleness of slope toward the water partings would be lost. And could the three views be combined, they would blend in faithful presentment.

Studied in greater detail the regularity and symmetry of surface forms is found to be interrupted in several ways. In some cases streams fall into sinks, and so there are broad plateaus or even inclosed basins without surface drainage; sometimes the terrane is of fragile rock, and so the surface is flat; again the terrane is of obdurate rock, and the hard ledges stand out as scarps miles or scores of miles in length; these scarps have been crenulated by erosion, and here and there the salients have been cut off and rise as completely isolated mounds and buttes perhaps miles from the escarpment of which they once formed a part; and some terranes are heterogeneous, and so the surface is further diversified by prominent knobs of hard rock and plains or parks underlain by soft rocks. Thus, besides the regular symmetric forms of autogenetic sculpture, there are multifarious minor forms determined chiefly by rock structure.

But the multifarious topographic forms of the driftless area possess one characteristic which can not fail to impress the student of surface forms, particularly if his training were in montanic regions. *The prevailing profiles are convex.* It is true that the profiles of the streams here as generally elsewhere are concave upward; it is equally true that the taluses at the bases of the river bluffs are concave in profile; it is also true that the compound curves of the bluff faces, where not interrupted by scarps and taluses, are partly concave; but such concave curves are exceptions to the prevailing conformation, and their sum is relatively slight. Probably not 3 per cent of the entire area exhibits the concave profiles characteristic of high mountains; probably 95 per cent of the area (allowing for the sensibly horizontal bottom lands) is made up of rounded hills, curving divides, swelling salients, and conical cusps—all positive topographic forms, all of soft contour, and all convex toward the sky.

So the driftless area surface is a strongly undulating plain of convex divides and ridges, relieved here and there by scarps and isolated mounds and by knobs and crags of the harder rocks, trenched by deep-cut waterways, and sometimes pitted by sinks and diversified by parks over the more fragile rocks; it is a rugose surface of autogenetic sculpture, modified by rock structure, and accentuated along drainage lines. This surface was little affected by Pleistocene agencies save along the immediate drift margin. Where it is mantled by Pleistocene deposits or its valleys clogged by Pleistocene débris, the ante-Pleistocene configuration is easily restored; and the present surface is essentially similar to that overlooked by the earlier Pleistocene ice-sheet at its first advent.

THE DRIFT BORDER AREA.

Within this zone the ante-Pleistocene configuration may readily be ascertained approximately. Where the loess is absent the marginal drift is commonly so thin that the configuration of the underlying rock may be observed or reliably inferred; and where the loess is present it sustains a curious but definite relation to the underlying rocks (set forth in detail later), varying somewhat with latitude but yet indicating more or less definitely the configuration of the rock below. The configuration so ascertained here is similar to that of the driftless area, save that some knobs and crags of hard rock are planed off or rounded, that the trenches of the waterways are few and small as befits a great divide, and that the great scarp by which the zone is defined on the northeast is higher and sharper than any within its bounds. It is manifest that the ante-Pleistocene surface of the drift border area was homogenetic with, and but an extension of, the autogenetically sculptured surface of the driftless area.

Toward the margin of its field the ice-plow acted idly and feebly, and modified little the ante-Pleistocene topography. In ante-Pleistocene times the border was, as it is to-day, the most elevated part of the territory; then as now its prevailing forms were of the type exemplified within the driftless area. But it differed from that area in its greater sharpness of contour; for the Niagara limestone is more obdurate and more heterogeneous than the older formations, and the surface was diversified by knobs and parks as well as by rounded divides and labyrinthine waterways. And its former condition differed from the present in that it was then the great divide of the territory; then the waters flowed down its northeasterly slope from the Niagara escarpment in short rivers of which the Yellow is the type; then the waters parted upon its crest and one part turned westward and found its way seaward in courses which may never be discovered; and it was during the ice period that the cañons of the Crane, the Volga, the Maquoketa, and other waterways were cut through the crest by streams born of the ice which crossed the escarpment at low passes and found their way into the upper courses of ante-Pleistocene valleys. So the streams that dissect the old divide flow in narrow, steep-walled gorges, and some of them are disproportionately large for their lower cañons.

THE DRIFT COVERED AREA.

To geologists trained in regions of profound glacial erosion, the statement that if the Pleistocene deposits were penetrated by a sufficient number of borings the ante-Pleistocene surface might be restored, may appear heterodox; but in this case heterodoxy is synonymous with truth. Let it be understood that throughout the 13,000 glaciated miles but a single example of glacial striæ has ever been seen, though rock surfaces are not rare and have been studiously examined by a score of geologists during twoscore years; let it be understood, too, that among the drift materials of sufficient size to be readily traced to their sources, certainly not 20 per cent and probably not 10 per cent, and in some areas of many square miles not 3 per cent, came originally from anywhere within the State; and let it then be understood that the present rock surface is nearly, if not quite, as rugose as that of the driftless area; and even the most skeptical must admit that, whatever may have been its function elsewhere, the ice sheet of Northeastern Iowa was an agent of construction rather than destruction.

The general configuration of the drift-covered area anterior to the first ice invasion was manifestly much the same as to-day; the great Niagara crest stood then as now to form a barrier which the ice failed to cross; the general southwesterly inclination of the surface from the obdurate rocks of the Niagara toward the incoherent shales and shaly limestones of the Devonian and the readily soluble chertless limestones of the Subcarboniferous existed then as now; and so existed, too, the shallow north and south trough extending from the Turkey to the present Cedar.

But the details of the topography were greatly different from now. The two hundred well sections exhibited in Pl. LI, show that the depth of the drift in each part of the territory is fairly harmonious over considerable areas, and so that the mean depth may be computed by any convenient areal units; but they also show that the drift occasionally thickens enormously, indicating the existence of great drift-filled pits or troughs in the subjacent rock. Thus, in the northeastern portion of the territory, the drift averages less than 50 feet in thickness, as shown by sections 17, 23, 25, 27, 29, 30, and 31; but the presence of notable depressions (which in a region of autogenetic configuration may fairly be considered buried channels) is proved by the exceptional thickness of drift found in sections 24 and 32. Such is the case, too, in Delaware and Buchanan Counties, though here the drift is thicker and the exceptionally deep wells are rarer—partly because in the deeper drift fewer well diggers have found it necessary to penetrate the deposits to reach adequate supplies of water. In the central and southern parts of the tract the data are less definite by reason of the still greater thickness of the drift, but the indications are the same. Especially noteworthy are the exceptionally thick accumulations of drift at Dysart (134), Blairstown (136), and Victor (170), and particularly at New South Amana where a bore failed to reach rock at 300 feet. Although so far from complete that they do not locate a single ante-Pleistocene waterway, the two hundred well sections prove that the area now covered with drift was, anterior to the ice invasion, ramified by waterways perhaps cut down as nearly to base level as those of the driftless area; yet the exceptional records at Dysart, Blairstown, Victor, and New South Amana suggest that the broad topographic trough coinciding with the Devonian terrane was occupied by a great river. This trough, be it noted, extends northwestward far beyond the limits of the territory into Minnesota, where it is occupied in part by Minnesota River; and indications of its existence may be found still farther northwestward, even beyond the national boundary.[1] The drainage basin was thus adequate to supply a great river, larger far than the Mississippi of to-day.

The data concerning elevations of the ante-Pleistocene surface are numerous and decisive. Below Manchester, from Delhi to and beyond Hopkinton, and north of Onslow, the Maquoketa exposes in its bluffs Paleozoic strata rising not only higher than the bed rock beneath the adjacent drift plains, but higher than the drift plains themselves. These strata unquestionably represent ante-Pleistocene knobs or ridges. The same is true of the Wapsipinnicon near Quasqueton, about Central City, and elsewhere; and the same relations hold on the Cedar at Osage, near Waverly, west of Brandon, northeast of Shellsburgh, at Cedar Bluffs, and indeed throughout a considerable part of its course; and the indurated rocks forming the cañon walls of the Iowa River at its great elbow rise fully 100 feet above the level of the drift plains in the direct course of the river 5 miles southwestward. Moreover, there are at many points between the rivers, knobs of Paleozoic rock projecting through the drift mantle which ranges from 50 to 100 or more feet in thickness in the immediate vicinity; and it is in the lee of such knobs that many of the paha are heaped.

These knobs and ridges prove that the surface of the area now covered by drift was, during ante-Pleistocene time, as strongly relieved by scarps and knobs as is the driftless area to-day; and the scattered well sections of exceptional depth indicate that it was at the same time as deeply trenched by waterways.

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[1] The most decisive data concerning the ante-Pleistocene rivers of Iowa come from 35 miles west of Marshall. The Skunk River here occupies a shallow trough in the drift, 1 or 2 miles in width. On both sides of this flood plain the low bluffs of drift-capped Subcarboniferous limestone are exposed here and there in cliffs rising 20 or 30 feet above the flood plain; yet within the flood plain a large number of wells have been bored to depths of 100 feet and more without reaching bed-rock. This ante-Pleistocene valley has been traced most of the way through Story County, and maintains its width and depth into Hamilton County, within a dozen miles or less of the extreme source of the river now occupying it; and many of the wells are artesian, indicating that the valley extends much farther to the northwestward toward the higher lands whence the water supply comes.

CHAPTER IV.

TOPOGRAPHY.

SECTION I.—THE DRAINAGE.

The entire territory of Northeastern Iowa drains into the Mississippi, sending 96 per cent of its waters into the great river through fifteen waterways ranging from mill streams a dozen miles in length to considerable rivers; and there are in addition a large number of streamlets and brooks of shorter courses, draining the remaining 4 per cent of the territory, which fall directly into the same river.

There are in the territory two principal types of drainage. The first is the widely branching dendritic type characteristic of the driftless area, and the second the more irregular yet remarkably long and slender type characteristic of the glaciated region; but careful examination of the leading features of the various waterways shows that they fall naturally into four classes, which sometimes intergrade but which are nevertheless quite distinct in typical development.

The first class of waterways belong to the widely branching dendritic type, and flow in the axes of broad, irregularly pyriform basins. The best example is Yellow River; but in the same class must be placed the Oneota throughout the greater part of its course, Village Creek, Paint Creek, Bloody Run, Snymagil, Buck Creek, the Turkey and the Volga in part, the Little Maquoketa, the Catfish, the Tête des Morts, most of the North Maquoketa, and Elk River. These streams exemplify the form generally assumed by the waterways of non-glaciated regions not materially affected by orogenic action. Their basins are relatively broad, and their tributaries are numerous, widely branching, and so uniformly distributed that the entire basins are effectively drained. Grouping the eleven streams belonging wholly to this class—Village Creek, Paint Creek, Yellow River, Bloody Run, Snymagil, Buck Creek, Little Maquoketa, Catfish, Tête des Morts, North Maquoketa, and Elk—the average ratio of mean width of basin to length of stream is 26 to 100, and the average ratio of maximum width of basin to stream length is 44 to 100. Throughout these basins there are neither lakes nor swamps; and within all of the basins the waterways divide and subdivide again and again toward their headwaters, and finally break up into plexuses of intermittent streamways, dry ravines,

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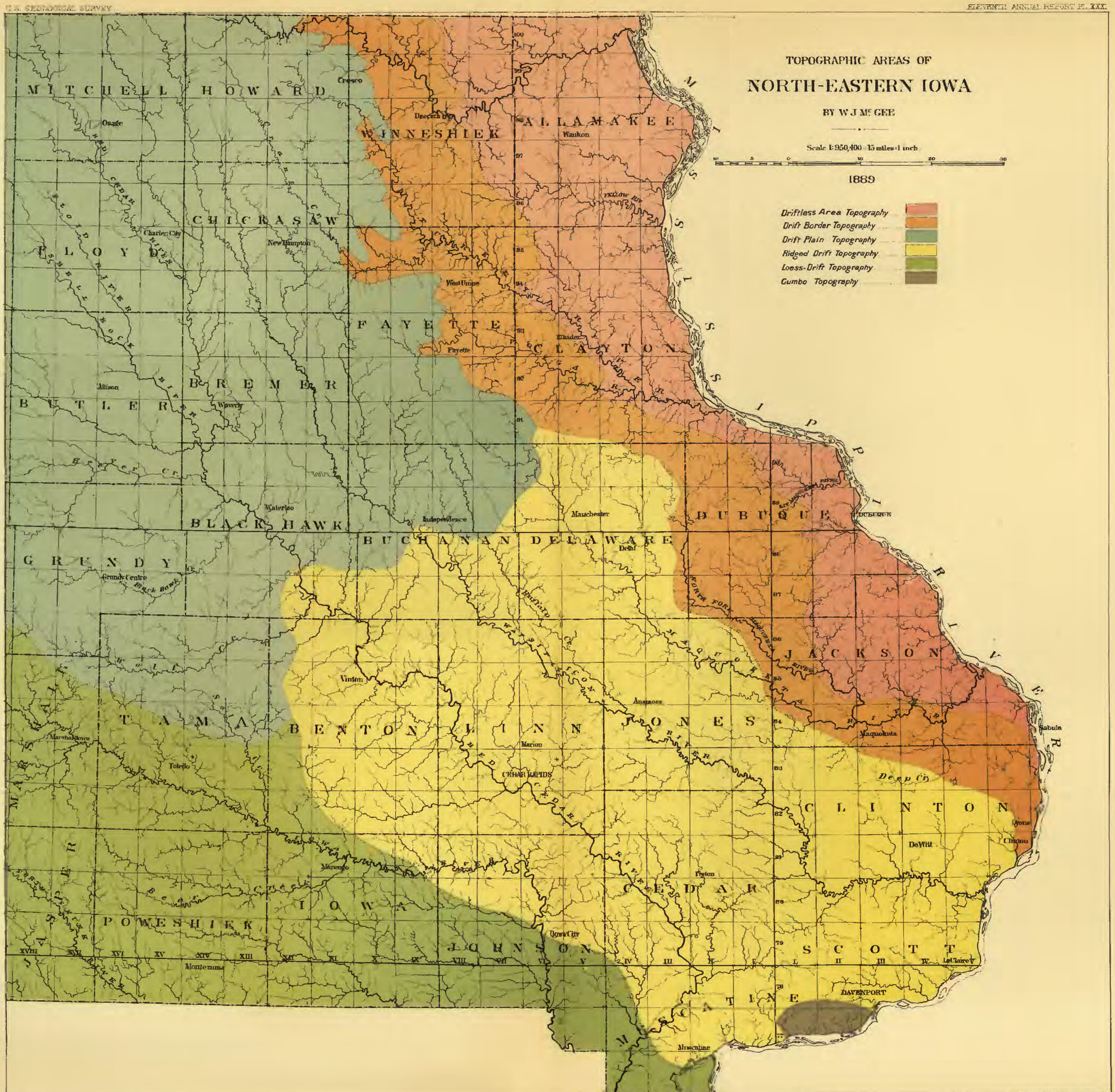
TOPOGRAPHIC AREAS OF
NORTH-EASTERN IOWA
BY W J McGEE
Scale 1:950,400 = 15 miles = 1 inch
1889
Driftless Area Topography
Drift Border Topography
Drift Plain Topography
Ridged Drift Topography
Loess-Drift Topography
Gumbo Topography
MITCHELL
HOWARD
WINNESHIEK
ALLAMAKEE
FLOYD
CHICKASAW
FAYETTE
CLAYTON
BUTLER
BREMER
BLACK HAWK
BUCHANAN
DELAWARE
DUBUQUE
GRUNDY
JACKSON
TAMA
BENTON
LINN
JONES
CLINTON
MARSHALL
JASPER
POWESHIEK
IOWA
JOHNSON
CEDAR
SCOTT
MUSCATINE
MISSISSIPPI RIVER
Osage
Cresco
Decorah
Waukon
Charles City
New Hampton
West Union
Elkader
Fayette
Allison
Waverly
Waterloo
Independence
Manchester
Delhi
Dubuque
Grundy Centre
Vinton
Anamosa
Marion
Cedar Rapids
Maquoketa
Sabula
Marshalltown
Toledo
DeWitt
Clinton
Lyons
Marengo
Tipton
Iowa City
Montezuma
Davenport
LeClaire
Muscatine

and storm-cut runnels, by which the entire surface is diversified and perfectly drained. The minute and nearly uniform subdivision of these autogenetic waterways is more or less perfectly represented upon all good maps of Northeastern Iowa by the multiplicity of minor tributaries which unite to form the principal streams.

The second class of waterways is that which prevails over the drift-covered portion of the territory. The best representative of the class is the Wapsipinnicon; but the headwaters of the Oneota, Turkey, Volga, and Maquoketa, as well as Little Turkey, Crane Creek, the Buffalo, the Cedar and many of its tributaries, and a part of the Iowa, fall into the same general class. The most striking characteristic of all of these streams is their great length in proportion to their volume, and the striking characteristic of the basins is their length and slenderness. Moreover, there is a dearth of small tributaries, and so occasional lakes and ponds (generally too small to appear on maps), swamps, and extensive sloughs are common. Indeed, the slough (pronounced *slew*) is a characteristic feature of the region; it stands midway between the swamp and the upland prairie; in pioneer days, when the prairie surface was heavily grassed, these tracts were thousands of square miles in extent, particularly in springtime, and were impassable to vehicles for most of the summer; muskrats and crayfish inhabited them, and they were dotted with the houses of the former and perforated by the chimneys of the latter; but with the incursion of settlers some of the sloughs dried up spontaneously, others were drained, and now nearly all have been invaded by the plow, or at least converted into pasture lands.

Another characteristic feature of these streams is the parallelism, not only among the streams themselves, but between the main streams and the tributaries. This parallelism is best exhibited in the southern-central portion of the tract mapped, and particularly by the Maquoketa, Wapsipinnicon, and Cedar Rivers, and their tributaries. Over the divide between the last two rivers the smallest brooklets as well as the larger streams display a disposition to assume the prevalent southeastward direction, and when they depart from this direction they generally do so at large angles. The same thing is true over the divide between the Cedar and the Iowa, particularly in Benton County. This curious behavior of the streams is but an expression of a remarkable longitudinal ridging of the surface in a direction parallel to the prevailing stream courses.

In the typical stream of the second class—the Wapsipinnicon—the ratios of mean and maximum width of basin to stream length, respectively, are 6 and 13 per cent, and if the several streams belonging wholly to the class—Little Turkey, Crane, Buffalo, Wapsipinnicon, Little Cedar, Cedar and Duck—be grouped, the corresponding ratios are 12 and 18 per cent. The contrast is even more strikingly shown when individual streams are compared. Yellow River and Buffalo Creek have like drainage basins, yet the mean width ratio of the former is 2.4 times that of the latter; the Little Maquoketa is only two-fifths as long as the Crane, yet the mean width ratio of the basin of the former is 3.6 times that of the latter.

The greater length of the principal streams of the glaciated area, the dearth of tributaries to these streams, and the remarkable parallelism in drainage are indicated by all maps of Northeastern Iowa. These features are represented in some detail in the drainage map forming Pl. XXIX; and the relations of length to width of the several drainage-basins are exhibited in the accompanying table.

River basins of Northeastern Iowa.

Name.	Length.	Area.	Mean Width.	Max. Width.	Ratio of width to length.	
	Miles.	*Sq. miles.*	*Miles.*	*Miles.*	*Mean.*	*Max.*
Oneota River	88	997	11.3	24	13%	27%
Village Creek	16	70	4.4	6	27	37
Paint Creek	20	73	3.6	6	18	30
Yellow River	33	237	7.2	12	22	36
Bloody Run	12	39	3.2	5	27	42
Snymagil Creek	9	32	3.5	6	39	67
Buck Creek	12	31	2.6	3	22	25
Turkey (system)	104	1,651	15.9	30	15	29
Volga River	45	408	9.1	14	20	31
Little Turkey River	24	114	4.8	6	20	25
Crane Creek	50	249	4.9	8	10	16
Turkey River	90	880	9.8	15	11	17
Little Maqnoketa River	20	146	7.3	12	36	60
Catfish Creek	12	70	5.8	9	48	75
Tête des Morts	12	37	3.1	6	26	50
Maquoketa (system)	102	1,850	17.6	32	17	31
North Maquoketa River	58	584	10.1	18	17	31
Maquoketa River	102	1,266	12.4	24	12	23
Elk River	14	78	5.6	12	40	86
Wapsipinnicon (system)	198	2,465	12.4	25	6	13
Buffalo Creek	51	236	4.6	7	9	14
Wapsipinnicon River	198	2,229	11.2	25	6	13
Duck Creek	17	76	4.5	6	26	35
Iowa-Cedar (system)	268	12,358	46.1	66	17	25
Cedar (system)	248	7,745	31.2	54	13	22
Wapsinonoc Creek	20	174	8.7	12	43	60
Sugar Creek	23	119	5.2	9	23	39
Mud Creek	15	92	6.1	9	41	60
Prairie Creek	38	192	4.1	9	11	24
Wolf Creek	46	324	7.0	15	15	33
Black Hawk (system)	38	346	9.1	18	24	47
North Fork Black Hawk Creek	38	232	6.1	9	16	24
Black Hawk Creek	20	114	5.7	8	28	40
Beaver Creek	39	390	10.0	17	26	44
West Cedar River	56	818	14.6	24	26	43
Shell Rock (system)	114	1,806	15.8	36	14	31
Lime Creek	74	728	9.8	20	13	27
Shell Rock River	95	1,078	11.3	19	12	20

River basins of Northeastern Iowa—Continued.

Name.	Length.	Area.	Mean Width.	Max. Width.	Ratio of width to length.	
Iowa-Cedar (system)—Continued.						
Cedar (system)—Continued.	*Miles.*	*Sq. miles.*	*Miles.*	*Miles.*	*Mean.*	*Max.*
Little Cedar River	58	307	5.3	9	9	15
Cedar River	248	3,177	12.8	30	5	12
Iowa (system)	240	4,613	19.2	34	8	14
Salt River	28	215	7.7	14	27	50
English (system)	70	619	8.8	16	12	23
South English River	33	127	3.8	6	11	18
English River	70	492	7.0	13	10	18
Old Man Creek	39	235	6.0	10	15	26
Clear Creek	24	96	4.0	5	17	21
Bear Creek	40	226	5.6	7	14	17
Iowa River	240	3,222	13.4	25	6	10

The third class of waterway is characterized by features that are inconspicuous on the map, though striking on the ground. It is represented by several tributaries of the Cedar, notably Prairie Creek and Wolf Creek, and less perfectly by the Beaver. The streams of this class exhibit toward their sources all of the characteristics of those last described; but as they gain in volume they depart from the prevalent southeasterly trend of the drift plain streams, and, veering to the left, curve first to the eastward and then to the northeastward, and finally fall into the principal waterway of the region at right angles to the general direction of drainage. Moreover, as they veer from the normal course the valley sides differentiate, the right bank remaining a low, monotonous, and perhaps sloughy drift plain imperfectly drained by rare tributaries, while the left banks, which are commonly closely hugged by the stream, become elevated, ridged in a northwest-southeast direction, and diversified and completely drained by a multiplicity of minor streams too small to appear on the map. This class of streams is, so far as known, unique.

The fourth class of waterways is a cross between the first and second. It includes a part of the Iowa and all of its tributaries from the south and west; and Old Man Creek may be considered its type. These streams are rather long in proportion to their volume, and their basins are narrow; the ratios of mean and maximum basin width to stream length in the typical case being respectively 15 and 26 per cent. The corresponding ratios in the five streams belonging wholly to the class—Bear Creek, Clear Creek, Old Man, English River, and South English—are 13 and 20 per cent. These streams, like those of the first class, tend to divide into numerous tributaries, and these in turn to break up into intermittent streamways and dry ravines; and, accordingly, nearly the whole surface is drained; and neither ponds nor marshes occur, particularly in the vicinity of streams. The multiplicity of minor tributaries in the region of this class of drainage is indicated by the maps; but there is a characteristic feature which the maps do not show: Despite the wide divarication of the drainage lines they have not completely invaded the plateaus forming the divides, and so these plateaus are sometimes imperfectly drained, and may be semimarshy even to within a stone's throw of sharp-cut ravines or of permanent waterways. In this feature the fourth class of drainage stands in sharp contrast to the second. In the basins of the Wapsipinnicon and Cedar, the sloughs are the lowest grounds and lie on the almost imperceptible slopes running down to the rivers; but in the region drained by the Iowa, most of the sloughs occur upon the highest grounds and form the divides between neighboring streams.

Other types and classes of waterways are exemplified in the territory, but their representatives are too few and small to require detailed consideration or to be susceptible of generalization. Thus there are, particularly within the Trenton terrane, many limited tracts of which the drainage is subterranean, and several examples of streams flowing partly upon and partly beneath the surface. The best example is Robert's Creek, in northwestern Clayton County, occupying the upper part of a continuous autogenetic valley, throughout which it evidently once flowed down to Pony Creek, and thus by a circuitous route of over 20 miles into the Turkey; while at present the stream falls into a cavern midlength of the valley, and its waters are supposed to reappear in an immense spring on the left bank of the Turkey only four miles away. Related examples are found in a tributary valley of Robert's Creek, in two considerable streams of southeastern Winneshiek County, and particularly in the millstream on which Clayton Center is located, in eastern Clayton County, and which is supposed to reappear as a proportionately larger stream three miles nearer Turkey River, at the mouth of Pony Creek. Then, in eastern Scott County there is a "Lost Creek," which derives its designation from the facts that it embouches upon a low, flat delta built on the Wapsipinnicon flood plain, and that shortly after white settlement the stream illustrated the behavior of its class by shifting from one to another radius of the fan-shaped delta, in consequence of which the position of its mouth was changed several miles. Another erratic stream is Duck Creek, in southern Scott County, which throughout most of its whole length flows nearly parallel to the Mississippi, but in opposite direction. Finally, there are in the territory a few examples of large channels either undrained or occupied only by petty streamlets quite too small to have fashioned them. By far the most conspicuous of these is that stretching across the tip of "Cromwell's Nose," from the mouth of the Maquoketa to the valley of the Wapsipinnicon; and a less conspicuous example is found in "The Cooley," in the northwestern part of Dubuque.

If the drainage be viewed in a general way, two striking characteristics appear. The first, which remains notable despite the large relative breadth of the waterways of the first class, is the great length of the drainage basins in proportion to their width. The area of 20,000 miles shown in Pl. XXIX is drained by forty rivers and principal tributaries, aggregating 2,000 miles in length. As shown in the accompanying table, the average width of drainage basin throughout the whole area is only 10 miles, and the average ratio of mean basin width to stream length is only 19 per cent. Probably nowhere else in the world can there be found an equal number of contiguous drainage basins of equal size in which the length is so great in proportion to the width.

The second characteristic is the parallelism in the drainage. For 175 miles the Cedar and the Wapsipinnicon are only about 13 miles apart on the average, and are approximately equidistant at nearly all points; the Maquoketa averages only 12 miles from the Wapsipinnicon, and is practically equidistant from it for 60 miles, while the northwesterly continuation of the valley of the former (occupied in part by Crane Creek and the headwaters of the Volga) maintains approximate equidistance from and parallelism with the Wapsipinnicon for 65 miles farther. But closer inspection shows that "parallelism" does not accurately express the relation between the streams —they are alike curvilinear and divergent from a central tract extending into the northwestern part of the territory from Minnesota. Each stream, from the Oneota to the Cedar and Iowa, veers gradually toward the left from its source to its lower reaches, and all radiate in a symmetric semi-lobate or fan-shape from their tract of origin toward the great river in which their waters are swallowed up. Yet despite the curvature and divergence of the streams, it is doubtful whether there can be found anywhere else in the world an equal number of contiguous streams of equal length which exhibit so decided parallelism in their courses; and certainly no more striking conformity to a general law of relation among water courses has ever been brought to light.

SECTION II.—THE GENERAL RELIEF.

Inspection of the stereogram forming Pl. III or of the accompanying hypsographic map (Pl. XXX)[1] will show that Northeastern Iowa represents parts of two broad shallow troughs, trending and gently inclining southeastward. The axis of the smaller and more elevated of these troughs is marked approximately by the Mississippi River from the northern boundary of the State to the tip of "Cromwell's

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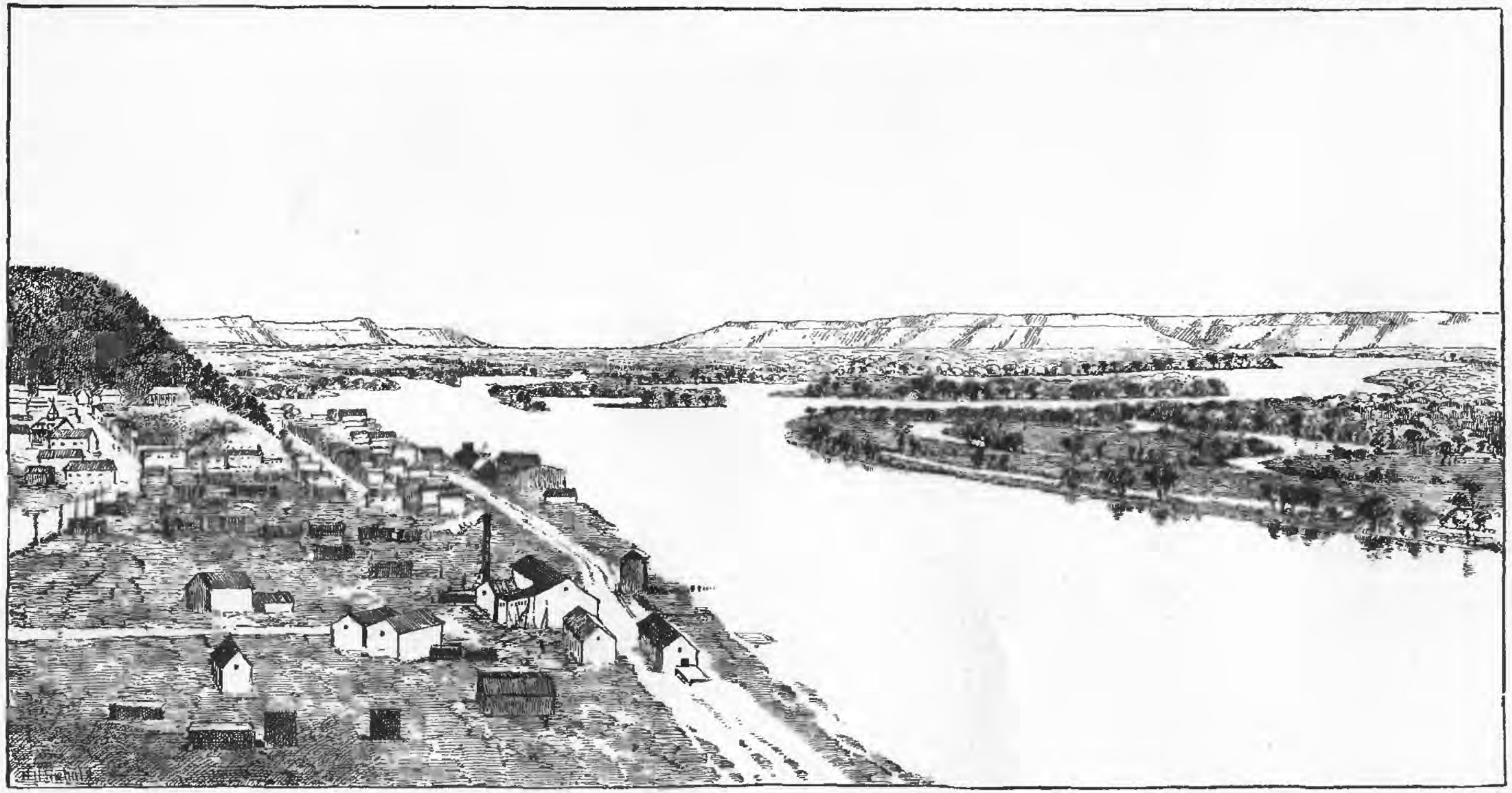
[1] In pocket at end of volume.

Nose" (the great eastern projection of the State) near the mouth of the Maquoketa. Its western rim is the ridge of Niagara limestone which enters Howard and Winneshiek Counties from the northwest and extends southeastward between the Oneota and Turkey Rivers to the southeastern part of Winneshiek County, where it divides, the lesser member—the Military Ridge—forming the water parting between Yellow and Turkey Rivers, and the greater continuing southeastward, independently of the drainage, through northeastern Fayette, southeastern Clayton, northeastern Delaware, and western Dubuque and Jackson Counties to the extremity of "Cromwell's Nose." This ridge forms the most elevated part of the territory. Southwest of its crest the surface inclines toward the axis of the second trough, which is occupied at first by the Wapsipinnicon and Little Cedar Rivers, afterward by the Cedar to somewhat below the center of the territory, and then by the Iowa from just above its great elbow in Johnson County to its mouth. Still farther southwestward the surface again rises, but more gently, to the divide between the Skunk and Des Moines Rivers, and again beyond the Des Moines to the "grand divide" separating the Mississippi and Missouri watersheds far beyond the limits of the map. These great troughs are indices of geologic structure: The first represents the friable sandstones of the Cambrian and the lower part of the Silurian, and its western rim is the escarpment formed by the obdurate Niagara dolomite; while the second represents the area of the non-indurated shales and little obdurate limestone beds of the Devonian. So, viewed in the large way, the surface of the tract is corrugated from northwest to southeast into a conspicuous ridge sloping down on both sides into shallow troughs; and the bottom of the broader trough again begins to rise in the southwestern part of the tract.

Now, even a casual glance at stereogram or hypsographic map shows that this gentle corrugation of the surface is independent of the drainage. True, the streams in the extreme northeastern corner of the State flow down the slope of the smaller trough into the Mississippi; but the Oneota rises in the larger depression, and finds its way through the bounding rim into this trough through a narrow gorge; the Turkey in like manner rises southwest of the culminating crest, and, after flowing parallel with it for 40 miles in one of its branches and for 50 in another, also cleaves the crest in a narrow, rock-bound cañon; the Volga, too, originates on the southwestward slope, and, like its primary, turns toward the elevated ridge and breaks through it in a constricted gorge; and the Maquoketa, in like manner, gathers strength in 60 miles of its course to successfully battle with the great crest and embouch through it directly into the Mississippi. On the northeasterly side of the greater trough, the independence of surface and streamway is still more striking; for the rivers do not seek, but on the contrary decidedly diverge from, the



GORGE OF THE MISSISSIPPI ABOVE LANSING.

general slope of surface: The Wapsipinnicon, rising about the axis of the trough, gradually climbs its sinistral side and closely approaches its prominent northeastern boundary; the Cedar at first enters the great depression, but, after following it 100 miles, sweeps to the eastward, like the Wapsipinnicon, and nearly reaches the Mississippi before it again turns in the direction of the surface slope to fall into the Iowa; and then the Iowa, which at first flows toward the axis of the trough, almost crosses it in Johnson County, and affects the eastern slope rather than its axis. The parallelism and narrowness of the river basins of Northeastern Iowa are indeed remarkable; but far more remarkable is the fact that the larger of these basins do not conform to the prevailing surface slopes but cross obliquely the deepest valley and the highest ridge of the general surface.

There is a rather inconspicuous but significant feature in the general relief of the territory, which may not, like the greater corrugation, be ascribed to geologic structure: A broad, shallow, vaguely-defined depression originates near the southern extremity of the Cambrian and lower Silurian trough about the mouth of the Turkey, and extends thence almost due south to the great elbow of the Cedar a few miles northwest of Muscatine, or nearly to the axis of the greater Devonian trough. It is at first occupied by the north-flowing Little Turkey Creek; it crosses the Niagara crest to the Maquoketa watershed as a broad, low pass; it is occupied by the North Maquoketa for 15 miles; it is represented by the low-lying divide between Rockville and Hopkinton; the Maquoketa enters it above Monticello and leaves it 5 miles below; it is lost for a time on the divide between the Maquoketa and Wapsipinnicon near Anamosa, but reappears and is possessed by the latter river as far as Olin; it traverses the next divide in a notable depression near Stanwood; and finally it passes into the expanded bottom of the Cedar near Moscow. It is the string of the bow represented by "Cromwell's Nose," and connects in direct course the deeper valleys occupied by the Mississippi to the north and the south of this projection. It crosses the culminating crest of the territory and intersects the various formations, hard and soft, from the Cedar Valley limestones (if not the Coal-Measure sandstones) to the Trenton; and its continuity is unbroken save by a belt of loess on the Maquoketa-Wapsipinnicon divide.

The lowest point in the territory (the level of the Mississippi at the extreme southeastern corner) is about 520 feet above tide. The highest point measured by railway levels (midway between Cresco and Glen Roy, in northeastern Howard County) is 1,321 feet, but altitudes of 70 or 80 feet greater, or about 1,400 feet, occur in the same vicinity.

The slopes of the rivers have been determined approximately, and express certain features of the relief in a general way. They are as follows:

Slopes of rivers of Northeastern Iowa.

River.	Maximum.		Minimum.		Length in miles.[1]	Slope in feet per mile.
	Point.	Altitude.	Point.	Altitude.		
		Feet.		*Feet.*		
Mississippi	Minnesota line	640	SE. corner of Muscatine County.	520	200	0.60
Oneota	Source (in Minn.)	1,325	Mouth	640	70	9.79
Village Creek	Source	1,225	...do	635	15	39.33
Paint Creek	...do	1,225	...do	630	18	33.06
Yellow	...do	1,275	...do	625	30	21.66
Turkey	...do	1,300	...do	605	85	8.18
Little Maquoketa	...do	1,150	...do	590	18	31.11
Maquoketa	...do	1,175	...do	580	100	5.95
Wapsipinnicon	Source (in Minn.)	1,300	...do	570	190	3.84
Cedar	Minnesota line	1,115	SW. corner of Muscatine County.	590	250	2.10
Iowa	Marshall	800	South line of Johnson County.	600	100	2.00

[1] Measured around larger but across smaller curves.

The distribution of relief is shown in detail, and with sufficient accuracy to exhibit general relations, in the hypsographic map forming Pl. XXX. It is shown quantitatively in a more general way in the following table, computed from the hypsographic map by means of a planimeter:

Altitude.	Area.
	Square miles.
Below 600 feet	171
Between 600 and 700 feet	883
Between 700 and 800 feet	2,065
Between 800 and 900 feet	2,869
Between 900 and 1,000 feet	4,075
Between 1,000 and 1,100 feet	3,416
Between 1,100 and 1,200 feet	1,609
Between 1,200 and 1,300 feet	1,238
Above 1,300 feet	192
	16,518

The mean altitude of the territory, computed from the foregoing data on the assumption that the slopes are uniform between the 100-foot contours, is 1,007 feet. With a smaller contour-interval the mean altitude would be slightly increased, since the prevailing land profiles are convex, i. e., the actual mean altitudes of the territory is somewhat more than 1,007 feet above tide.

SECTION III.—THE LOCAL RELIEF.

THE TOPOGRAPHIC AREAS.

While in a general way Northeastern Iowa is naturally divisible into the driftless area in the extreme northeast, and the drift covered area constituting the greater part of the territory, there are in reality half a dozen areas of distinctive configuration. The first of these comprises what may be called the Driftless Area topography, which is moderately constant and uniform throughout the whole of its extent. The second is the area of Drift Border topography, which skirts the margin of the driftless area and partakes of its character to some extent, but which is nevertheless variable in certain features and apparently unique in others. The third topographic area comprises the Drift Plain configuration, the characteristics of which are moderately constant, though within the general area there are occasional examples of other topographic forms. The fourth area includes the Ridged Drift topography, which is variable in certain characteristics, and which grades into other forms but nevertheless remains the most striking configuration of the upper Mississippi Valley and is at the same time, so far as known, quite unique. The fifth area includes the Drift-Loess topography of the southwestern part of the territory, within which the topographic features are moderately constant and generally distinctive. The last topographic area has but a small development within the territory, though it has enormous extent in southern Iowa and Illinois, and in Missouri. Its features are generally constant wherever it is found; and it may be called, from the deposit which gives rise to it, the Gumbo area of topography.

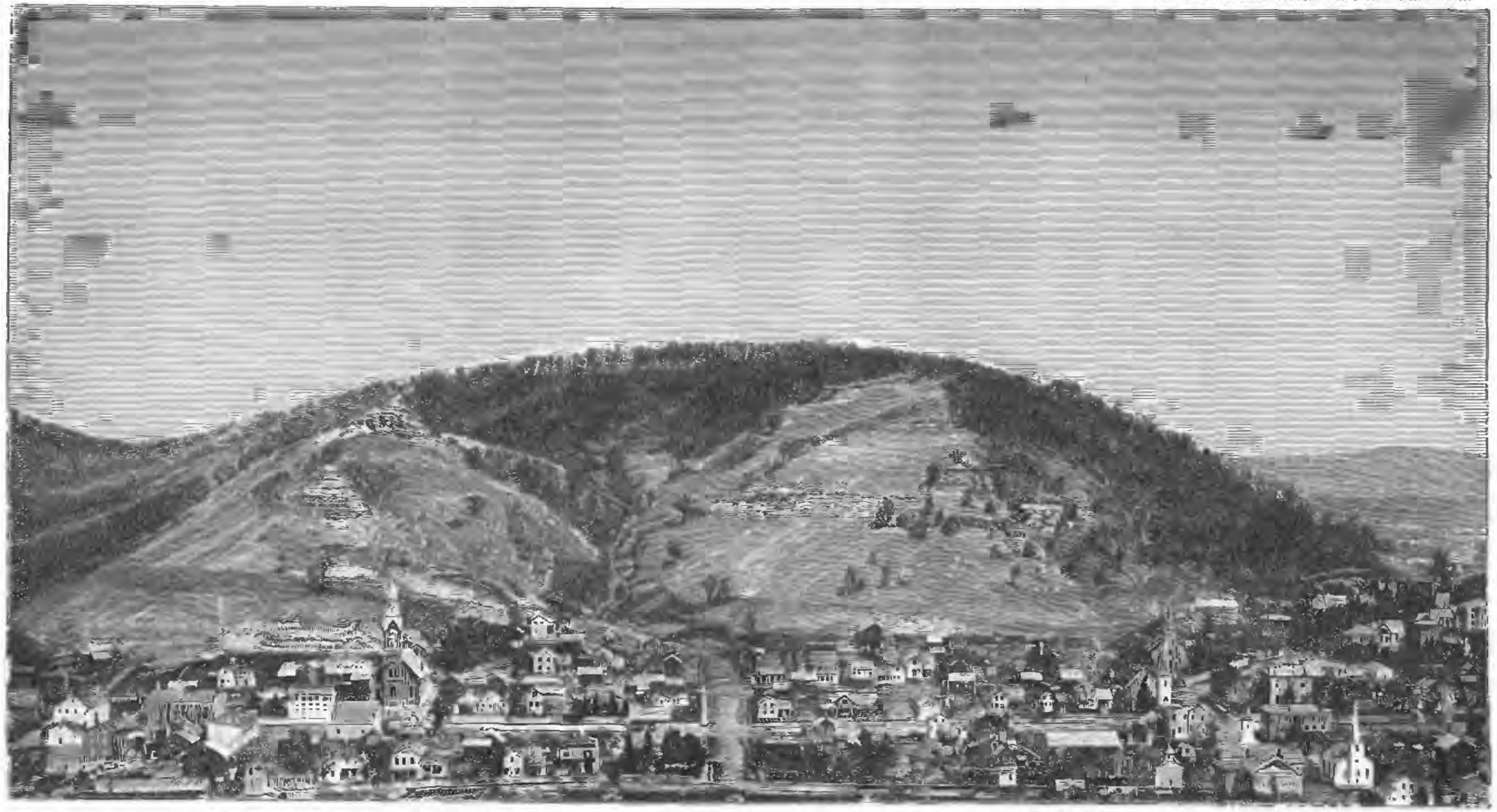
These topographic areas are represented upon Pl. XXXI.

THE DRIFTLESS AREA.

The most prominent geographic feature of the driftless area is the Mississippi cañon—a steep-sided, flat-bottomed gorge ranging from a mile to 7 or 8 miles in width, and gradually diminishing in depth southward from nearly 500 feet at the north line of the State to less than 200 feet at the tip of "Cromwell's Nose." Yet, although a veritable rock-bound cañon, similar in genesis to that of the Colorado and in depth approaching that of the Hudson, this gorge is not confined between continuous palisades, but rather guarded by lines of isolated or nearly isolated bluffs stretching along either side of the great river like lines of giant sentinels. Sometimes, indeed, the bluffs are closely crowded, and for a score of miles the cliff wall may be broken only by narrow ravines or the constricted gorges of petty streams; but again the interspaces widen and the bluffs contract until the cañon wall, as seen from the river, becomes but a line of isolated buttes, now round-topped, again crowned with a fillet of precipitous rock, and always forest clad on the north slopes but grassed toward the sun. Yet viewed from one of their own summits, the sentry-like bluffs are seen not as buttes but as salients —the extremities of divides stretching and rising far into the interior of the strongly undulating plain forming the driftless area. At the same time, too, the interspaces are found to be but broad reentrants or amphitheaters, bounded by the converging sides of the salients, themselves sculptured into lines of bluffs as high and steep as those overlooking the river channel. Yet now and then there may be seen mural precipices nearly as steep as the Palisades of the Hudson, and continuous perhaps for two, three, or even five miles.

FIG. 21.—Truncated salients. Below Lansing.

The tourist who views the cañon walls of the upper Mississippi from the deck of one of the packets plying between St. Louis and St. Paul can not fail to note two distinct aspects in the bluff faces. The prevailing cañon wall is a line of gracefully rounded bluffs whose slopes are either continuous from base to summit or broken by one or more sensibly horizontal ledges of hard rock cropping out now in narrow precipices and again in nearly continuous vertical faces 10 to 100 feet high. In Allamakee County the principal outcropping ledge by which the bluff faces are broken is the Oneota dolomite. In the northern part of the county and in the lower bluffs, the ledge simply crowns the eminences and converts their summits into mesas; but in the southern part of the county and in the higher bluffs the limestone face skirts the palisades, winds in and out about the reentrants and around the salients composing the cañon-wall, and in the reentrants often forms cascades over which brooklets leap 100 feet before they are dashed into spray upon the rugged talus below; and the steep slopes above and below the vertical face of the ledge are of débris formed from its disintegration and from the disintegration of the rocks of the summit, and represent the angle of stability of such materials. In the northern part of Clayton County two conspicuous ledges score the



BUTTE-LIKE BLUFF, LANSING.

face and interrupt the slopes of the rounded river bluffs, the lower representing the Oneota dolomite and the upper the Trenton limestone; but toward the mouth of Turkey River the lower ledge disappears

FIG. 22.—Cañon wall of Mississippi, opposite Buena Vista. Rounded bluffs of Galena limestone with precipitous faces of Trenton limestone half concealed by flood plain forests.

beneath the Mississippi alluvium, and thence southward there is a single cliff line diminishing in altitude to the southern end of the cañon at the lower extremity of the driftless area. Moreover, while

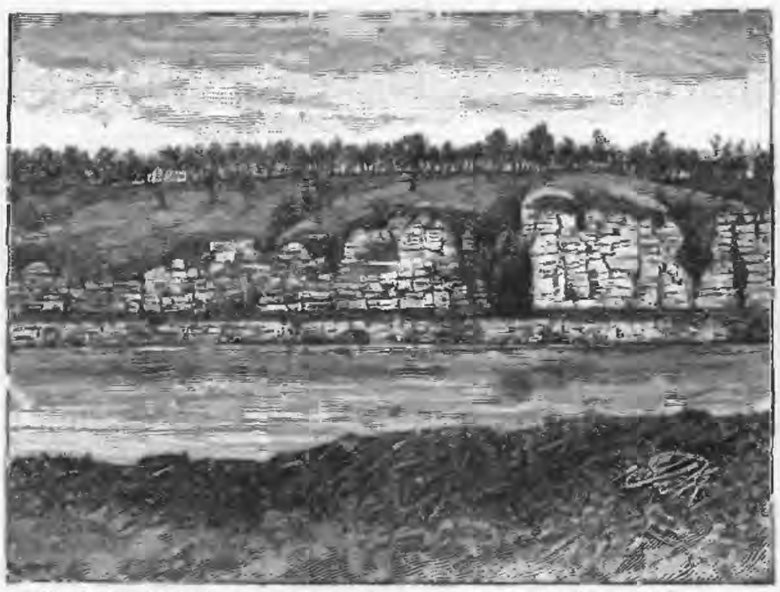


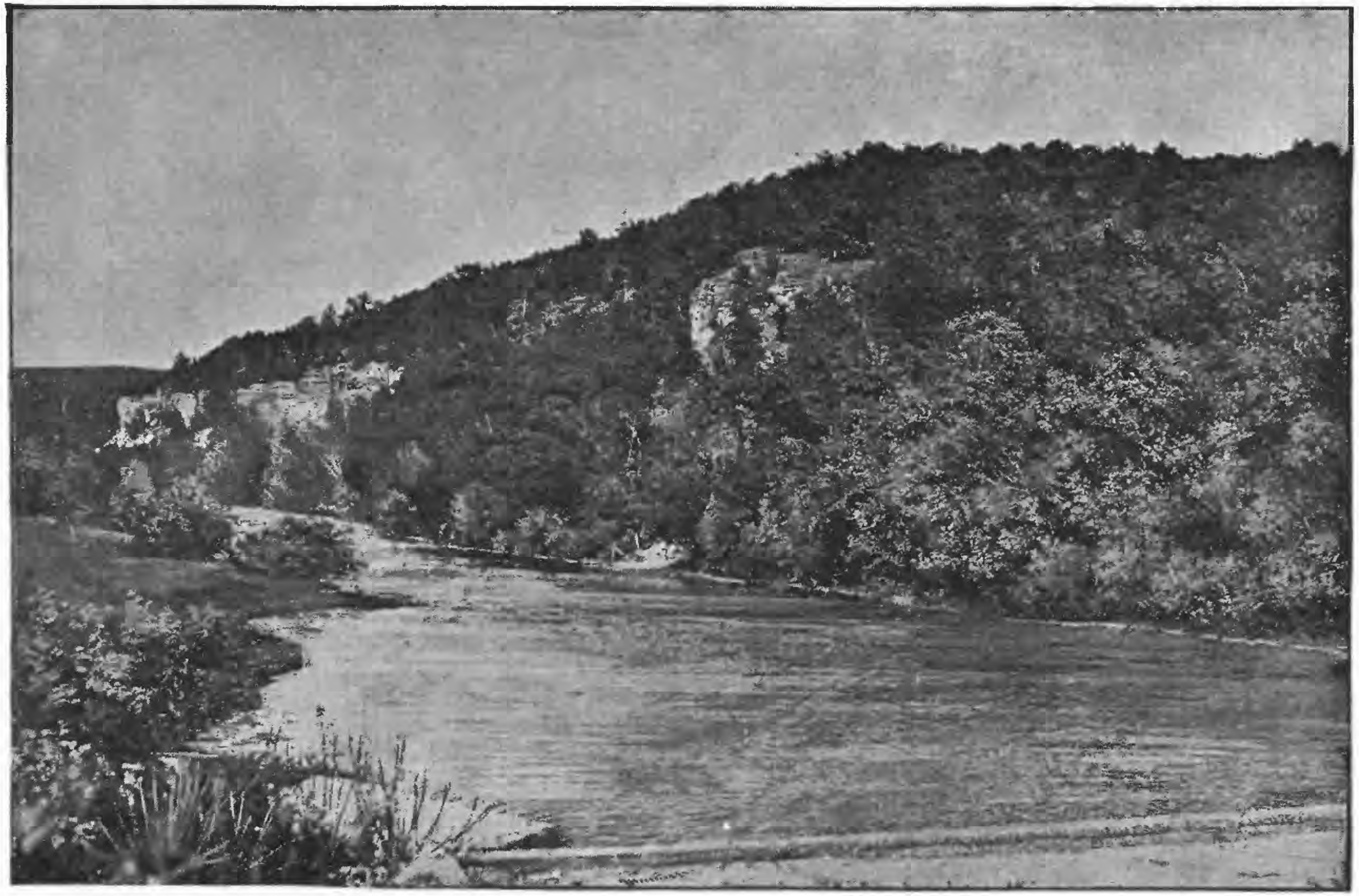
FIG. 23.—Cañon wall of Mississippi, opposite Dubuque. Mural precipice of Galena limestone with the prevailing rounded uplands of the driftless area rising from the cliff crest.

the gracefully rounded contours of the first aspect of bluff faces continue, and while the eminences diminish in height, the cañon walls are steeper and more rugged south of the Turkey than toward the Oneota; for the Trenton and Galena limestones are more homogeneous and more obdurate than the alternating calcareous and arenaceous beds of the subjacent formations so well developed in the extreme northeastern corner of the State. These rounded bluffs have been subjected to erosion for a long period; they are mature forms.

The less common form of bluff bounding the cañon of the upper Mississippi is a precipitous cliff or mural face extending from summit to base of the cañon wall, perhaps cumbered by a talus below, and exposing the more friable as well as the more obdurate ledges from the St. Peter above to the Potsdam below in a buttressed wall so steep that no shrub finds place for its rootlets in the ledges of solid rock, and no less hardy tree than the dwarfed but vigorous

FIG. 24.—Typical truncated bluffs. Near Dubuque. Illustrating topographic youth in the cliffs, topographic maturity in the gentler slopes.

cedar takes root in the crevices and crannies between them. Generally these precipitous cliffs pass suddenly at their extremities into the more characteristic bluffs of gentler slopes; and generally they are found at the extremities of salients which elsewhere take the prevailing rounded contours. Sometimes, indeed, a completely



PLYMOUTH ROCK, ONEOTA RIVER.

isolated butte of the soft contoured aspect appears to have been cleft in twain, leaving a vertical face overlooking the area where once stood half its base. The precipitous bluffs are young.

The rounded bluff overlooking Lansing (shown in Pl. XXXIII) illustrates the common aspect of the bluffs, and represents topographic maturity; the cañon walls of the Mississippi opposite Buena Vista and Dubuque (Figs. 22 and 23) represent respectively topographic youth and infancy; the sharply truncated salients just below Lansing and near Dubuque, shown in Figs. 21 and 24 illustrate the steeper cañon wall, and lie between the two extremes in topographic development; and the curious isolated knobs, evidently once symmetrically

FIG. 25.—"Sugar Loaf," near Winona, Minnesota. An almost exact image of this "Sugar Loaf" occurs a few miles below Lansing, Iowa.

rounded but now cleft in twain, like Sugar Loaf near Winona and its homologue near Lansing (Fig. 25), and like Barn Bluff at Red Wing, illustrate the diverse contours of the two stages.[1]

The reason for the diversity in form of the bluffs overlooking the Mississippi gorge is evident from a casual inspection of the cañon itself, or indeed of the illustrations representing it. The rivers, the valleys, and the hills are all of the autogenetic type, and were evidently fashioned by the progenitors of the present streams during a vast period of constant base-level, perhaps somewhat lower than now; but latterly the base-level has been disturbed, the Father of Waters has silted up his bed, and in his wanderings from side to side has

[1] Figs. 25 and 26 are from Chamberlin and Salisbury, 6th Annual Rep. U. S. Geol. Survey, pp. 233 and 235.

impinged now against this and now against that part of the cañon wall, and so by the process which Gilbert calls "lateral corrasion" has truncated the limiting salients and thereby formed additional material for the further filling of his bed.

Next to that of the Mississippi, the valleys of Oneota and Turkey Rivers are the most conspicuous geographic features of the driftless area in Iowa; and toward their mouths they are but miniature copies of that of the great river to which they pay tribute. The local relief which they have formed, and which is measured from their waters, also simulates that of the Mississippi.

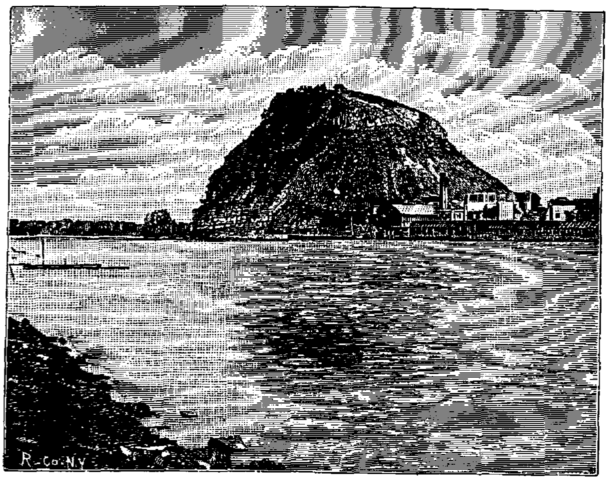


FIG. 26.—"Barn Bluff," Red Wing, Minnesota.

The principal features of the Oneota and its bounding bluffs have already been noted,[1] and those of the larger Turkey are similar. In its lower stretches (particularly below the mouth of the Volga) the latter river meanders through an alluvial bottom as does the Mississippi on a broader scale; and like the Mississippi it is flanked by rocky bluffs, generally assuming gracefully rounded contours, though sometimes precipitous and rugged, and rising nearly vertically from the water's edge to the general level of the upland. Below the mouth of the Volga these bluffs, like those of the Mississippi between the Turkey and the Maquoketa, are carved out of homogeneous Trenton limestone and so assume regular forms; but on the Turkey above Elkader, on the Volga, and along the small tributaries from the south below the Volga, a second line of cliffs overlooks the broad terrace to which the lower hilltops rise. This second cliff line is the great Niagara escarpment—the most prominent feature in the relief of Northeastern Iowa, and for a hundred miles the boundary between the driftless area and the drift border area to the southwest. In general the Turkey bluffs are somewhat less abrupt than those flank-

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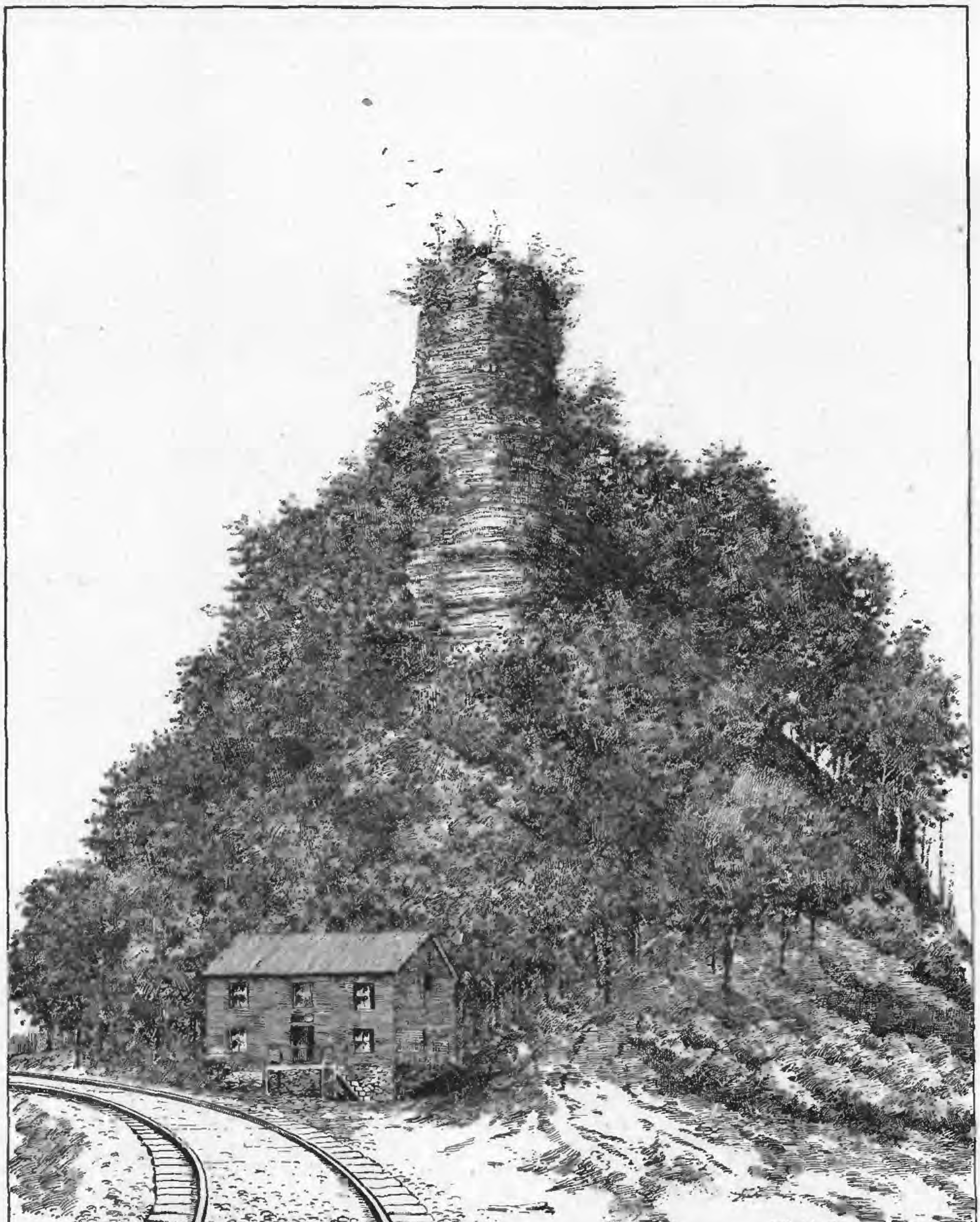
[1] In chapter 1, pp. 204, 205.



ESTELL POINT, NORTH OF TURKEY RIVER.

ing the Mississippi; for not only are they less affected by lateral corrasion (indeed above the mouth of the Volga these evidences of lateral corrasion are rare), but they are frequently skirted by Pleistocene terrace deposits, sometimes forming definite benches though more frequently making only irregular slopes of débris hanging around the spurs and filling the lesser reentrants of the cañon wall.

A striking illustration of the effects of lateral corrasion in Northeastern Iowa occurs just above the mouth of Turkey River. Here there is a great bend in the Mississippi, and its deflected current has long impinged against the narrow salient separating its channel from the Turkey valley; and a corresponding bend has thrown the current of the Turkey against the opposite side of the same salient. So the salient has been carved away, chiefly by the greater river though to some extent by the lesser, until the streams are now separated only by a knife-edged wall of Trenton limestone 200 feet high, so steep-sided that scarce a cedar takes root in its crannies, and so narrow that the first individual who dared creep out to its extremity was immortalized in the name of the point. The extremity of this spur—Estell Point—is cumbered by a wooded talus, yet stands forth as a bold tower forming a noted landmark. It is represented in Pl. XXXV.

The cañon of Yellow River is a narrow, steep-sided, and exceedingly sinuous gorge; and about its mouth the sides of the gorge are rounded bluffs skirted by outcropping ledges of Oneota dolomite like those of the Mississippi. But throughout the greater part of its course, this river flows, not through a broad, alluvium-lined bottom, but over a rocky bed, bare or thinly covered by the annual freshet deposit—it is a V-shaped gorge of the typical form assumed in growing autogenetic drainage, with a mean declinity of nearly 22 feet per mile; and only in the lower stretches has the river been affected by sedimentation in the broader cañon. In this respect Yellow River is representative. Village Creek, Paint Creek, Bloody Run, Snymagill, Buck Creek, Little Maquoketa, Catfish, and Tête des Morts also flow in narrow, sinuous, V-shaped gorges, and are evidently corrading their channels to-day, albeit at an easy pace. On ascending any of these streams, or any of the numerous tributaries which combine to give them volume, the same topographic characteristics are found to prevail; there is the same V-shaped gorge rising in rounded bluffs, themselves cleft by numberless ravines; there are the same soft and graceful contours, perhaps broken by firm ledges, gradually rising to the level of, and gradually passing into, the general upland plain; and as the stream grows smaller and smaller and finally runs into the intermittent waterway, or the ravine filled only during rain storms and the vernal melting of the winter's snow, the slopes diminish and the materials of the slopes become finer, first from great house-like blocks to rubble, then from rubble to angular gravel, next from angular gravel to earthy sand, and finally from earthy sand to the rich red loam or residuary clays prevailing over the driftless area uplands; and the upland itself is simply a maze of minor divides meandering this way and that and converging toward the principal divide, all forming a billowy plain, itself rising and falling in broad and gentle undulations. The plain is not without accentuation, it is true; the escarpment of the Oneota limestone recedes from the rivers and breaks the plain about the confluence of the Oneota with the Mississippi; the Trenton escarpment is a noteworthy feature and generally easily traceable across Allamakee County and part of Clayton; and while the prevailing surface materials are the characteristic residuary clays which never interrupt but really emphasize the distinctive autogenetic topography, the rock configuration of the southwestern margin of the driftless area tract is sometimes masked by the marginal deposits of the loess, which mantles the valleys more deeply than the hills.

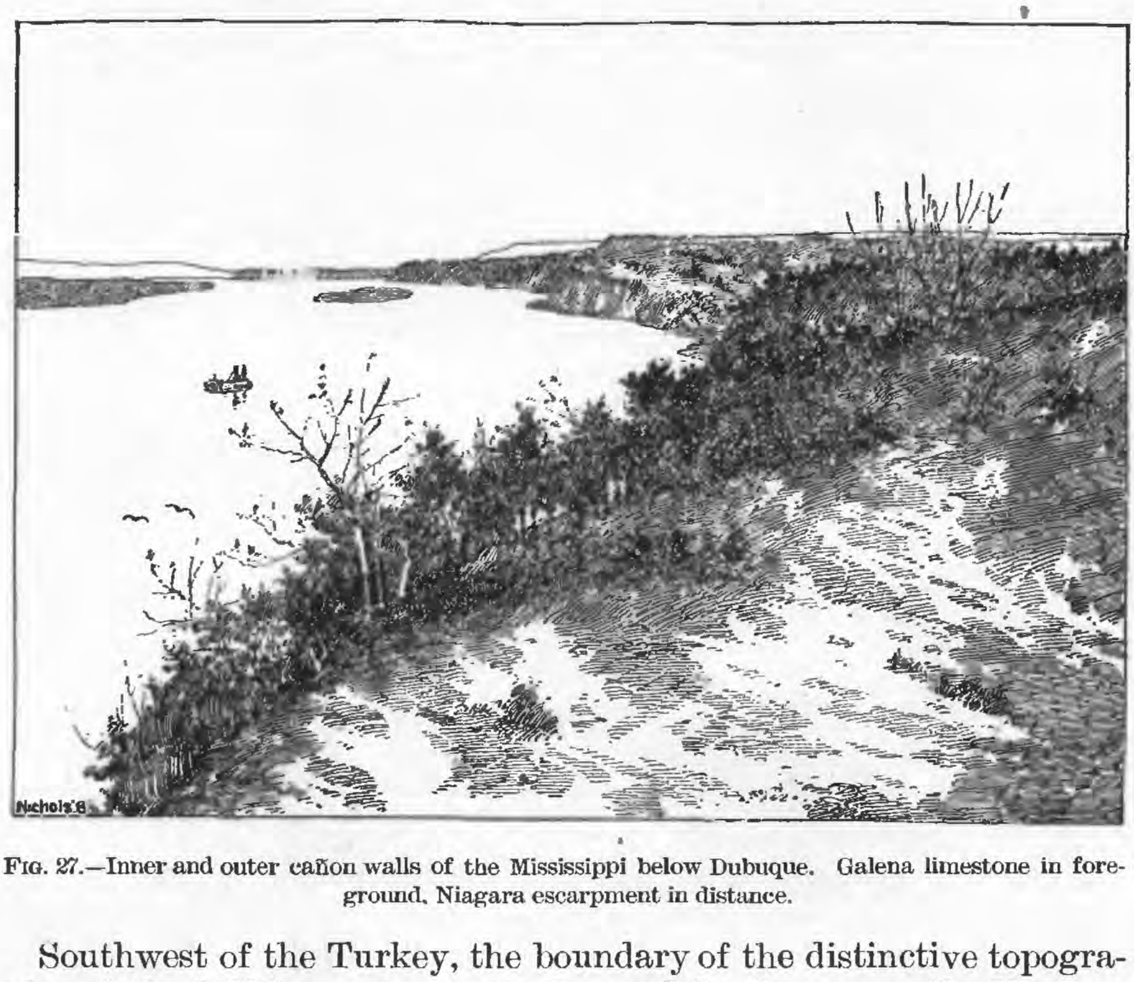


FIG. 27.—Inner and outer cañon walls of the Mississippi below Dubuque. Galena limestone in foreground, Niagara escarpment in distance.

Southwest of the Turkey, the boundary of the distinctive topography of the driftless area approaches and finally crosses the Niagara escarpment; for, although both ice sheets stretched eastward to that escarpment in this part of the State, their action was feeble and their effect upon the topography insignificant. So the prominent line of cliffs, spurs, and knobs forming the escarpment is a conspicuous feature of the southwestern part of the driftless area. Thus the Little Maquoketa and the Tête des Morts rise among rock-bound but

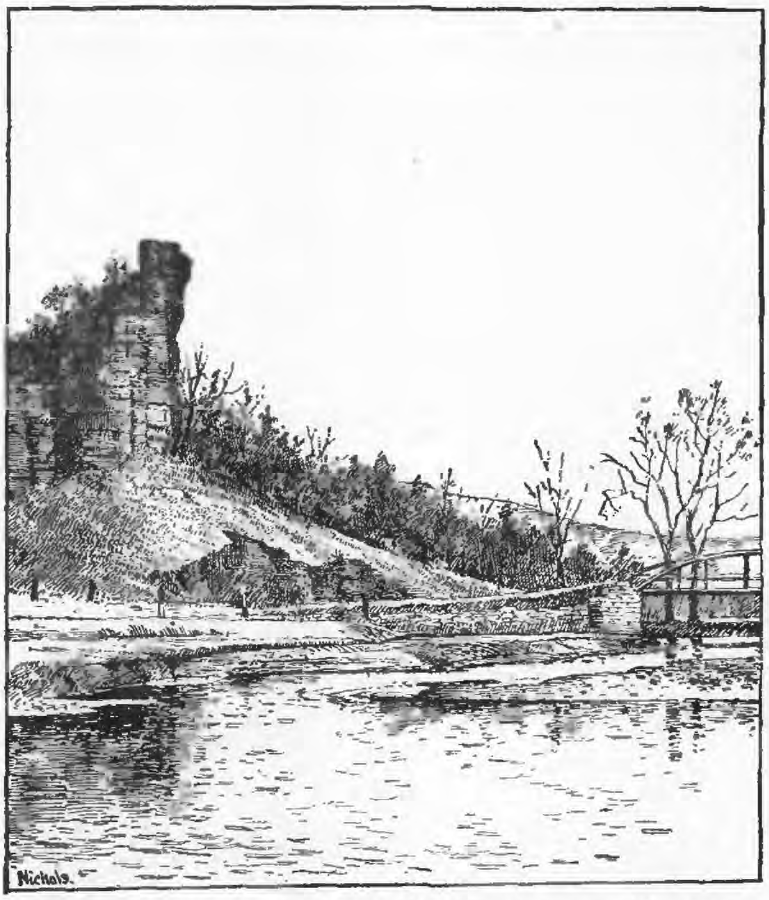


FIG. 28.—Erosion tower on the Little Maquoketa, near Durango.

rounded hills, as do Village Creek and Snymagil, and like them flow in narrow V-shaped gorges gradually increasing in depth and

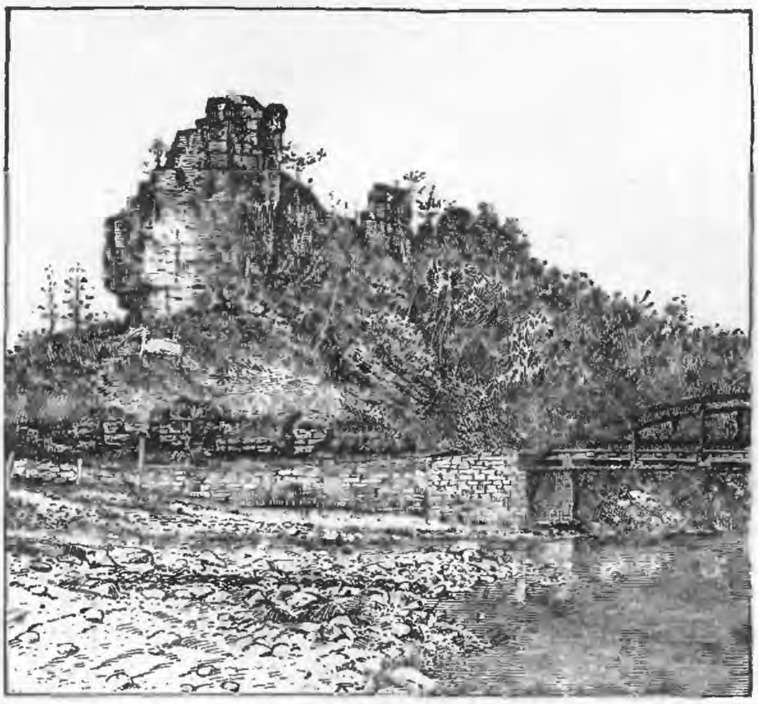


FIG. 29.—Salient on the Little Maquoketa, near Thompson's Mill, 4 miles northwest of Dubuque.

in the ruggedness of their sides; but half way to its mouth the cañon walls of the Little Maquoketa withdraw, the gorge first becomes U-shaped and then flat-bottomed, and at length its channel deepens into an inner gorge incised into the Galena limestone; and in this inner gorge, which exhibits all of the characteristic features of those of other driftless area rivers, it once found its way directly into the Mississippi. Then the mouth of the stream was just above the present position of Dubuque. But during some ante-Pleistocene shift of the great river the western bluffs were cut away, and the channels, greater and smaller, anastomosed some miles above the original confluence; when the larger stream withdrew, the smaller followed, building a delta plain like that of the Turkey, which has not since been invaded; and the channel between the old confluence and

FIG. 30.—Niagara limestone cliffs at headwaters of Catfish Creek, near Julien.

the new is a deep, rock-walled gorge, broad enough for a river, though occupied only by a spring-fed brooklet. This was "la coulée" of Julien Du Buque and his compatriots, and is "The Cooley" of the present; while the course of the brooklet is followed by "Couler" Avenue.

The headwaters of the Catfish gather on the Niagara terrane, but they accumulate so near the escarpment that they soon leap down to the smoother surface of the subjacent Maquoketa shale in a series of cascades; and the Tête des Morts, like the Maquoketa, has a double cañon, the outer carved in Niagara limestone, and the inner in the Galena limestone. The south-flowing tributaries of the Maquoketa occupy the homogeneous Niagara terrane alone, and the varying aspects of each, from source to embouchure, are identical with those of streams of corresponding size in Allamakee County, save that here the declivity is less and the slopes proportionately lower, while the valleys are more completely clogged with Pleistocene deposits.

The Niagara escarpment is a far more conspicuous topographic feature than those of the Trenton and Oneota formations, despite the higher local relief where the latter are best developed. The line

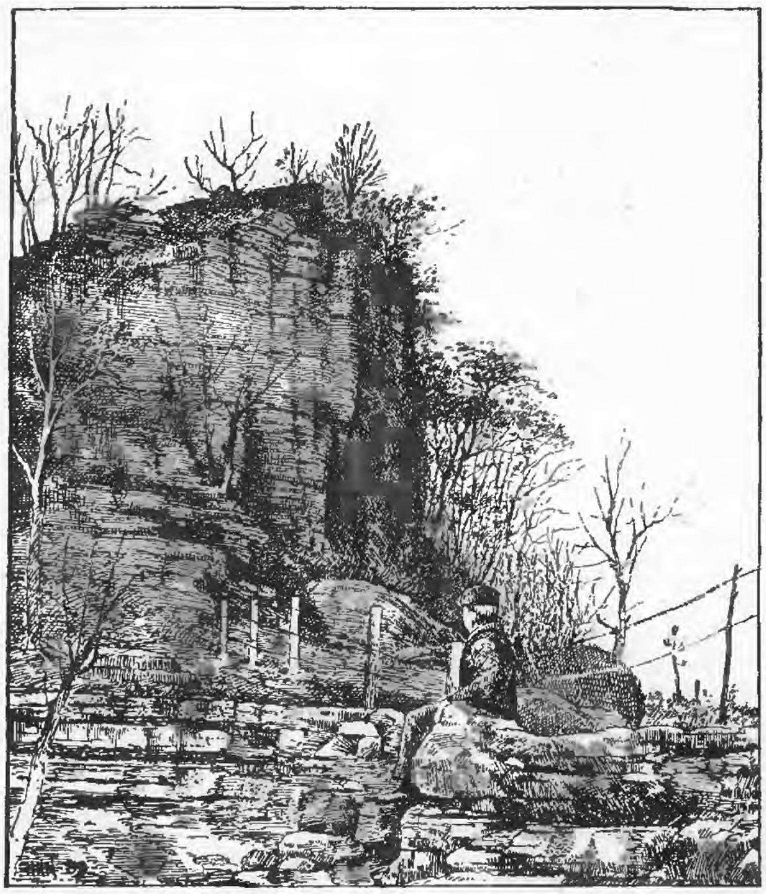


FIG. 31.—The hill where Julien Du Buque was buried—a typical cliff of Galena limestone near the mouth of Catfish Creek.

of bluffs and cliffs bounding the Niagara terrane on the northeast is everywhere conspicuous; the greater streams break through it in narrow gorges; the smaller streams generally leap down the precipitous ledges in cascades or at least in rapids; and even along the divides the slopes are too steep for travel and traffic, and the wagon roads wind here and there in ascending and descending them, while railways never cross the Niagara line save through the stream gorges. And not only is this escarpment exceedingly sinuous, stretching out in long salients on the divides and receding in deep dells excavated by the streams, but in the progressive recession of its cliffs it has left numerous outliers, some completely isolated from the main body of limestone, and a few lying miles or even scores of miles distant from the general escarpment. Sherrill Mound (in northeastern Dubuque County) is the best example of these isolated mounds in Iowa; and beyond the Mississippi, in Wisconsin and Illinois, there are many others, the most notable being Sinsinewa, 15 miles southeast, the Platte Mounds, 30 miles northeast, and the Blue Mounds, 80 miles east-northeast, all measured from Sherrill's.

The entire driftless area, of which only a small portion extends into Iowa, has been so recently and so admirably described by Chamberlin and Salisbury as to render it unnecessary to set forth its topographic features in detail. As recognized by these geologists, and indeed by all others who have studied its characteristics, the hills and valleys of the entire area were fashioned by the streams now meandering among and through them; and every character of the relief is the expression of some character of the streams; though some characters of the rocks are reflected in the streams.

Viewed from the standpoint of the systemist, the streams essentially belong to the autogenetic type. The Oneota and its neighbors, as far south as the Snymagil, are transverse to the strike of the outcropping formations, and, flowing away from the direction of dip as they do, represent the anaclinal class of Powell; and the Little Maquoketa and the Tête de Morts belong to the same type, order, and class of drainage; the south-flowing tributaries of the Maquoketa also flow transverse to the strike, but with the inclination of the strata, and so belong to the cataclinal class; while the Lower Turkey flows in the direction of the strike and is thus a longitudinal stream, and since it hugs an escarpment belongs to the monoclinal class; but the inclination of the beds is so slight that the structural element in this Powellian classification is unimportant if not insignificant, and the general configuration thus expresses agencies rather than conditions, and so approaches the pure autogenetic type. At the same time the terranes which the streams have sculptured are heterogeneous in the vertical dimension, and so the slopes are unequal. Again, the prevailing profiles are convex by reason of the excess of disintegration over transportation and the consequent masking of the rocks by superficial débris, and the surface is thus a stable one. Moreover, the topography is essentially adolescent, as indicated by the steep slopes of the valley sides and of the ravines in which the waters first gather, and so in degree of development the configuration must be placed between infancy and maturity, though nearer the latter stage; yet at the same time it is to be noted that by reason of a relatively recent accident—the ice invasion—the deeper valleys are undergoing sedimentation and the cañons of the greater streams are suffering lateral corrasion, and hence that while the configuration is predominantly immature in certain parts of the tract, it is already senescent and indeed replaced by constructive forms in other and more limited areas.

But the types and orders and classes of the systemist are meaningless save in so far as they represent the history of development of the surface; and in the driftless area of Northeastern Iowa they are pregnant with records of the past. In brief, this is the story told by the hills and valleys of the area when analyzed and classified:

Half way, one-fifth of the way, or one-tenth of the way back to the beginning of geologic time, the region comprising what is now the driftless area rose gently as a level plain from the waters of the Paleozoic ocean; as the plain lifted the American continent proper was born. The Appalachian Mountains of the east were elevated, and the Paleozoic Atlantis, whose débris was swept even to the new-formed land, disappeared; land was submerged beneath ocean, and ocean bottom was lifted to form land over a million of square miles; and the Paleozoic of the geochronist gave place to the Mesozoic in a cataclysm, far from world-wide it is true, yet the most extensive ever suffered by the American continent. The Appalachian Mountains rose to the eastward, the Laurentides with their outlying spurs to the northeastward, and the great plain which is now the Mississippi Valley dipped gently southwestward toward and beneath the receding sea. Rivers were born upon this plain, and, dividing and branching toward their sources, gradually drained its whole surface; and as the land continued to rise slowly and with many minor oscillations, they deepened their channels and gave rise to an autogenetic configuration which was the prototype of that yet existing in the same region.

At first the land rose slowly and displaced the waters of the Carboniferous sea without the development of deep cañons; then it rested, and even sank a few scores or hundreds of feet and the later Carboniferous waters broke up the old soil and swept earthy sandstones into the shallow valleys. Once more it rose and now more rapidly, and during the whole of Jurassic and Triassic time the land surface stood so far above ocean level that none of the formations of these periods even encroach upon the area. During the Cretaceous period it again sank, and the ocean broke up the soil and drowned the vegetation and swept earthy sands into the valleys for the second time, and the great fishes and saurians and the smaller creatures forming their food disported over the territory, probably as far as the present course of the Mississippi; but the Cretaceous sea soon retreated and the land was once more lifted, and has ever since stood far above ocean level. Whether or not the prototype of the Mississippi came into being during the pre-Cretaceous elevation no man knows; but its place must have been selected immediately after if not before that epoch, and perhaps has been ever since maintained without material change.

With the post-Cretaceous elevation—and indeed with each successive elevation of whatever date—the surface and the strata were tilted somewhat to the southwest, and so the courses of the streams and the forms of the hills they fashioned were modified, yet but slightly. The entire continental basin has always been one of feeble action on the part of the more potent agents of geology; but so long ago was the post-Cretaceous elevation of the land that they have wrought a wonderful work. Over much of the driftless area in Iowa, Cretaceous deposits were removed; then the outliers of the Carboniferous were carried away; next the Devonian limestones and shales, probably 200 or more feet in thickness, were swept out into the ocean; following this an average of some 300 feet in thickness of Niagara limestone was carried away so nearly that only isolated remnants of it remain as the impressive series of "mounds" in the three States; next in order the waters attacked the Maquoketa shale and carried away another hundred feet in vertical thickness; then the Galena and Trenton were assailed and, in the extreme northeastern part of the State, completely removed despite their thickness of 300 feet and over; and still the insatiable waters continued to devour the land, and bit by bit carried away the St. Peter sandstone, the Oneota limestone, and finally the Potsdam sandstone, with an aggregate thickness of 600 feet or more, over scores of square miles. In the extreme northeastern corner of Iowa, an eighth of a mile of strata has been removed from the hilltops, and a quarter of a mile from the valleys; over the 2,000 square miles of the driftless area in the State the average denudation since the Cretaceous submergence is at least a tenth and perhaps an eighth of a mile; and so from this area alone more than 200 cubic miles of solid rock have been carried by the Mississippi into the Mesozoic ocean and the Tertiary gulf to build up the Cretaceous and Tertiary formations of southern United States.

Perhaps the Mississippi was diverted from its original course along the bridge of "Cromwell's Nose" by the obdurate Niagara dolomite at some undetermined period; perhaps the ante-Pleistocene Mississippi was a pigmy stream draining but a limited area lying east of a great river flowing over the Cretaceous plains of the northwest directly into the Gulf, and west of another great river by which the present area of the St. Lawrence drainage was reduced; but in general the streams of to-day in the driftless area were born during late Cretaceous time and yet occupy the courses they then selected. The streamlets of to-day were the streamlets of the olden time, and the hills of to-day mark the sites of their prototypes standing about the close of the Mesozoic a thousand feet above their present summits.

By the stream courses of to-day the stages of degradation within the driftless area may be traced with some certainty and measured with some accuracy: When the Mississippi first cut through the Niagara escarpment in what is now the extreme northeastern corner of Iowa, the Oneota began, like the Tête des Morts of to-day, with its main stream cutting across the escarpment and its tributaries flowing at first down the dip but afterward turning along the strike to unite with it; and as the escarpment receded the ancient Oneota River maintained its course at right angles to its trend, and the tributaries tapped adjacent streamlets, and so its basin was both widened and lengthened. At a certain stage Village Creek, too, fell directly down the Niagara escarpment; but as the escarpment receded the drainage basin behind its verge decreased until the dwindling stream was unable to cut its channel through the cliffs, and so it came to drain only the front of the escarpment and in its upper course to flow almost parallel with it; and a little later it proved too small to enlarge the basin below the cliff line as rapidly as the cliffs receded, and Paint Creek came into existence, skirting the escarpment for many miles from the Mississippi. Then this drainage way, too, was left behind, and for a time its place was filled by Yellow River; and probably about this time Canoe River was the principal branch of the Oneota, and, like the Yellow, skirted the base of the escarpment. The general process was one of extension of the larger basins and curtailment of the smaller; and the larger streams maintained their courses at right angles to the escarpment, while the smaller were deflected to wash its base. The process was in some measure affected and facilitated by gentle undulations of the strata trending in the direction of the receding scarp.

Then as the surface configuration and attitude of the strata indicate—for the deposition record here is blank—there was a long period during which the land stood low, but yet above sea-level, during which the rivers were so sluggish that they preferred to seek new courses rather than to attack the cliffs, and during which the escarpment first receded toward, and then long formed, a divide. Within this period the Niagara escarpment reached the axis of the modern Military Ridge, which stretches from beyond the source of the Yellow River to the Mississippi some miles below its mouth; many smaller streams gathered on the gentle southwesterly slope of the divide, and united to form a river of such size that it has ever since maintained its course; and thus the Turkey came to lie in the shallow synclinal in which its present bed is made. Again the land resumed its rising, and the escarpment retreated beyond the divide; but the streams had become impressed with characters which they were unable to shake off, and so the old divide persists though the rocks which originally formed it have utterly disappeared. Perhaps the long persistence as well as the original determination of the divide between Yellow River and its southerly neighbors is due in part to the gentle undulation of the strata; but none the less the modern Military Ridge must mark a former position of the Niagara escarpment, and also a divide selected and fixed when the land stood low. As the escarpment continued to recede there was formed south of the Turkey another divide, which also persists to this day between the Mississippi and the Little Maquoketa. This ancient divide was almost certainly determined largely by a low anticlinal from which the waters were diverted in both directions; and the process of its origin is attested, and the origin of other ancient divides indicated, by remnants of the rocks which formed its original crest in the forms of salients and isolated "mounds."

The Little Maquoketa, the Catfish, the Tête des Morts, and the lower stretches of the Maquoketa, represent early stages of a sequence in which the Oneota has reached the closing episodes; and the northern branch of the Little Maquoketa with the abandoned distal portion of the stream ("The Cooley") and the North Maquoketa are infantile images of the ancient Yellow and Turkey Rivers respectively.

So the present condition of the southern streams and divides represents a past condition of those of the north; but the history is incomplete, since the uniform course of events of which the driftless area most eloquently tells was interrupted by the ice invasion, which enlarged some rivers and reduced others; obliterated a few streams and created several; modified many small divides, and turned half a dozen rivers over the culminating ridge and greatest ancient divide of Northeastern Iowa.

THE DRIFT BORDER AREA.

Skirting the driftless area on the southwest, there is a belt ranging from 8 or 10 to 20 miles in width in which the topography is of hybrid character. The configuration of this belt, indeed, comprises every variety of forms, from the round-topped polygonal hills and dendritic drainage-ways characteristic of the driftless area (and the similar configuration in miniature of loess areas) to the flat or gently undulating bowlder-dotted drift plains, the associated dome and basin forms of terminal moraines, and the longitudinally ridged and furrowed surfaces fashioned by ice in the southern-central part of the territory. Throughout its length the belt is a border land between distinctive types of configuration. The forms sometimes approach the water-carved type, and again some phase of the ice-fashioned type; it is a region of strongly individualized forms, which can seldom be generalized and which tell of complex and varied conditions of development; and its character can only be set forth by detailed description of some of the more prominent features.

The drift border belt coincides with the great ridge separating the nearly parallel Mississippi and Cedar-Iowa troughs of the general relief, and constitutes the highest upland and the most conspicuous topographic feature of Northeastern Iowa; but it maintains its character as a representative feature of this region of topographic paradoxes, and, despite its height and continuity, does not form a divide for any considerable part of its length. It is, indeed, cut through in different parts of its length by four considerable rivers—the Oneota, the Turkey, the Volga, and the Maquoketa—as well as by two or three large creeks.

The Oneota gathers in the gently undulating drift plain of the northern part of the territory, and enters the hybrid belt near the northeastern corner of Howard County; and within an hour's journey its valley is transformed from a broad, shallow, indefinite, and ill drained depression into a rock-bound gorge averaging half a mile in width, the walls of which rise higher than the drift plain whence the waters flow. At Lime Spring the Oneota is a bluffless drift stream; but at Foreston, three miles below, it is steeply bluffed and exhibits all of the characteristics of the driftless area rivers. Here, and indeed most of the way to Decorah, the bluffs and the upland into which they merge are mantled with loess, and the greater round-topped, polygonal hills into which the driftless area is sculptured are carved into the lesser round-topped and steep-sided polygons which everywhere characterize that deposit. Northeast of Cresco the Niagara limestone withdraws from the river banks, and in the terranes of the Maquoketa shale, the attenuated Galena limestone, and the thick shales of the upper Trenton, the bluffs diminish in height and sharpness of contour, and the stream again approaches its prairie-land character, particularly on the south; but the loess continues the prevailing superficial deposit, and minor streamlets abound, dividing into numberless ravines embracing numberless loess hillocks, and the northern bank frequently rises into prominent bluffs, as at Plymouth Rock (Pl. xxxiv).

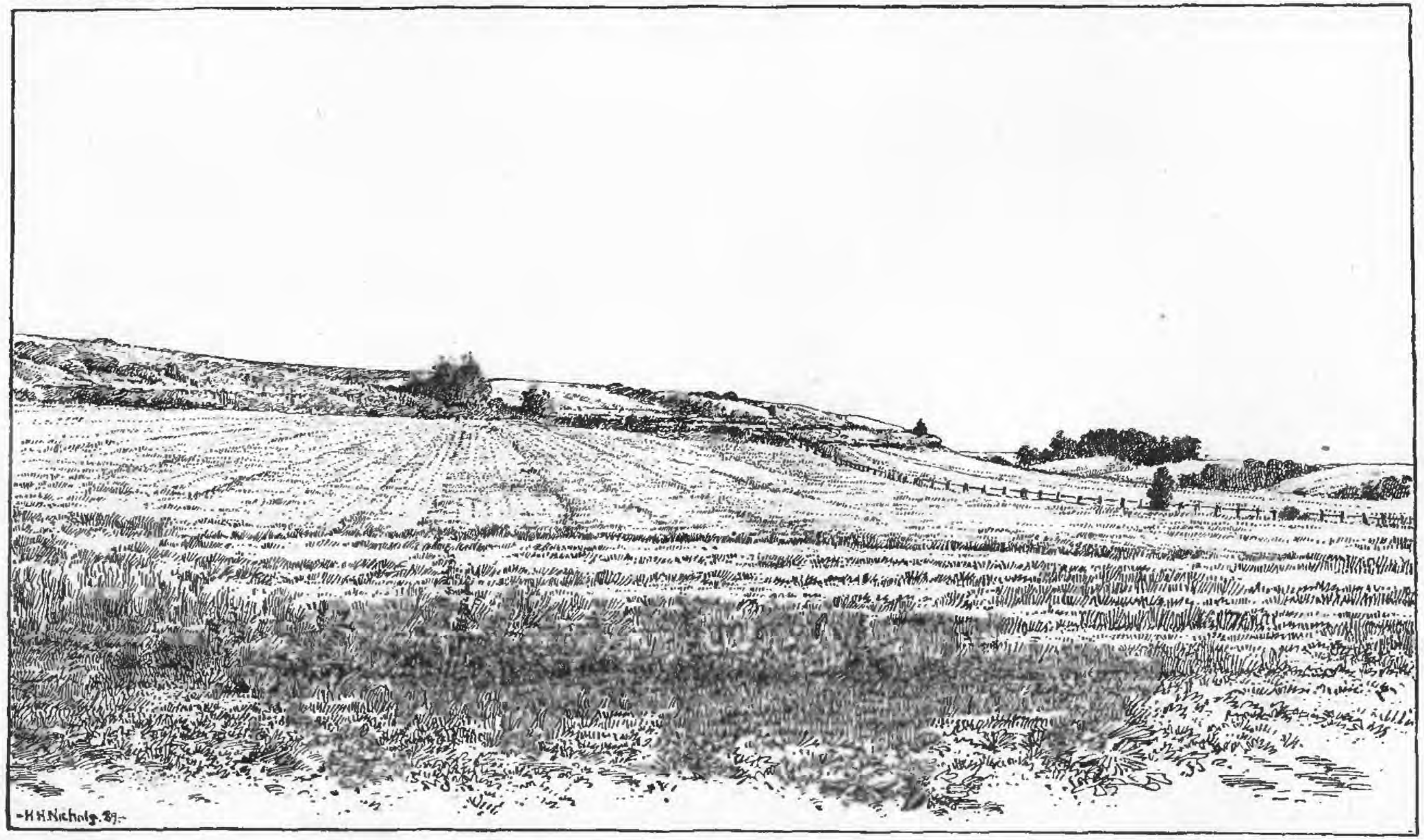
Southwest of the river, in western Winneshiek County, the surface is broken up into low, flat buttes overlooked by low, rounded scarps—the marginal cliffs and outliers of the Niagara limestone (here less than 50 feet thick), rounded and softened by the grinding and sometimes by the filling of the glacier; but the drift and the loess are both thin, and the limestone ledges are often within reach of the spade of the fence builder, and may even be touched by the plow. Between the buttes on both sides of the low scarp the surface is flat and often ill drained, and, between Cresco and the Oneota, Silver Creek is sometimes flanked by sloughs dotted with muskrat houses. Northeast of the river, however, the surface is more broken, the loess thicker, and marks of glacial action are seldom seen; but two miles northeast of Plymouth Rock one of the tongue-like drift basins so characteristic of the drift border belt farther southward juts down from Minnesota, forming the divide between the Oneota and Bear

Creek; and like the drift divides of the drift border belt generally, it is abundantly dotted with bowlders and overlooked on both sides by the loess-capped hills which flank the streams into which it drains.

Nearer Decorah the relief is higher, the slopes steeper, and mural precipices and cuspid salients of rock, naked or clothed with evergreens, jut out here and there on both banks of the Oneota and along its tributaries, particularly those flowing from the north. Here, too, appears an anomalous hybrid configuration (which is fully developed in the southern part of the drift border belt) in which the hilltops are ice-fashioned ridges and domes of soft and graceful contour, while the valleys exhibit the equally definite characteristics of autogenetic sculpturing; and here, as in the south, rounded glacial bowlders and beds of gravel occasionally appear on the uplands but are exceedingly rare in or totally absent from the intervening ravines and valleys, save in the flood plains of the larger streams.

Thus there is a vertical relation as well as a horizontal one between the two principal topographic areas and types (driftless and drift covered); about the common boundary the characteristics of the driftless area appear first at low levels and along the waterways, and the characteristics of the glaciated area die out at high levels and along the divides.

The divide between the Oneota and the Turkey is an elevated, smooth-topped ridge, broad and indefinite at Cresco, but narrow and sharply defined toward Ridgway, dropping rather steeply on the south and more gradually on the north into a strongly undulating plain traversed by autogenetic drainage—the crest of the divide displaying soft contours and occasional accumulations of glacial pebbles, while the contours of its slopes quickly sharpen and the coarser glacial débris diminishes in volume. Near Ossian the ridge divides, the lesser member veering to the northeastward between the Oneota and Yellow Rivers, and quickly losing its glaciated aspect within the driftless area, while the greater maintains its course, flanking the Turkey to the northwestern part of Clayton County, and more gradually exchanges its smooth for sharper contours. So even, smooth, and uniform is this ridge in Winneshiek County that the Niagara escarpment finds no topographic expression along its crest; but on its southerly slopes in the northeastern part of Fayette and in the northwestern part of Clayton Counties the streams quickly descend to the level of autogenetic sculpture and their profiles take the inequality due to vertical heterogeneity in structure, and the Niagara outliers form conspicuous features upon the subordinate divides. The most conspicuous of these outliers, Williams Mound, is the prominent hill of circumdenudation from which Roberts Creek and several smaller tributaries of the Turkey and the Yellow radiate.



WATER-CARVED VALLEY, WITH ICE-MOLDED RIMS, NEAR PRESTON.

The Turkey, like the Oneota, collects its waters among muskrat swamps in the monotonous drift plain of the northwest; but its passage into the rock-bound cañon of the border belt is less abrupt. Twelve miles southeast of Cresco the meandering scarp of the Niagara appears in the valley sides, the drift attenuates, and the rugged contours of autogenetic sculpture become apparent in the low bluffs, although here, as on the Oneota, the relief is slight and the slopes gentle on the adjacent uplands; and not until within a few miles of Fort Atkinson does the more constricted and steep-sided gorge begin. But the mantle of loess overlies the drift on both sides of the river and impresses its peculiar configuration upon the landscape; and so, almost from its entrance into Winneshiek, the Turkey may be assigned to the border belt. Loess hills flank the Little Turkey and Crane Creek to a point even farther westward, and these waterways must be similarly assigned.

Somewhat above Fort Atkinson on the Turkey, and somewhat below the confluence of the Little Turkey on the Crane, the bluffs rise suddenly into precipices and prominent salients, isolated knobs of Niagara limestone begin to diversify the surface, and while the river deepens its channel the general surface rises; and thus the relief is accentuated both above and below. So rapid is the transition that at Fort Atkinson on the Turkey and at Douglas (Massillon) on the Crane the sculpture of the valleys is in all respects similar to that of the Oneota, Yellow, and Turkey Rivers toward their mouths; and at the confluence of the streams near Eldorado this configuration extends to the summits of the bluffs, the soft contours of glaciation appearing only on the main divides to the north and south. Thence downstream the Turkey and its bounding bluffs and cañon walls belong to the driftless area type.

South of the Crane in northwestern Fayette County the surface quickly descends from the sharp-cut loess bluffs flanking the stream to a bowlder-dotted drift plain, which stretches eastward parallel with the stream about to West Union; and thence the divide between the Turkey and Otter Creek is loess-covered and quickly assumes the autogenetic type. But south of Otter Creek the western margin of the border belt takes on a new phase—the monotonous drift plain rises sometimes into irregular loess hills, sometimes into gracefully rounded lenticular eminences capped with loess but made up chiefly of stratified sand passing down into drift, and again into more irregular hillocks of bowlder-charged drift interspersed with shallow ponds, the whole simulating the typical moraine of the dome and basin type. The hillocks and associated ponds are irregularly distributed over an area of several square miles lying between West Union and Fayette; while the lenticular loess hills, occurring sometimes as isolated eminences and again as lines of paha stretching a little south of east, extend some distance farther down the divide between Otter Creek and the Volga. Still farther eastward, along the same divide, the loess thins and finally fails; and 10 miles east of Fayette there is a basin of bowlder-dotted drift completely inclosed by a rim of loess hills through gaps in which small streams find their way toward both the Turkey and the Volga. Still farther eastward the loess attenuates once more, and the divide assumes the uniform smooth-topped form exhibited by the Military Ridge; and this form is maintained to, and indeed constitutes the prominent salient of, the Niagara escarpment terminating 4 miles southwest of Elkader.

Perhaps the best illustration of the anomalous behavior of those streams which rise on the lowlying drift plain and thence force their way into the higher driftless area adjoining is that afforded by the Volga. Its headwaters gather in a well defined but shallow and monotonous basin, taking the general northwest-southeast trend of the drift plain, and from both directions they flow toward the center of the basin, uniting in its lowest point a few miles west of Fayette. Thence for two or three miles the waters meander through extensive sloughs with little declivity, and a mile west of Fayette they quickly enter a rock-bound gorge whose walls rise higher and higher until at Albany the river is confined in a narrow cañon 250 feet deep and perhaps a quarter of a mile wide. The cañon walls are coated with loess, and beneath the loess there is generally a mantle of drift; but solid ledges of Niagara limestone appear in vertical faces of 75 feet well toward the summits of bluffs rising 150 feet above the level of the stream at its entrance into the gorge, and 50 feet above the highest part of the drainage basin. The sculpture is autogenetic within the valley throughout the drift border belt, though ice molding characterizes the divides on either side of the river for many miles farther eastward.

The divide south of the Volga, from Brush Creek to Greeley, either coincides approximately with or falls a mile or two south of the loess margin. Here, as generally elsewhere, the loess is heaped upon the highest summits; and so the traveler upon the water parting looks upward to his left toward a line of paha and irregular loess hills, and downward to his right over a level, monotonous, ill-drained plain of bowlder-dotted drift in which the waters of the Maquoketa gather. But there is a method in the idiosyncracy of the loess hills: Sometimes, indeed, the loess highland juts southwestward in a salient about the headwaters of a streamlet; but more frequently the deposit begins as series of gracefully rounded lenticular swells, at first scarce rising above the drift level and gradually increasing in height and width to the southeastward until they unite to form a continuous loess-capped ridge 30 to 50 feet high and miles in length. These lines of hills and ridges have an east-southeasterly trend, and curve slightly to the left; and they blend with the body of driftless area loess by falling into the upland at small angles or by entering a salient marking a stream source.

These lenticular hills and elongated ridges are the first representatives of the paha so well developed over the tract of ridged drift to the southward; but here they may be referred to the drift border belt, as may be also the less conspicuous loess hills between Fayette and West Union illustrated in Pl. XLV.

Over the divide between the North Maquoketa and the small streams flowing directly into the Mississippi, and generally about the headwaters of the south-flowing tributaries of the former stream, the surface is loess covered, and the configuration assumes the round-topped polygonal aspect characteristic of the driftless area, although (as is usual in loess-covered areas) the elements are smaller than these developed from the indurated rocks. Here the local relief seldom exceeds 50 to 100 feet, only the larger streams cutting down through the superficial deposits to the underlying Niagara limestone.

But there are exceptions to this symmetrically dendritic sculpturing: Along the first 10 miles of the course of the principal branch of the North Maquoketa, and in some other cases as well, the loess is of limited thickness and a broad valley has been carved completely through it to the adjacent drift sheet, so that the uplands exhibit the characteristic loess configuration, while the streams meander through little undulating drift plains, sometimes dotted with bowlders though frequently veneered with alluvium. Again, while the next 20 miles in the course of the same stream generally marks the western boundary of the principal body of loess, the soft contoured lenticular loess hills constituting the distinctive feature of the adjacent topographic area to the southwest occasionally extend beyond it. Thus, near Dyersville, a line of these swells stretches east-southeastward to 3 miles beyond the river and village, when it is interrupted by a drift-basin only to reappear near Epworth, where the isolated and connected paha merge and pass into the loess mantle extending thence to the Mississippi.

Still more noteworthy are certain tracts of typical drift topography nearly or quite surrounded by elevated rims of loess. A conspicuous example extends from near Dyersville to Epworth, as a tract of bowlder-dotted drift plain of the ordinary type, 9 or 10 miles long and 2½ or 3 miles in maximum width, its longer axis being parallel with the loess ridges and lines of lenticular swells by which it is bounded and which digit its sides and extremities. Like such drift basins generally, this lowland tract forms a divide; and the waters falling upon it stand long in sloughs and then drain off to the east and west toward the bounding loess rim, which is broken by the narrow gaps leading into the gorges of the North Maquoketa and the Little Maquoketa respectively. A similar drift basin stretches eastward from Worthington, and drains through its southern rim into two widely separated tributaries of the North Maquoketa. A third, which is of considerable dimensions and especially notable by reason of the great width of loess by which it is separated from the continuous drift plain, lies in the southern part of Dubuque County. It is simply an isolated bit of drift plain, as level, uniform, and abundantly dotted with bowlders as any portion of the great drift area in the northwestern part of the territory, but completely encircled by loess hills rising 30 to 80 feet above its level; it is a divide between two considerable streams (Prairie Creek and Lytle's Creek), and the gaps connecting with these deep-gorged streams have been so far lowered that the basin is fairly drained; its margin is digitate, and the usual lenticular loess hills jut into it from the west and rise from its surface and pass into the bounding wall on the east; and on the north the basin is flanked by an exceptionally prominent loess-capped ridge.

In the 20 miles of its southerly course, coinciding roughly with the boundary between Delaware and Dubuque Counties, the North Maquoketa well exemplifies the paradoxical behavior of the streams of this tract of topographic paradoxes. The principal branch of the river originates almost at the verge of the Niagara escarpment, within sight of the Mississippi bluffs and within sound of the blast of the passing packet. At first it flows directly down the dip of the limestone beds in the direction of the steepest general surface slope of the entire territory; in 10 miles it diverges from this general slope, and for the 20 miles of southerly course it flows at right angles to the local development of that slope in such manner that it

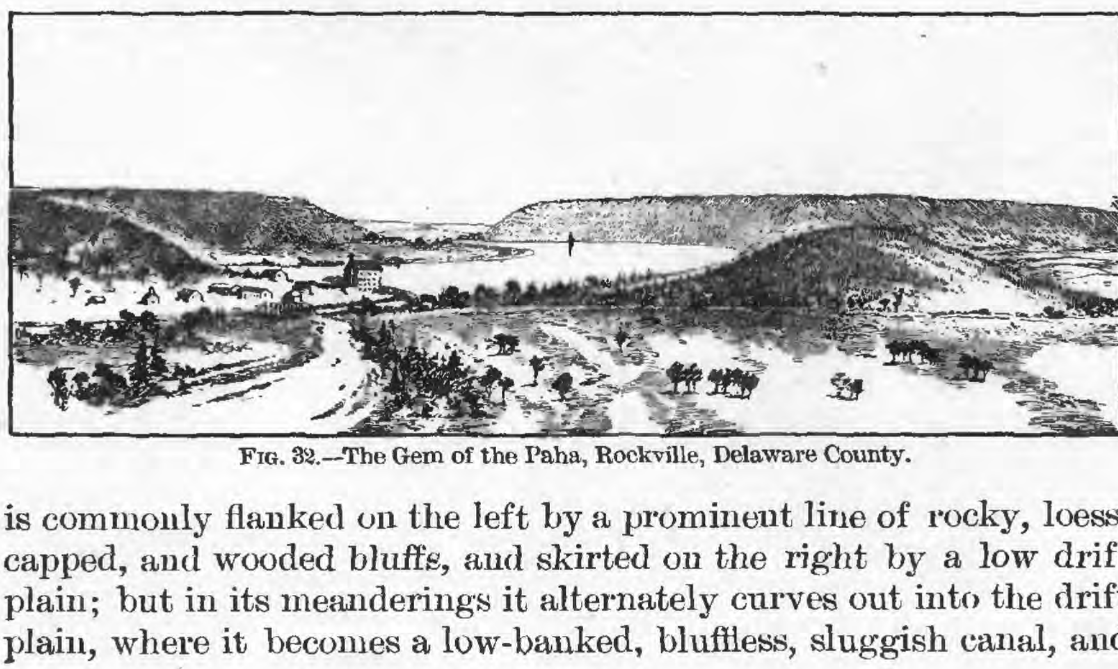


FIG. 32.—The Gem of the Paha, Rockville, Delaware County.

is commonly flanked on the left by a prominent line of rocky, loess-capped, and wooded bluffs, and skirted on the right by a low drift plain; but in its meanderings it alternately curves out into the drift plain, where it becomes a low-banked, bluffless, sluggish canal, and

WATER-CARVED VALLEY IN ICE-MOLDED REGION, NEAR PRESTON.

cuts into the rugged edge of the plateau, where it ripples over a rocky bottom between precipitous rock-bound walls 50 to 150 feet high.

At Rockville the incurving stream slices from the upland border a miniature plateau a mile or two across, and this isolated fragment of upland is rich in significant features. It is in itself a typical illustration of the paradoxical stream behavior and topography of the territory; it is partly crowned by a remnant of the probably Cretaceous Rockville conglomerate, the only one known within 100 miles; and a ravine in the isolated plateau leads down toward a small but wonderfully symmetric and graceful mound of loess—the Gem of the Paha, illustrated in Figs. 32 and 33,—and the relations between

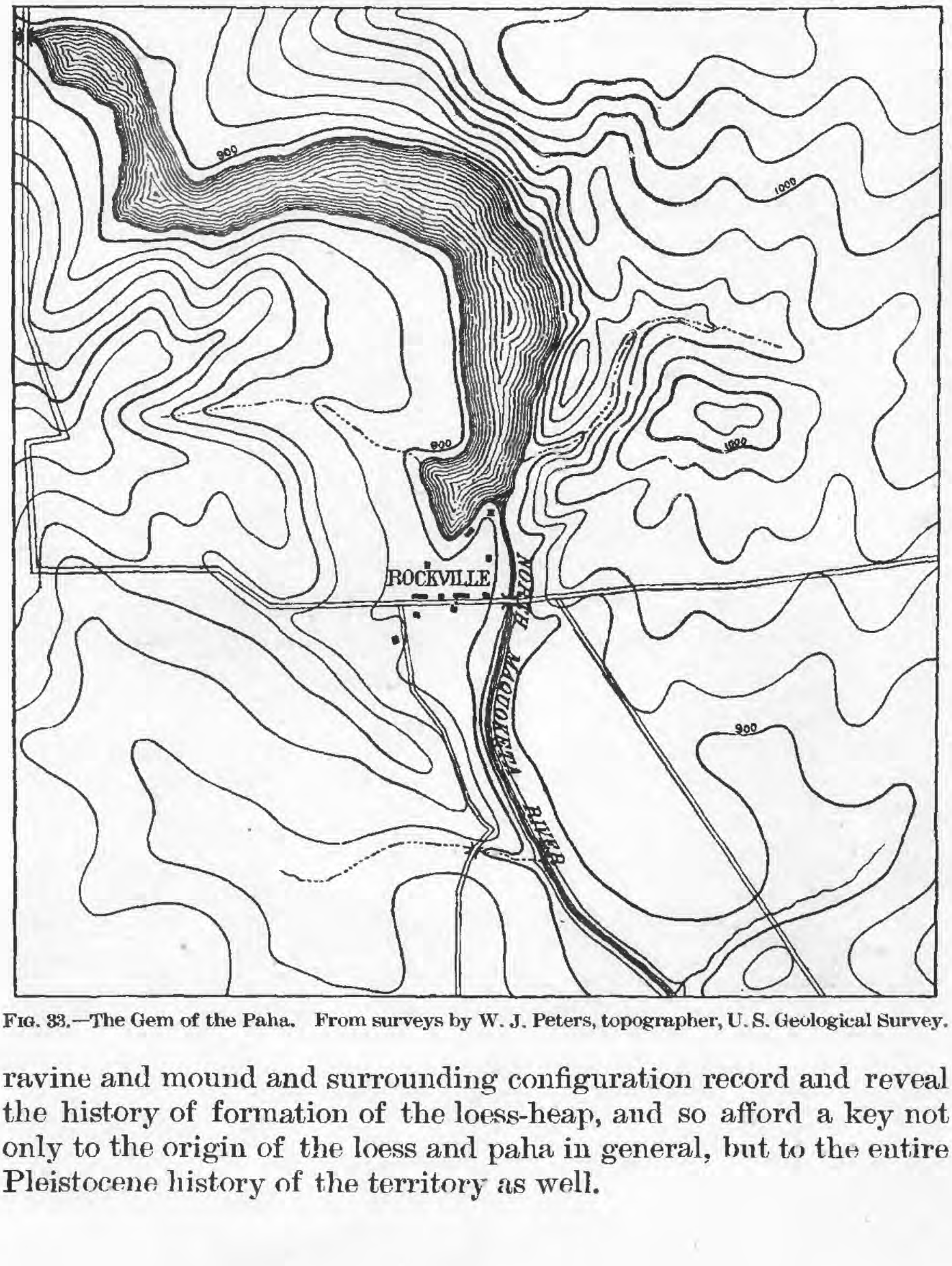


FIG. 33.—The Gem of the Paha. From surveys by W. J. Peters, topographer, U. S. Geological Survey.

ravine and mound and surrounding configuration record and reveal the history of formation of the loess-heap, and so afford a key not only to the origin of the loess and paha in general, but to the entire Pleistocene history of the territory as well.

Below Worthington the curves of the river into the plain become shorter and less numerous and the deflections into the plateau longer and more frequent, until in the southwestern corner of Dubuque County it turns at nearly a right angle toward the great Niagara upland, and thence occupies a steep walled gorge to its mouth.

The drift plain skirting the North Maquoketa on the west from New Vienna to 5 miles below Worthington is somewhat diversified by paha and tors. Near Dyersville there are a number of isolated outliers of Niagara limestone like those occurring in the vicinity of Cresco, but higher, sharper, and less regular in form and altitude; generally they are grouped in congeries, together forming elevated tracts which gradually rise to the eastward and really constitute parts of the general upland culminating in the Niagara escarpment, though cut off by the river; but sometimes (e. g., the knob a mile and a half west of Dyersville) they are completely isolated and rise like rounded rocky islands from a sea of sloughy prairie-land. Sometimes, too, such a limestone butte is connected with the upland to the eastward by a ridge of loess which appears to have originated in its lee and gradually extended and risen toward the greater loess area beyond the river; elsewhere lenticular loess hills and elongated loess ridges rise gradually from the drift plain and, extending to the eastward, unite in digitate form toward the river banks and completely conceal the older drift, which reappears no more save in the drift basins of Farley and Fillmore; yet in other cases, as for example, 3 miles southwest of Worthington, the lenticular hills are as completely isolated as the limestone knobs. In the same vicinity the drift plain is diversified in another way: within an area of half a dozen square miles there rise from the plain about as many hillocks of bowlder-charged drift clay, and associated with the hillocks are a few shallow ponds. These domes and basins are evidently morainic, yet they are not definitely connected among themselves, and the hillocks tend to pass into the smoother contoured loess hills; while the basins tend to shoal and spread into monotonous prairie-land of the drift plain type.

Like its northerly neighbors, the Maquoketa River collects its waters upon the drift plain, and then turns into and finally passes entirely through the loess-mantled upland by which that drift plain is overlooked. It is the largest of all of the rivers of like deportment at its entrance into the deep gorge intersecting the plateau; for although it passes through a number of elevated tracts of Niagara limestone in its upper course, it does not finally assume the autogenetic character until it enters Jackson County. Even then it at first repeats the behavior of the North Maquoketa in its upper reaches, and for 15 miles just skirts the margins of the upland and in some of its larger southerly bends breaks out for a little way upon a lowlying

LATE PLEISTOCENE CHANNEL OF THE MISSISSIPPI, NEAR GOOSE LAKE.

plain—or rather a trough 3 miles in width—bounded on the northeast by the great Niagara upland and on the southwest by a lower belt of loess-capped drift, the trough itself being generally drift lined. So its tributaries from the west—Bear Creek, Beer Creek, and lesser runs,—which meander obliquely across this lowland plain, finally fall into the Maquoketa through gaps in the generally continuous plateau in the margin of which the Maquoketa cañon is excavated. Although commonly floored with bowlder dotted drift, this lowlying plain, like its more northerly homologues, is diversified with lines of lenticular loess hills, particularly about its margins, where they jut out from or run into the general loess sheet; and elsewhere (e. g., along the lower stretches of Bear Creek) by projecting knobs and bosses and even considerable buttes or still more extensive and deeply ravined tracts of Niagara limestone, thinly covered by drift and only slightly rounded by ice work; but there are here no morainic hillocks.

Below Maquoketa, the river and its immediate bluffs take on the configuration characteristic of the driftless area, though the divides are somewhat masked by the mantle of loess and the valleys by the accumulation of terrace deposits. Toward their mouths the north flowing tributaries exhibit similar features, but toward their sources they gradually change in character from autogenetic to drift plain streams and assume the striking parallelism characteristic of the drift plain drainage—Deep Creek, the most notable example of this hybrid type of drainage, flowing 15 miles upon, and with the direction normal to, the drift plain, and then turning at right angles to enter the gorge through which it finds its way into the Maquoketa.

On the south side of the Maquoketa, on both sides of the north-flowing portion of Deep Creek, and about the headwaters of Elk River, occur the best examples of the anomalous topographic type more sparingly developed in Winneshiek County: Over a considerable area the waterways assume the dendritic form, and the sculpture of the valley sides is characteristically autogenetic; the whole surface is divided into irregular polygons by the streams, and the streams are overlooked by mural precipices and flanked by sharp cut salients of horizontally bedded Niagara limestone; and in the valleys east of Deep Creek little if any erratic material occurs among the superficial deposits. At the same time the summits and divides are rounded and stretch off to the eastward in gracefully curved dolphin-backs such as everywhere tell of ice action; and the testimony of form is corroborated by that of material, for occasional bowlders peep out from the upper slopes, and patches of gravel are turned up by the plow and exposed in the roadside gullies over the uplands.

This hybrid configuration is one of the most striking phenomena of Northeastern Iowa. Its eems anomalous, incongruous, almost incredible, that the hilltops should be molded into the long and gracefully rounded swells of rock turned out from the ice-mill, and that in the

FIG. 34.—Hybrid topography near Spragueville. Water-sculptured cliffs in foreground, ice-molded uplands in background.

same vicinity the older valley bottoms should exhibit the rugose aspect of water sculpture; but the fact is patent to any observer, and indeed forms the conspicuous topographic feature of the drift border region.

Another unique feature is developed in this part of the drift border area. From its elbow near Goose Lake to its mouth at Spragueville, Deep Creek occupies a disproportionately large cañon, which is lined with alluvium and flanked by precipitous bluffs of Niagara limestone 100 to 200 feet high. That the occupation of this gorge by Deep Creek is fortuitous is shown by the fact that the gorge continues southward to Goose Lake and thence across the Maquoketa-Wapsipinnicon divide and down the farther slope to the Wapsipinnicon River 8 miles above its mouth. About the water-parting this broad, flat-bottomed gorge is undrained, and Goose Lake itself is but the deeper part of a marsh several miles in extent from which Goose Creek and Brophy Creek flow in opposite directions. The gorge indeed is as definite and continuous and as sharply bluffed as is that of the Mississippi of to-day, 12 miles to the eastward; and it is the record of some of the most interesting episodes in the late glacial history of the region.

The diverse and hybrid features of the configuration of the drift border belt can not be generalized nor interpreted by themselves—indeed, the definition of the belt is not constant. In the north it represents the transition from the typical drift plain to the driftless area, and marks the termination of the drift and the dying out of ice molding, and the transition from ice carving to water carving is little obscured by adventitious deposits; in its middle portion it represents the same phenomena and relations, together with some morainic accumulation and an extensive accumulation of loess by which the relations of drift area and driftless area are masked, and in addition that paradoxical relation between drift and loess exemplified in the ridged drift area; while in its southern third it well represents the vertical as well as the horizontal transition from ice-wrought to water-wrought topography, and the gradual dying out of the drift toward the driftless area with no morainic accumulations.

Yet two salient facts distinguish the belt throughout its whole extent: From the Minnesota line to the tip of "Cromwell's Nose" it is a prominent crest from which the surface slopes strongly in both directions; and the drainage of the drift plain converges toward this elevated crest, and all of the rivers originating on its western slope escape through it in narrow gorges which they have themselves excavated. The great ridge successfully barred the Pleistocene ice sheet which had swept over mountain and valley and plain for many hundred miles, only to be overcome in its turn by half a dozen petty streams.

THE DRIFT PLAIN.

Seventy-five miles west of the driftless area, on the Iowa-Minnesota line, lies one of the limbs of the great terminal moraine stretching from Long Island to the Rocky Mountains. This limb is the eastern border of the long moraine lobe extending from central Minnesota to Des Moines. Its direction is almost exactly north and south, and it is thus nearly parallel with the margin of the driftless area; the Cedar, the Shell Rock, the West Cedar, Beaver Creek, and the Iowa gather among its hillocks, and after resting awhile within its sloughs and lakelets, turn obliquely toward the border belt upland, and for 200 miles continue in unavailing efforts to reach its crest. This limb of the terminal moraine lies just beyond the limits of the territory herein designated Northeastern Iowa, and requires no further notice.

Between the terminal moraine and the drift border belt, and between the Minnesota line on the north and a line approaching the Iowa River and cutting the Wapsipinnicon and the Cedar at mid-course on the south, lies an ideal prairieland, a magnified meadow with the purling rills enlarged to rivers, the ant-hills to muskrat houses, the gravel grains to bowlders huge as houses, and the rods measuring its breadth to miles. Roads run upon the land lines by which it is reticulated, turning neither to the right nor to the left, without cutting or embankment save in the causewayed sloughs or low bridge-approaches, for a day's journey; and the bowlder on the flattened divide casts its shadow for a furlong. In the driftless area, brooklets or larger streams take the place of milestones, and the surface is drained dry; but here each flowing stream is welcomed by the weary horseman as a watering station, although the surface may be half marsh.

To one fresh from the giant Rockies, the lesser Appalachians, the pigmy precipices and plateaus of the driftless area, even the faintly embossed paha of the ridged drift area, this featureless prairieland is the acme of monotony. But as the eye becomes accustomed to the scarce perceptible reliefs by which a sluggish drainage is determined, method appears in the monotony, and divides rise and creek basins sink with the development of a stimulated perception until the monotonous plain becomes converted into a system of waterways gathering among hills, crests, and plateaus as definite in imagination as those of montanic regions in reality; but the distribution of divides and water courses is peculiar. If the trivial effects of erosion be conceived to be obliterated, the surface is found undulating gently but irregularly, and taking the form of exceedingly broad and shallow basins and exceedingly broad and low domes—the horizontal element in both domes and basins measuring nearly as many miles as the vertical dimensions measure in yards. In the northwestern part of the tract the domes and basins are approximately circular, though both send out branches and spurs by which each is connected with its neighbors in an endless plexus; but in the southeastern part of the plain both elevations and depressions are elongated in a northwest-southeast direction, and indeed pass by imperceptible gradation into the ridged type of drift which prevails on the lower Cedar and Wapsipinnicon Rivers. Even to-day the surface is so little modified by erosion that the dilatory work of the waters of each storm and each vernal freshet illustrate the development of the secondary features: To-day the raindrops falling on each flat dome are gradually parted, and the film of water covering its almost imperceptible slopes moves gradually down toward the three, five, or seven basins by which it is surrounded; the sheet of rain water in each basin thickens with the flood from the environing domes and half submerges the grass stems and rises about the muskrat houses, and the basin is converted into a pond a furlong in extent and a foot in depth; then the waters gradually escape over the lowest point in the divide into a neighboring basin to form a larger pond, thence into a third, into a fourth, and finally, collecting in great volume, make their way by tortuous courses from depression to depression until the river is able to break down obstacles and take a more direct course down the steepest general slope. Such was indeed the genesis of the drainage of the region; and so the streams of the drift plain are exceedingly tortuous, particularly toward their sources; but the general flow is commonly in the direction of general slope.

It is true that toward the eastern margin of the area, where the great barrier of the Niagara upland rises, and in the southeastern portion, where this area merges into the next, the streams diverge from the prevailing slopes; it is also true that there is a great trough extending from near the northwestern corner to near the southern extremity of the territory, which is occupied at first by the Wapsipinnicon and Little Cedar Rivers, then by the Cedar with its tributaries from the west, and finally by the Iowa, and that in deserting this trough each stream successively diverges from the general slope; but these and other exceptions to the usual relation only serve to connect the drift plain of the northwest with the neighboring topographic areas.

Apparent exceptions to the tortuosity in drainage characteristic of the drift plain are found in Little Turkey and Crane Creeks, in Howard and Chickasaw Counties; but the exceptional character of these streams is inconspicuous, if not imperceptible, on the ground. Like the Wapsipinnicon and Cedar, they pass from basin to basin in shallow troughs flanked by semi-alluvial plains of sand, which attenuate and even merge laterally into the prevailing drift soil; and the bounding divides are commonly but little higher and more irregular than those 50 miles to the southwest. In the western portion of Fayette County, indeed, the surface is somewhat broken over the divide between the Little Wapsipinnicon and the headwaters of the Volga by a series of inconspicuous moraine-like hillocks, some of which are grouped in lines like the loess hills of the southeast; and similar hillocks occur in the central part of Grundy County north of Black Hawk Creek; but these departures from the common uniformity of divides are quite local.

Exceptions to the general uniformity of the plain are found along each of the larger rivers, which generally meander in low-banked canals through wastes of sandy alluvium half a mile to 3 miles in width; and these alluvial stretches are sometimes clothed with willows and other water-loving trees, and sometimes the adjacent drift plains support straggling copses of hazel and crab-apple or fire-stunted forests of scraggy oaks. Such bottom lands generally pass gradually into the low drift hills by which they are bounded; but sometimes indefinite and discontinuous terraces connect them, and again, the sand plains themselves may be terraced; and not infrequently the sands are blown into dunes on the leeward (northeastern) side of the plain.

Other and more notable exceptions to the uniformity of the drift plain occasionally occur along the larger rivers (particularly the Cedar) in the form of elongated uplands and narrow plateaus, wrought by the characteristic sculpture of the loess and clothed with hard-wood forests. The most conspicuous of these is the prominent plateau southeast of Waverly. This plateau stretches from the locally contracted flood-plain of the Cedar to the curious elbow of Quarter Section Run, save that it is cleft in twain by Baskin's Run and deeply dissected by a multitude of minor tributaries of these waterways; it is bounded on northeast, east, and west by steep scarps, and these scarps overlook the prairie land on all sides from heights varying from 25 to nearly 100 feet. Only less conspicuous is the elongated plateau, cleft longitudinally by the Cedar, in southwestern Mitchell County. In this portion of its course the river flows in a rock-floored bed, confined between rock-faced, loess-mantled, and forest-crowned bluffs; the precipices of the cañon walls rising above the general level of the prairie land on either side of the plateau. Lesser accumulations of loess, always affecting local elevations and always exhibiting the characteristic features of sharp-cut autogenetic sculpture and forest covering—features especially conspicuous in this area of flat prairie land—occur elsewhere on the Cedar and on some of its tributaries. And it is significant that all of these accumulations are evidently connected intimately with the drainage; for not only are they found along the waterways, but in most cases the waterways are of erratic deportment in their vicinity, as is well illustrated in the case of the Waverly plateau. But these exceptions to the general uniformity of the drift plain are only alien representatives of a configuration characteristic of a neighboring area—that of ridged drift—and constitute a bond of genetic relationship between the areas.

Viewed in its entirety the drift plain area is a land of flat, monotonous, sparsely drained prairie land of wide scattered and wide wandering streams, interrupted only by half wooded alluvial belts along the larger waterways, and by a half-dozen wooded islands of loess rising from its ocean-like expanse.

THE RIDGED DRIFT AREA.

Southwest of the driftless area with its distinctive border belt, southeast of the featureless drift plain, and northeast of the Iowa River save at its great elbow, lies a broad tract in which the topographic paradoxes of the territory culminate, and in which a unique configuration stands out in sharp contrast with that of all other portions of the earth's surface thus far explored. It is the land of the paha, of the river ridges, of lowlying divides, of aberrant river-courses, and of Titanic ice-molding so magnified that the flutings are hills, and the striæ valleys.

Despite the general unity of the tract, three types of surface appear: The first type is represented by the paha—the elongated swell of soft and graceful contour, standing apart on the plain or else connected with its fellows sometimes in long lines, again in congeries, and locally merging to form broad loess plateaus; the second type is a simple extension into this area of the configuration prevailing in the drift plain—i. e., a smooth plain, commonly of bowlder-dotted drift, rarely of loess; and the third type is the round-topped, polygonal block or biscuit-like sculpture characteristic of the loess, frequently sloping down into precipitous rock bluffs in the vicinity of waterways. The three types of surface are widely distributed and variously related, and so the tract is almost as difficult of general description as the drift border belt; but it is along the rivers that the distinctive topographic characteristics of the area are best displayed, and in connection with the rivers that these characteristics may be best described.

The Maquoketa enters the northwestern corner of Delaware County as a widely meandering stream of the drift plain type; but near Forestville its banks gradually rise into 50-foot bluffs, thinly loess-mantled as to summits and rock-bound as to bases. This shallow cañon is but 3 miles long; it lays open to view the western extremity of an irregular loess-covered and forest-clad tract rising 30 to 50 feet above the general drift plain level; west of the river the elevated surface quickly descends to the drift plain; and to the eastward the hills stretch off for miles and break up into loess ridges, some of which cross the divide to the North Maquoketa and so connect with the loess area of the upper Mississippi.

Toward Manchester the Maquoketa again becomes a drift plain stream, though round-topped loess hills appear occasionally on the west and more frequently on the east. Just below Manchester and the mouth of Prairie Creek, the surface again rises into a wooded loess belt like that 10 miles to the northward, but higher and more conspicuous; and through it the river meanders in a rock-bound gorge. These timber-clad, loess-capped hills, like those of the more northerly belt, stretch a little way to the westward of the river, and to the eastward break up into a line of paha crossing the upland between Delaware and Delhi and expanding into a considerable loess area on Plum Creek; and a few spurs jut out beyond that creek toward the loess belt skirting the Maquoketa, but all fall short of it and terminate on the lowlying divide—for here this divide lies in the line of the broad, indefinite depression extending from the Niagara escarpment near the northeastern corner of Delaware County almost directly southward to the great bend of the Cedar.

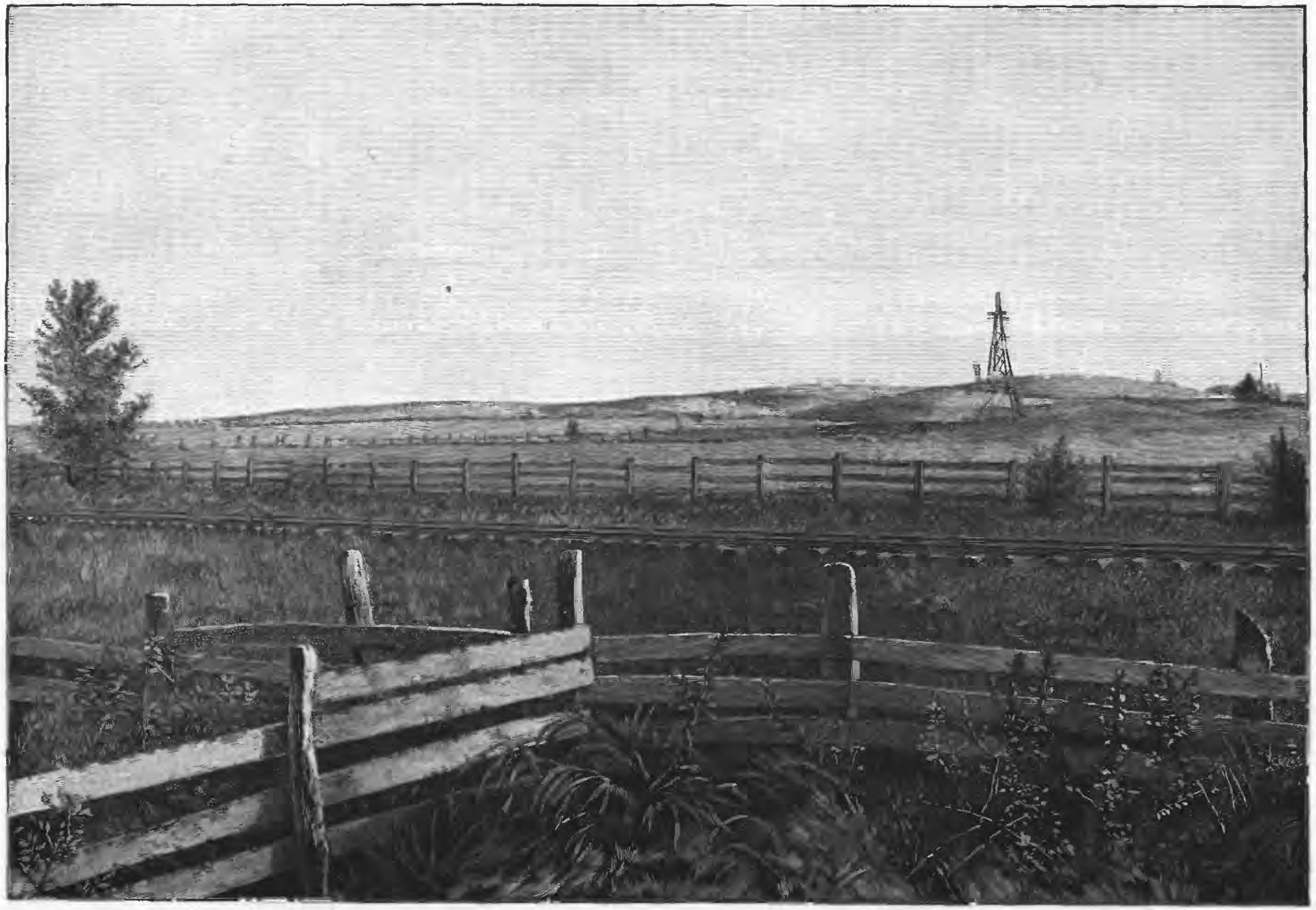
Three miles below Manchester the bluffs quickly decline, and the valley once more assumes its plain drift type, and the level wagon road of the flat prairie is causewayed up to the bridge spanning the river. Just southwest of this bridge there is a rounded, rocky knoll, from whose summit another reach of the river can be seen. Off to the northeastward stretches the loess-covered upland last noted; away to the southwestward a smooth expanse of drift plain extends to the horizon; southeastward, and in the line of the river for the last 15 miles of its course, the smooth drift plain gradually descends riverward into a drift-lined valley, low and sloughy, little above water level at the flood, dotted here and there with bowlders and flecked with half-drained pondlets; and to the left of this lowland there rises a wooded upland, loess-crowned as indicated by its forests and by its steeper slopes, but rock-lined as indicated by occasional crags peeping through the loess and by the peculiar verdure of rock-loving cedars; and this upland stretches far to the eastward and unites with that lying northeast of the bridge. But the eye seeks in vain for a river channel meandering through the low valley—in vain, because the river has avoided the valley and made for itself a rocky bed among the hills, going miles out of its way in the making.

Through the upland the waterway is a rock-bound gorge, its limestone cliffs rising above the level of the low valley to the westward; and the bordering hills are cleft by steep-sided lateral ravines. On the left of the river the loess hills stretch off to the eastward in a series of Titanic but motionless billows to and beyond Plum Creek; yet they do not cross the divide, though some of the spurs and outlying billows fairly reach its axis. And it is to be noted that about the confluence of Plum Creek with the Maquoketa, loess is heaped up in exceptional volume in a broad, forest-clad plateau, with extending digits and outlying swells of distinctive form.

The drift-lined valley lying west of the river opposite Delhi widens and inclines southeastward. Near Hopkinton, it is a broad, ill drained depression, locally known as "The Bay, sloughy in early days, and now traversed by causewayed roads." To the westward the surface rises gently into bowlder-dotted and obscurely ridged drift prairie; to the eastward the drainage ways escape through narrow gorges cut through the high, wooded loess ridge in which the Maquoketa cañon is carved; while to the southward the valley is invaded by digit-like spurs thrown out by the expanding loess ridge.

Midway between Hopkinton and Monticello, the Maquoketa tires of the hills and turns into the plain which it before avoided; but the plain is higher and rougher than before, and now and then long, loess-capped ridges sweep obliquely from the northwest to its flanks, and isolated or confluent loess hills rise on its eastern side; and here

LATE PLEISTOCENE CHANNEL OF THE MISSISSIPPI, NEAR GOOSE LAKE.



THE MONTICELLO PAHA.

and there the Niagara limestone crops out at the extremities of the ridges, or at the bases of the hills in precipitous cliffs. Near Monticello the plain is smoother for a space; but a few miles below, the river abandons a lowlying drift plain and swerves more and more to the left into a wooded upland stretching off toward and nearly to the Mississippi; and the sluggish prairie stream becomes a swift-flowing, cliff-bound river.

Below Monticello, the divide between the Maquoketas is generally loess-mantled; but now and then its axis sinks into a flat bottomed, bowlder-dotted drift basin surrounded by loess hills save at the narrow gates through which it is drained. Such an upland basin was Bowen's Prairie of early days—the Bowen of to-day.

West of Monticello on the Maquoketa-Wapsipinnicon divide, long paha stretch far southeastward, but fall short of the Maquoketa; for they are cut off by the indefinite trough connecting the Turkey and the Cedar, as are the loess ridges jutting from the Plum Creek belt a score of miles northward. Low these ridges may be, so that the railroad cuts through them and the farmer plows over them, but smooth and gracefully rounded are they always, so that the tourist discriminates them, the artist enjoys them, the topographer is impressed by them, and the geologist hastes to delve into their hearts.

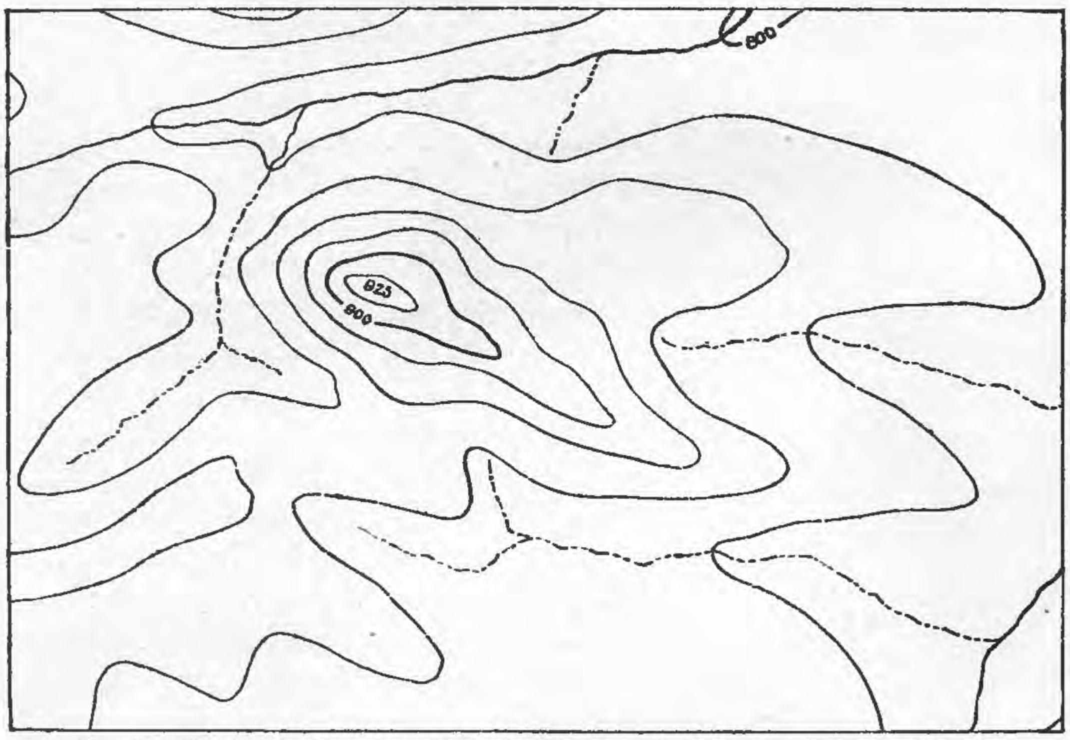


FIG. 35.—The Monticello paha. Scale, 3 inches=1 mile;[1] Contour interval=20 feet.

Their ever changing but always characteristic contours are illustrated in the triple paha three miles southwest of Monticello, shown in the contoured map constructed from minute surveys forming Fig. 35, and also in Pl. XL.

[1] This paha, with the contiguous country, is represented on a scale of 1:62,500 with 20 foot contours on the Monticello sheet of the Topographic Atlas of the U. S. Geological Survey.

Southwest of Monticello, such paha and lower ridges of drift diversify the plain all the way to the Buffalo; but only a narrow belt of loess crosses the Turkey-Cedar depression near Anamosa. Midway between Anamosa and Monticello, the lowlying drift plain forms a divide at first between the Maquoketa and Wapsipinnicon and then between the former and Bear Creek. This plain stretches off to the eastward in a gradually narrowing tongue extending almost to the eastern line of Jones County; and this paradoxical plain, which is at the same time a basin, and the parting from which the waters are shed to right and left, is bounded north and south by forest-crowned loess hills 25 to 100 feet high; and its boundary is made digitate by injutting fingers of loess, while its bottom is diversified by isolated paha rising ever in graceful profiles and well rounded contours like the bottoms of Titanic canoes inverted in the prairie sea. At Onslow the loess hills rise 75 feet above the drift tongue on the south, and 60 to 100 feet above it on the north; and the profile connecting the Onslow hills with the Maquoketa River (Fig. 55) cuts two of the inverted canoes of the interior. Here the drift tongue is not, however, the principal divide; for the Maquoketa robs the Wapsipinnicon of its legitimate territory, and true to the character of this land of paradoxes, sends a tributary (Bear Creek) down the general slope to within rifle shot of the Wapsipinnicon, and reduces the principal divide to an insignificant line of pygmy hills.

The Buffalo is a typical river of this area of anomalously placed plains and ridges; but the configuration of the slender ribbon of land drained by it represents two types: For a third of its length it is a prairie brook wandering through the basins of sloughs, and the narrow belts of willows sometimes skirting its shores cast shadows furlongs in length over the bounding plains when reached by the first rays of the rising sun; and everywhere the stream-course marks roughly the axis of a trough, albeit so shallow and broad that its concavity is scarcely perceptible.

In the middle third of its course the trough occupied by the stream contracts, and its sides alternate from low, bowlder-dotted plains of drift to little plateaus cut through by the river and faintly sculptured by its short tributaries, and perhaps clothed with scraggy oaks; now and then the plateaus send off finger-like ridges to the northwest perhaps miles in length before they gradually fade into the drift plain; while to the southeastward higher and steeper ridges, showing the characteristic profiles of the paha and the minor sculpture of the loess, stretch to still greater distances, some of them nearly crossing in oblique direction the low water parting between the Buffalo and the Maquoketa. In the lowlands traversed by the stream it still occupies the axis of the topographic trough in drift plain fashion; but in the alternating uplands the immediate river banks are high as and sometimes higher than the general prairie level.

In the lower third of its course the river generally occupies a shallow cañon cleft in the axis of a loess-capped ridge, sometimes quite down to the Cedar Valley and Niagara limestones. The cañon is only 80 to 100 or perhaps 150 feet deep, it is true, and its walls are never too steep for pasture land and seldom for the plow; but they are sculptured by wide branching ravines into characteristic autogenetic forms, and the slopes are shadowed by forests; and moreover from the summits the eye spans the bounding divides and falls upon the similar bluffs skirting the Wapsipinnicon on the southwest and the Maquoketa 15 miles away on the northeast; and one coming from the drift plain about the source of the stream is impressed with the rugosity of the surface. Here as elsewhere the lines of bluffs bounding the stream are occasionally cleft by gaps cut down below the level of the contiguous drift plains; and through these gaps flow the sluggish streamlets draining the sloughs and flat prairie lands which form the principal divides.

As the Buffalo is the type of the smaller, so is the Wapsipinnicon the type of the larger rivers of the ridged drift area; for it, too, drains but a ribbon of land, and its general course is nearly direct though slightly curvilinear.

In the upper half of its length the flow of the Wapsipinnicon commonly marks the direction of general surface slope, and its course defines the axis of a shallow drift plain trough; but about Independence its banks gradually rise until they approach the mean altitude of the contiguous plain and until they overlook the river in rounded and occasionally rocky bluffs 40, 50, even 100 feet in height; and here, as elsewhere in the territory, when the surface rises and the bluffs steepen the surface bowlders disappear, the subsoil changes from drift to loam with small pebbles and then to loess, and the land becomes forested with hard woods, sometimes scant and scraggy under the frequent visitation of forest fires, but on the lee-side of the water comprising many century-old oaks.

The wooded upland southeast of Independence is as high as the prairie land stretching away toward the Buffalo, and higher than that extending toward the Cedar; so that here, as over the Wapsipinnicon-Cedar divide for 75 miles, the testimony of the stream tributaries as to surface slope is true—the divide skirts the southerly shore of the Wapsipinnicon, as the drainage indicates.

Seven miles downstream from Independence the upland swings to the eastward of the mean river course to send out long spurs, some of which cross the divide to the Buffalo; and the drift plain on the west sinks into a low ill drained trough lying but little above river level like that in the course of the Maquoketa between Manchester and Hopkinton. Here as there the trough is exactly in the line of the river; but here as there the river avoids it and turns into the upland, where it occupies a rock-bound cañon whose cliffs are higher than the surface of the avoided valley.

At Quasqueton the plateau ends and the Wapsipinnicon resumes its drift plain type and swings back nearer to the line of the trough; but a few miles further the banks rise again and continue elevated to the confluence of the Buffalo at Anamosa; and in this stretch of 30 miles the river cleaves the axis of a ridge of rock, its ripples wash precipitous cliffs of limestone, and its waters are shadowed by deeply sculptured remnants of the loess ridge which rise twice as high above the waterway as above the bounding divides.

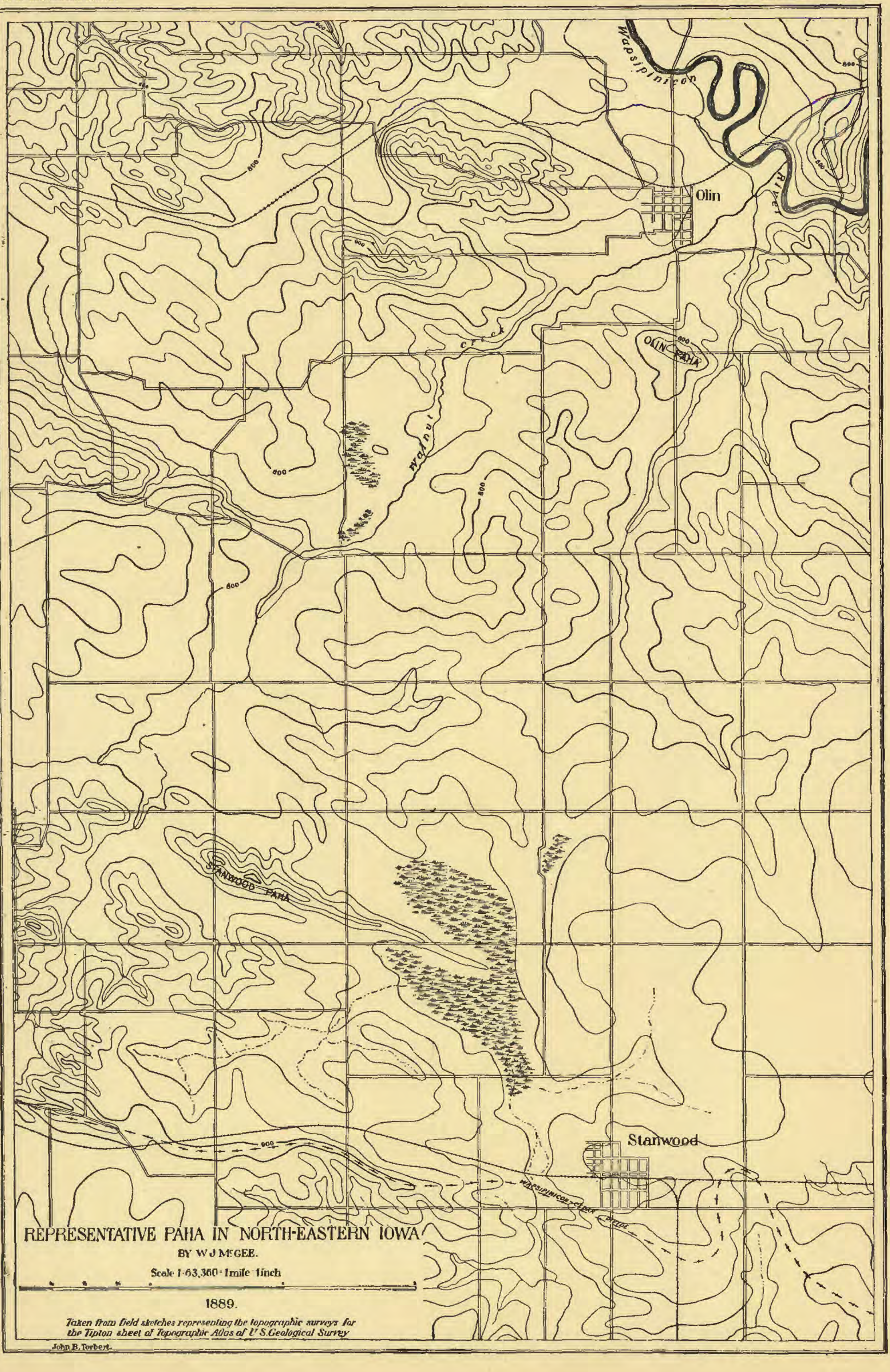
West and south of Anamosa the loess plateau divided by the river is complicated by paha coming in at a small angle from the west-northwest. Some of these paha are continuous ridges miles in length, while others are elliptical swells arranged in lines traversing obliquely the broad divide from the similar but larger loess ridge of the Cedar about Shellsburg; and the Wapsipinnicon ridge is no longer isolated, for the elevated loess mantle occupies much of the surface, not only southward toward and beyond the Cedar but also eastward and northeastward toward the Maquoketa. Below Anamosa, too, the channel occupies for 15 miles the great Turkey-Cedar depression by which Cromwell's Nose is marked off, and which is here exceptionally narrow and definitely bounded. So on both sides of the main waterway the minor configuration represents the characteristic sculpture of the loess, save where the Martelle drift-lobe runs down to the river banks at Olin and where the Newport-Hale drift basin blends with the river alluvium on the north.

Southeast of Olin the river hugs the northern flank of a high, loess-capped ridge through which many streamlets and one mill stream, originating in the drift plain to the southward, make their way in narrow gaps; but after washing the base of the ridge for 10 miles the river changes its course and turns directly into the upland midway between Oxford and Massillon. The lowlying plain deserted by the river stretches on to the eastward, with few interruptions for 40 miles, to the Mississippi between Clinton and the mouth of the Wapsipinnicon; it is bounded on the north by a prominent scarp of loess, sometimes 100 feet high; and throughout most of its course it is abundantly bowlder-dotted, just as are the wider plains of the northwestern counties, and so flat and low as to be ill-drained and haunted by the muskrat and the crayfish. Below its deflection, by Massillon and Toronto, the river hugs low cliffs of Niagara limestone; commonly these rise above the level of the drift surface to the northward; and above the rock the loess rises in high hills of sweeping contour marred somewhat by water-sculpture, each of which represents the termination and culmination of paha stretching off to the west-northwestward, sometimes only one, but again a dozen miles. The directions of these ridges are marked by the courses of the minor streams which flow in the valleys between them. The cliffs disappear from the riversides below Toronto, to reappear at Big Rock, for in this portion of its course the river just skirts the eastern margin of a rocky plateau of considerable extent overlooking by 50 feet the drift plain to the eastward and itself capped with another 50 feet of the eminence-loving loess; and a mile or two above Big Rock the river enters the plateau and slices off its eastern margin. Still farther southeastward the river appears to be deflected by the rocks, and again turning to the left, breaks out of the plateau and thence skirts the common margin of loess-mantled upland and bowlder-dotted lowland. South of Dewitt the alluvial flood plain of the Wapsipinnicon widens; for here the abandoned river channel cutting off the tip of "Cromwell's Nose" comes in from the north; and the sudden expansion of the flood-plain and the widening of the alluvium no less than the drowning of the smaller tributaries toward their mouths tell of a greater river coming down from the north than the one now flowing from the west. This broad, alluvium-lined flood plain does not stop at the present comparatively narrow channel of the Mississippi, but sweeps away southeastward as the great Marais d'Ogée of Illinois, and thence southward, southwestward, and finally westward in the disproportionately broad, alluvium-choked valley of Rock River to rejoin the far narrower channel of the modern Mississippi immediately below Rock Island.

The divide between the Wapsipinnicon and the Cedar is generally drift mantled; but it is not a uniform, monotonous plain like that of the northwestern part of the territory: Its monotony is relieved by the multitude of gracefully rounded lenticular hills and elongated ridges, the paha of the aborigines, embossed upon it. Sometimes these originate and again die out upon the drift plain in solitary fashion and, since they are commonly loess-capped and so naturally wooded, simulate canoe-shaped islands rising from a gently undulating sea of pairie land; again they extend in groups or lines from the elevated loess belt of the Cedar to die out upon the flat prairie within a mile or two or perhaps 5 miles; elsewhere they originate upon the flat prairie and gradually expand east-southeastward, to finally merge into the loess belt of the Wapsipinnicon; more rarely they completely span the divide from river bluff to river bluff, overlooking the Cedar on the northwest and the Wapsipinnicon on the southeast; and all, whatever their length, whatever the density of their forest mantle, whatever the thickness of their loess capping, however numerous their breaches of continuity, are sensibly parallel in each landscape. Yet the general direction in the northwest differs from that in the southeast by several degrees. Those of the northwest are parallel among themselves, and those of the southeast are alike parallel among themselves, and the intermediate ridges take intermediate directions; so that the system represents a slightly divergent and a slightly curvilinear series of corrugations.

The canoe-shaped loess ridges of the Wapsipinnacon-Cedar divide are exemplified by the paha near Stanwood and the shorter and broader Olin paha, as well as the neighboring elevations illustrated in Plate XLI. The Stanwood and Olin paha are not only interesting and typical representatives of their class: by their configuration and their relations to the drift plain from which they rise they limit inference as to the origin of the insulated loess deposits. It is a ready hypothesis that the paha represent remnants of a once continuous mantle of loess now nearly removed by erosion; but the contours of these paha are evidently not erosion contours, the hills are evidently not hills of circumdenudation. Moreover, the plain from which they rise is evidently not a plain of hydrodynamic degradation; the surface displays in all of its parts the distinctive sweep of ice molding; there are no characteristic water-cut channels within miles of the Stanwood paha, and the waters of storm and snow-melting find their way slowly through swamps or by seepage into distant waterways; there are no alluvial accumulations marking the positions of ancient drainage; the relations of the rivers and smaller streams on either hand are such as to demonstrate, through the principles of geomorphology, that the base-level has not been materially lifted since the rivers were outlined; the paha stand, one near a divide where erosion can never have been active; the other, with still more perfect form, near a river; the plain itself is of bowldery drift throughout and entirely without trace of loess except in the characteristic eminences shown in the map. It must be evident from inspection of the map, and it is perfectly evident from examination of the ground, that the drift plain retains the character impressed upon it by the ice, barely marred by subsequent erosion, and that the paha similarly express original characters, barely masked by the work of the storms.

The corrugations of the drift surface determine the positions of sloughs and the directions of smaller streams, and lead to that parallelism in the minor drainage which is perhaps the most striking feature of the drainage map. The ridging even extends beyond the limits of the loess; and in the northern and eastern parts of Cedar County, in western Scott County, and in northeastern Muscatine County, the drift is ridged as characteristically as, though less conspicuously than, the loess-crowned divide 50 miles northwest. Indeed, the entire surfaces for a thousand square miles in this part of the territory is thrown into a series of low, parallel drift ridges, perhaps but 5 and seldom more than 20 feet high, perhaps but a quarter of a mile though often 5 or 10 miles in length, a furlong to half a mile in width, and 1 to 3 miles apart; and within the troughs between these low ridges the waters gather and flow for miles before they find gaps through which they may escape.



REPRESENTATIVE PAHA IN NORTH-EASTERN IOWA

BY W J McGEE.

Scale 1:63,360 = 1mile 1inch

1889.

Taken from field sketches representing the topographic surveys for the Tipton sheet of Topographic Atlas of U. S. Geological Survey

John B. Torbert.

In the eastern part of Scott County the configuration takes on a distinctive character. In the southeastern part of the county, about Davenport, a uniform loess plain, as smooth, where not invaded by erosion, as if just fashioned by the waves of a lake, inclines gently northward toward Duck Creek; and the waters falling on the Mississippi bluffs, within a stone's throw of the river at Davenport, flow northward down the slope to the creek, and so, after a circuit of a dozen miles toward all points of the compass, back to the bases of the same bluffs on the river front. The loess attenuates and finally disappears on the creekward slope, and a bowlder-bearing drift is exposed along the smaller waterway in a half-mile belt. North of the creek there is another loess area, whose surface plane is not coincident with that of the first but nearly horizontal; and this area expands into the broad horse-shoe shaped zone flanking the Wapsipinnicon and Mississippi and skirting the drift lobe which forms the water parting between these rivers.

Toward the southern side of the drift lobe the loess gradually thins, as it does toward Duck Creek, and its characteristic sculpturing gives way to gently undulating bowlder-dotted drift prairie without definite demarcation; on the north the loess begins as a series of paha overlooking the drift plain by 20 to 40 feet, and the lowland streams enter and traverse the elevated tract in deep-cut ravines leading out to the broad Wapsipinnicon bottom; and to the eastward the common margin of drift and loess approaches sometimes the one and sometimes the other of these types.

The surface of this loess horse-shoe fringing Duck Creek, the Mississippi, and the Wapsipinnicon for 45 miles is sensibly horizontal (save in its nothern rim), and, though deeply ravined by waterways and storm rills, its uplands and divides blend in a horizon line definite, sharp, and smooth as the horizon of a waveless lake; yet comparison of altitudes at widely separated points shows that it inclines gently southeastward, while the analogous plateau between Duck Creek and the Mississippi inclines strongly north-northeastward. Thus the two surface-planes are far from coincident. But along one line the greater plain departs from its horizontality: The northern margin is tilted up 30 to 50 feet above the general level, so as to form a series of paha (as shown in Fig. 57); and beneath this upturned rim the Niagara limestone crops out in conspicuous cliffs, and the steep-coursed runnels embouching upon the Wapsipinnicon bottom have carved the cliffs and the paha into a line of autogenetic bluffs nearly as distinctive as those of the Mississippi in the driftless area.

Once the Wapsipinnicon-Cedar divide extended many miles east of its present extremity; but in the wanderings of the great river inaugurated by the ice invasions, this divide was cut off just as was the Maquoketa-Wapsipinnicon divide, save that in the one case the new channel was not subsequently abandoned. So, from the mouth of the

Wapsipinnicon to the mouth of the Rock, the Mississippi flows over rocky rapids in a narrow bed not yet enlarged to its needs, save when, during great freshets, a part of its waters follow the old course through the Marais d'Ogée and Rock River in Illinois. The bluffs of sandstone and limestone of the Coal Measures and the Cedar Valley and Niagara formations washed by the rapid waters are low yet steep and continuous, and tell of topographic youth. The swift current seriously impedes navigation at Le Claire and Rock Island; and here the river is without the usual broad flood plain. The only notable island of rock on the Iowa shore half blocks the new channel at the city to which it has given name (Pl. XLI).

The Cedar represents in a large way the relations of parts exhibited in minature by the Buffalo. At first a typical drift plain stream meandering about the axis of a shallow trough, it gradually increases in volume without materially changing its deportment (save at Osage, Waverly, and elsewhere, as already noted) until it becomes a broad and broad-bottomed river which long checked the current of pioneer population; but about Laporte City the immediate valley contracts and the bounding slopes rise until the river bluffs are sometimes the highest land within reach of the eye. A few miles below, the bluffs become wooded and assume the minute sculpturing characteristic of the loess, and the river assumes the ridged drift type.

As on the Maquoketa and the Wapsipinnicon, so on the Cedar, the river ridges curve more sharply to the left than the rivers, and the upland commencing about Laporte City bears away beyond Brandon village, leaving a lowlying drift-lined trough to the right. But the Cedar, like its fellows, avoids the valley and seeks the hills, and lengthens its course 5 miles and flows in a rugged gorge 100 to 200 feet deep to escape a direct natural channel 7 miles long. Five miles above Vinton the river abandons the loess plateau, which breaks up into a series of paha of southeasterly trend, and resumes its old course in the drift valley; but only for a few miles. Vinton lies in the valley, which extends with unbroken continuity to Shellsburg, Palo, and Cedar Rapids, and is occupied by the great thoroughfares for travel and traffic by both horse and locomotive; but the river turns perversely out of a ready-made bed scarce 40 feet above its flood (as shown by detailed topographic surveys reproduced in the hypsographic map forming Pl. XLIII) and into a rock-ledged plateau 200 feet in height, flowing through 18 miles of rugged upland to avoid 9 miles of level lowland. Here, as toward Brandon, the river follows the plateau until it begins to break up into paha stretching out toward the water parting and the Wapsipinnicon; and then it returns to its old course. Below Palo, the course of the Cedar is more regular than in the middle reaches; but here and there it departs from its general direction, and always to avoid lowlands and enter higher lands; and commonly its immediate bluffs rise higher than the bounding divides. Wherever this is true it is also true that the surface deposit is loess, which is as usual free from bowlders, clothed with forests, and sharply sculptured into a characteristic configuration of small horizontal elements. So behaves the Cedar from Laporte City to its great elbow at Moscow.

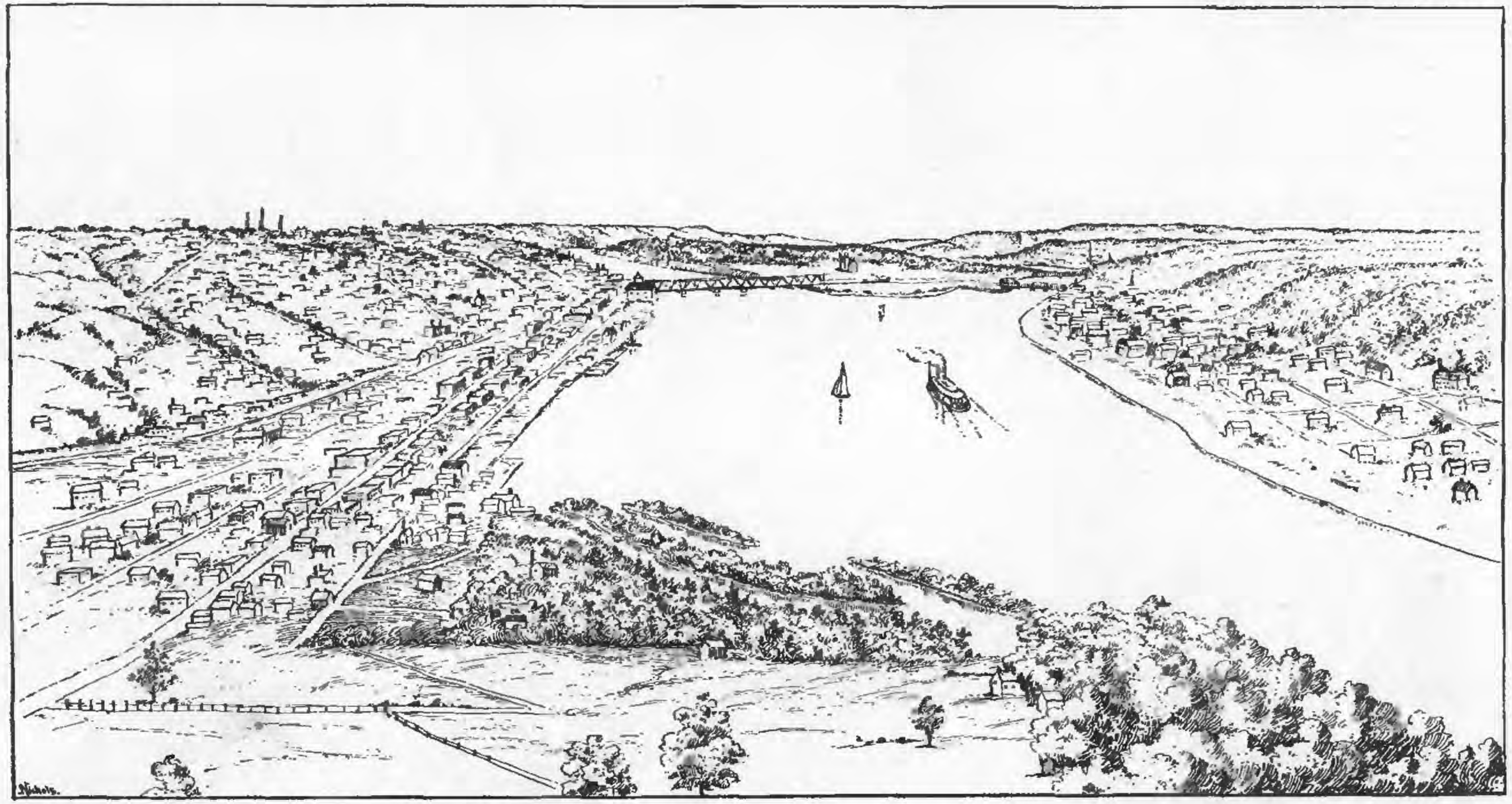
Three miles south of Mount Vernon, the rocky cliffs called the "Palisades" rise nearly as high as the divides in either direction, and from the higher summits the wooded bluffs of the Iowa can be seen to the right and those of the Wapsipinnicon 20 miles away to the left. At Cedar Bluff there is a knob of Niagara limestone so obdurate that the ice mill failed to grind it down, and the Cedar has gone out of its way to carve a cañon through the center of the knob, leaving a lowland of drift on the left and a still lower trough of ante-Pleistocene alluvium a mile wide on the right—a trough so low and flat that freshets have flooded it even since the plowing of the fields. At Rochester the hills immediately overlooking the river are the highest lands within sight, and the loess plateau on the west bank inclines away from the river and merges gradually into the drift plain dividing it from the Iowa River. Even at Moscow the river hugs and half circumscribes a loess-capped knob of Hamilton limestone 100 feet high, while 5 miles of lowland stretch away from its opposite bank; and at a dozen other points it displays the paradoxical behavior of the ridged drift rivers.

The Cedar bottom begins to widen rapidly a few miles below Rochester; Sugar Creek enters the bottom 5 miles above its confluence with the river; the flood plain is 4 miles wide at Moscow, all on the eastern side; and below, the widely flaring river bluffs embrace a wonderfully smooth but faintly terraced plain 6 to 10 miles wide, stretching from the elbow of the Cedar to its confluence with the Iowa—a plain in which the terraces are miles in extent to each yard in height and in which each scarp is invisible in the distance from that of the next lower member. Thus the stretch of river below the Moscow elbow stands by itself.

Over the Cedar-Iowa divide the configuration generally reflects that of the next great divide to the northeastward. There is an extensive, gently undulating plain of bowlder-dotted drift rising here and there into ridges miles in length, sometimes of drift but generally loess-capped and wooded, which determine the courses of the minor streams. But these embossed ridges are not parallel with those between the Cedar and Wapsipinnicon—they everywhere trend in a more southerly direction, and the curvature of the series to the eastward from their inception in the northwest to their termination in the southeast is less decided; yet the two series and those on the Wapsipinnicon-Maquoketa divide together combine in a wonderfully symmetric system of approximately parallel yet slightly divergent and regularly curvilinear corrugations. Some of these are indicated in the map of part of the ridged drift area forming Pl. XLIII; and so many of them are loess-crowned that their arrangement is fairly shown in the map of Pleistocene deposits forming Pl. XLVI.

Between the Cedar and the Iowa there are a number of erratic streams which are at first parallel with the principal rivers of the region, but which soon depart from the prevailing direction of flow and swerve more and more to the left until their waters run directly against the prevailing surface slope of the region and fall into their principal at right angles; and the land forms by which they are flanked are as erratic as the streams themselves. Black Hawk, Wolf, and Prairie Creeks are the principal examples; and the last is the type of the class. Prairie Creek originates in a representative ridged drift plain of southwestern Benton County, and the small feeders of its freshets as well as some of the larger streamlets take directions determined by the ridging; but as the waters gather in volume they bear southeastward in partial conformity to the general surface slope, and flow parallel with Salt Creek as if to fall into the Iowa through the small mill stream called Coon Creek; and it is in this portion of its course, where its banks are alike gently sloping prairie land, that "Prairie Creek" finds its name. But 5 miles from the Iowa bottom the creek turns sharply to the left and flows parallel with that river; and meantime its left bank rises and becomes more rugged, and its right bank sinks and becomes smoother, and the Iowa-Prairie divide is but a mile or two from its channel and so low as to be scarcely perceptible. Such is the stream at Blairstown and Watkins. Still farther downstream the left bank increases in ruggedness and at Norway is transformed into a line of cuspid salients overlooking the stream from 75 to 150 feet above its level, while smooth prairie land slopes gently down to the water's edge on the opposite side; and when the cuspid salients are examined, each is found to be the termination and culmination of a paha rising from the drift plain 1 or 3 or 10 miles away to the northwest and gradually assuming a capping of loess and a clothing of forest as it approaches the stream. Still farther eastward the spurs increase in height and finally merge into the loess tract flanking the cedar above Cedar Rapids. Wolf and Black Hawk Creeks are similar, save that the left bank bluffs are less frequently loess-mantled and forest-crowned.

In the upper portion of its course, beyond the limits assigned to Northeastern Iowa, the Iowa River, which rises among the ponds and lakelets of the terminal moraine and has its early course determined thereby, assumes the plain drift character displayed by the upper Cedar and Wapsipinnicon. This character is maintained to the Second Correction line (latitude 42° 30′), where the Iowa is transfigured



CONTRACTED GORGE OF THE MISSISSIPPI AT DAVENPORT AND ROCK ISLAND.

even more suddenly and completely than are the Maquoketa, the Wapsipinnicon, and the Cedar in about the same latitude. Between Iowa Falls and Eldora lies an ill drained, swampy drift valley in the direct line of the river above and below, its extremities measuring 13 miles apart. But the river turns sharply to the left near Iowa Falls, deserts the lowlying drift valley, and enters an elevated tract of Coal Measure sandstone mantled with loess and crowned with forest. Through this upland it has carved a gorge 18 to 20 miles in length and 100 to 200 feet deep; and at Steamboat Rock and other points the cañon is narrow and rock-bound. At Eldora the river returns to the lowland, and thence to Marshalltown its course marks the southwestern margin of an irregular loess-covered plateau terminating at Toledo and Tama.

Throughout most of the territory mapped the banks and bluffs of the Iowa represent the loess-drift type; yet in a part of its course it turns out of its proper topographic region and a lowland plain to enter at the same time the Ridged Drift area and a great loess-capped and rock-lined upland. This is in northern Johnson County.

South of Blairstown, Watkins, Norway, and Fairfax, the surface rises gently and uniformly from Prairie Creek to a low indefinite divide 1 to 3 miles south of the channel; here it becomes differentiated into flat plains and flat-bottomed valleys inclining toward the Iowa, and elliptical knolls or elongated ridges which rise relatively and sometimes absolutely to the southeastward; then the eminences expand and the plains contract until the former unite in the loess-mantled and wooded upland skirting the northern bank of the Iowa River, and the latter are transformed into gaps through which the south-flowing streamlets find their way to the river. So this upland is digitate on the north; but about Western College and thence to and beyond Solon the boundary is trenchant and generally marked by a forest-clad scarp of loess 40 to 80 feet high overlooking the lowland divide—a scarp readily visible from the higher bluffs of the Cedar 10 miles to the northward. Near Solon the scarp turns southeastward and, passing by Elmira, stretches off toward the headwaters of the Wapsinonoc, gradually losing its sharpness of outline as the drift of the adjacent plain becomes loess-like above and surface bowlders disappear. This 50-mile scarp, at first digitate, then sharp cut, and then indefinite, is the northern boundary of a continuous belt of loess 1 to 6 miles wide flanking the Iowa on the north from Luzerne to Elmira; and along it the minor topography is a combination of the graceful curves of the paha and of the sharper contours of water-sculpture.

The southern boundary of the same loess belt is definitely marked by the broad Iowa bottom from near Belle Plaine to a few miles below Amana. About Amana the loess margin is marked by a low plain, at first alluvium-veneered but gradually changing to bowlder-dotted drift, which widens slowly to a point midway between Western College and Oxford, and then expands rapidly to 5 miles or more at Roberts Ferry, where the river turns from the lowland into the upland, and rock-ribbed, loess-capped bluffs rise between. The slice of the upland thus cut off by the river forms a scarp, sometimes trenchant, sometimes digitate, and again undulating, extending from Roberts Ferry half way to Iowa City, where it recurves upon itself in a complex digitate loop and returns to the Iowa bottom north of Oxford.

So, where it encroaches upon the ridged drift area the Iowa River half circumscribes a tract of bowlder-dotted drift which is completely circumscribed by loess; and, as usual, the drift surface is a lowland, while the contiguous loess surfaces are uplands rising 40 to 100 feet above the lowland level. The drift basin is indeed so low that the waters of the Iowa flood parts of it during freshets; and it is ill drained, marshy in places, and, flecked by lakelets and ponds which scarcely find outlet to the river by which they are almost overshadowed. From the head of the basin, 5 miles west of Roberts Ferry, to its foot a few miles above Coralville, no part of the bottom of the basin is more than 60 feet above the freshet level of the Iowa River; yet the tortuous cañon by which the river has chosen to dissect the upland is 200 feet deep on the average and 275 at a maximum, and cliffs of Devonian limestone capped with Carboniferous sandstone rise 150 feet above water level or 100 feet above the surface of the drift lining the basin; and the cañon is 20 miles in length, while the lowlying basin which the river avoided in order to enter the upland is but 11 miles across. This bit of lowlying drift plain is well known locally as the North Liberty basin. From it have been brought the huge bowlders guarding the campus and commemorating the classes of the State University at Iowa City.

The loess belt into which the Iowa turns at its great elbow stands far above base level, and is deeply sculptured in autogenetic fashion by a multitude of labyrinthine ravines, and the score of tortuous streamlets which they unite to form. This minor configuration is representative of that of the loess everywhere along the margin of the driftless area, in the bluffs of the Maquoketas, and upon the Wapsipinnicon and Cedar outside of the area already mapped topographically; and this typical configuration is well shown in the accompanying hypsographic map (Pl. XLIII in pocket) of a representative topographic area.

Black and white blend in gray; hill and valley unite in a single surface; and the diverse and antagonistic topographic features of the ridged drift area may be combined in a conception which will be truthful in a general way, even though the minor and significant detail be completely lost.

Let the tract be conceived as a rude rectangle 60 or 70 miles wide and 125 miles long, with its length extending northwestward and southeastward; let the surface be tilted until the southwestward slope is 7 or 8 feet per mile and the southeastward slope 3 or 4 feet per mile; let this surface be gently corrugated by scarcely perceptible folds running in the direction of its longer axis; then let this gently corrugated surface be diversified, first by a number of irregular elevations generally elongated in an east-southeasterly direction, and second by a multiplicity of more regular ridges, sometimes only elongated hillocks, but sometimes rounded crests a score of miles in length, all extending in nearly the same direction, but diverging toward the southeastward and curving slightly to the east; and let these diversifying elevations, both irregular and ridge-like, be much more conspicuous than the gentle corrugation of the surface; next let the surface be further diversified by a series of considerable rivers flowing down the lesser slope a little to the right of the direction of the longer axis of the tract, but like the ridges, diverging slightly and curving slightly to the left as they flow; let these rivers generally seek the axes of the irregular elevations and ridges, sometimes turning out of lowlands, and greatly extending their courses in so doing; then let the elevations sought by the rivers be deeply carved with a dendritic sculpture, and let the smaller streams, originating on the smoother parts of the surface, flow through gorges in the remnants of the elevations into the main streams; finally, let the smoother parts of the surface be prairie land, and the elevations, both irregular plateaus and regular ridges, be forest clad, and their apparent height thereby increased—and the conception of the configuration of the area will be complete and fairly accurate.

THE LOESS-DRIFT AREA.

South of the drift plain area of the northwest, and southwest of the ridged drift area of the southeast, lies the fifth area of distinctive topographic characteristics. Like the driftless area, but unlike most of the other half arbitrarily defined topographic areas, its type of configuration is strongly marked, distinct, and readily recognized wherever seen; and its typical features fail only toward the northern and eastern margins where it merges into neighboring areas.

The area is a land of planes—planes once continuous but now carved with a delicate tracery of dendritic fretwork, each pattern beginning with a main stem which throws out branches right and left, the branches dividing into branchlets, these into twigs, and these again into innumerable leaf stems as do the branches of an oak; and trunk, branches, and twigs are engraved into and not embossed upon the surface of the planes. The trunks of the tracery are so sparsely distributed that the branches, the branchlets, the twigs, even the minute leaf stems, seldom touch; so that between the twigs and branches of each system of tracery, and between the different systems, there lie surfaces untouched by the graver; and the Titanic straight-edge—or its substitute, the line of vision—laid across the surface remnants show that all are indeed parts of the same once-continuous plane surface. The graven lines are deep and often narrow, so that the slopes by which each plane is broken are steep; and the traveler over the region can not fail to be impressed by the alternation of steep slope and dead-level expanse in lieu of the usual succession of ever-varying slopes given by undulating plains. Toward the main stems of the dendritic systems the troughs are indeed wider, and the great branches and the minor twigs springing from them sometimes interfere; and the whole surface over many square miles may be reduced below the level of the plane and sculptured into a multitude of forms each betraying the dendritic configuration of water carving in its minor lines; and here the traveler might imagine himself in a region of hills which he could conceive as regular or irregular according to his training. But on ascending to what appears an undulating divide when seen from below, he might again find himself upon a visually illimitable plain (for the ravines are not seen until closely approached); and should he choose his course rashly he might become mired in the marshes of the ill-drained uplands; for the uplands of Iowa and Poweshiek Counties are mazes of hills and labyrinths of ravines; yet the labyrinths never merge, the hills run into the divides, and the divides are parts of a plane surface above which the hills never rise.

Examination of the entire loess-drift area indicates that its character is not determined by a single plane, but rather by a dozen or a score; yet all have common features. In the northern part of Iowa County the Iowa River wanders through a broad alluvial bottom, and the alluvium thins laterally and finally passes into a zone of flat-lying drift like that in which all the longer rivers rise. The river bottom is overlooked from the north by a plateau of loess rising to a plane surface—the western extension of the long loess belt which is skirted and cleft by the river at its great elbow north of Iowa City—perceptibly inclining southward from the line of paha and digit-like spurs which form its northern margin two-thirds of the way to Prairie Creek. It is overlooked from the south by a scarp which, seen from the river, appears to be a line of paha similar to those overlooking Prairie Creek from the same direction; but on reaching the summit of one of them the soft-contoured swells are seen to rise but little above the upland beyond, and the upland is seen to form one of the characteristic plane surfaces of the loess-drift area, stretching away to the southeast, the west, and the south as far as the eye can reach, and like the plane on the other side of the river, inclining gently southward—i. e., the northern rim of each plane is uptilted and warped, and carved into the semblance of the paha of the ridged drift plains. So the raindrops falling on the crest within rifle-shot of the river at South Amana are divided; a part run swiftly down the steep slope and across the flat-lying drift and alluvium to the Iowa; and a part flow gently down the easier slopes, still more sluggishly down the tilted plane to the southward or southeastward, and slowly gather into another river system. Following the gentle incline toward the lesser waterway, the plane surface becomes more and more diversified with the enlargement of the converging ravines until it breaks up into a maze of low hills rising but a little way above the principal waterway. But beyond this, in its turn, lies another line of paha-like hills; and when its crest is reached, this line, too, is found to be but the northern upturned rim of another broad plane inclining gently southward and gradually broken up by growing ravines. Thus each east-flowing waterway—and they all flow eastward—is flanked on the north by a line of salients carved out of a low plane, and on the south by the upturned rim of a higher plane, yet little marked by erosion. This is the case of Bear Creek, of Clear Creek, of Old Man Creek, of English River, and of the South English; for every stream of considerable dimensions is definitely related to a gently inclined plane on the north of it and a similar one on the south of it.

It is needless to follow the various streams through their numberless ramifications or to traverse the various divides in their interminable convolutions; for in this region there is a type, and to this type the upland plain, the stream, and the minor topographic element which the latter has carved out of the former, conform to it consistently and constantly.

Let there be conceived a plane surface with a dendritic tracery of ravines and minor waterways carved into it; let the plane be elongated east and west and slightly inclined eastward; let its northern margin be tilted upward into a somewhat irregular and discontinuous rim, and let the surface incline from this rim southward more rapidly than to the eastward; let the upturned rim generally form the divide, and let the ravines widen, deepen, and unite southward to form a stream marking the down-tilted southern side of the plane—and a satisfactory general picture of each interfluvial tract of the loess-drift area will be formed. Then let a dozen or a score of just such planes, varying in extent and rounded as to corners, be thrown together to form a triangular area of 3,000 square miles; let each be a little lower than its neighbors on the north and west, so that the mean surface inclines gently southeastward; let the areas intergrade from east to west though separated by the bounding streams from their neighbors on the north and on the south; and let these streams wander in alluvial flood planes among mazes of hills of circumdenudation, round topped when low, flat topped when high, porpoise-backed on the south—and the general conception will fairly represent the surface configuration of the loess-drift area.

THE GUMBO AREA.

When the loess-drift area of Northeastern Iowa is traced southward into southern Iowa and northern Missouri, the surface is found to undergo gradual modification with the attenuation and final disappearance of the loess and of the upper till into which it grades; the independently tilted planes bounded by waterways disappear; and the general surface comes to represent a single practically continuous plain diversified by deep-carved drainage systems of the wide-branching type, and by occasional inconspicuous scarps. With the growing indefiniteness of the individual plains, the uptilting of their northern margins fades and the divides approach the median lines of the watersheds, while the drainage assumes the direction of slope, and the drainage systems become regularly dendritic and not monstrously asymmetric as in the one-sided basins of Iowa County. At the same time the divides widen, the slopes of the ravines steepen, and the storm-carved ravines increase in number and diminish in length, so that the spring-time traveler either flounders through the mire of the ill drained upland or threads a labyrinth of narrow ravines interdigitating steep-sloped salients of slippery clay.

Such is the configuration of the gumbo region of the Mississippi Valley, that gigantic will-o'-the-wisp of the geologist which, according to the testimony of the inhabitants, is never at hand but always "in the next county," and is never found so long as the searcher hearkens to interested counsel.

In Northeastern Iowa there is but a limited tract of the peculiar tenacious clay called "gumbo." It overlooks the Mississippi in the extreme southeastern corner of Muscatine and the southwestern corner of Scott Counties, aggregating less than 100 square miles in area. Even here its characteristics are mainly masked by the mantle of loess skirting the river bluffs; and they are lost also in the valley of Pine Creek, which has cut its channel down to the Carboniferous and Devonian rocks and, with its larger tributaries, sculptured these rocks in the autogenetic fashion illustrated in the driftless area. Yet in the central part of the little gumbo area the individuality of the configuration is as pronounced as in the greater areas of lower latitudes; the divides are scant rifle-shot across, but level as a floor and so badly drained that crayfish haunt them and rushes and flags sometimes take root in the dense clay despite the discouragement of summer droughts. From the divide the area would seem a perfect plane for miles did not treetops apparently protrude from its surface here and there; and it is only on reaching the very verge of the ravine scarp that the traveler realizes the existence of deep and sharp-cut ravines cleaving the plain in all directions and giving support to a natural forest growth upon their steep sides. Yet these ravines are so narrow and steep-sided that where the local relief is 50 feet or more they are impassable to animals, and the roads wander here and there upon the endless convolutions of the divides, or descend obliquely into waterways large enough to cut through the gumbo and flow on drift or rock below.

Conceive a typical "bad land," with its wide-branching ravines dividing knife-edged crests, salients, spurs; let the local relief be 400 or 500 feet, and the height above base level such that every ravine and stream-way is V-shaped in section and sharp-curved with concavity upward in profile; then let the upper half or two-thirds of the mass be sliced off by a horizontal plane, thus truncating every crest, salient, spur, and curtailing every ravine and stream-way—and the conception will fairly represent the configuration of the gumbo area.

SECTION IV.—RÉSUMÉ.

Northeastern Iowa may be classed with the Mississippi Valley or with the Great Plains at will. Yet there is an individuality and variety in surface configuration which not only set it apart in many respects, from other portions either of valley or plains, but yields a classification by surface forms of different parts of its own area. True, the driftless area in the extreme northeast is a part of the great area of like characteristics in Wisconsin, southeastern Minnesota, and northwestern Illinois; true, the drift border belt stretches northward into Minnesota and eastward into Illinois and, with some modifications, circumscribes the entire driftless area; true, the drift plain region of the northwestern counties connects with that of southern Minnesota and extends to the terminal moraine in central Iowa and is the homologue of many other drift plains in northern United States and in other countries; true, the loess-drift area stretches westward and southward over many thousand square miles; and it is equally true that the little gumbo area is but a hand specimen illustrating the indefinitely larger areas of similar configuration in southern Iowa, Illinois, and Missouri: but the ridged drift area is without parallel elsewhere; nowhere else are the drainage basins of glaciated areas so long and narrow, the rivers so closely coincident in direction, or the drift surfaces so continuously and concordantly ridged; and nowhere else do half the rivers avoid low plains and seek eminences, even to the extent of carving cañons in the most conspicuous elevations within a radius equal to their length. By its pronounced individuality and variety in configuration, Northeastern Iowa is clearly set apart from the Mississippi Valley at large or the Great Plains at large; and by its eccentric, even paradoxical topography, the central part of the territory is set apart from the rest of the world. The configuration of the ridged drift area is absolutely unique.

A final hasty glance at the topography of the territory may be profitable.

The most conspicuous feature is a culminating ridge rising gradually from the drift plain in Minnesota and stretching southeastward, cutting off the northeastern eighth of the entire territory; from its crest the surface descends in steep but broken slopes in many undulations northeastward to the Mississippi, while on the southwest it slopes more gently and with fewer and slighter undulations for 100 miles to a broad indefinite trough, the farther side of which rises in easy undulations.

Next in prominence, on the map as on the ground, is the length, slenderness, notable parallelism, and gentle curvature of the rivers; and these features, remarkable in themselves, become wonderful when it is known that their courses are independent of the greater elements in the topography, or rather that the culminating ridge has attracted the rivers toward it.

Only a shade less prominent is the relation of the rivers to the minor surface irregularities: Here, as generally elsewhere, some streams flow on the lowest grounds and in the direction of general slope; but aside from the general convergence of the rivers toward the highest crest, several of the streams are locally deflected toward and into minor ridges in whose axes they have carved cañons ; and some of the principal idiosyncracies in the courses of the rivers exist because the waters have avoided the lowlying valleys and turned into adjacent plateaus.

The parallelism in the drainage of Northeastern Iowa is remarkable; the combined parallelism and convergence of the drainage toward the highest upland is a wonder; but the combination of parallelism and convergence toward the upland with the minor departures from parallelism made that the streams may avoid valleys, traverse uplands, and flow in the axes of ridges, is a marvel.

CHAPTER V.

THE POST-GLACIAL PHENOMENA.

SECTION I.—ALLUVIUM.[1]

Since the recession of the Pleistocene ice-sheet beyond its borders, the rivers of Northeastern Iowa have accumulated greater or less volumes of alluvium. Also, while yet swollen by the waters from the melting ice, many of the rivers accumulated considerable slack-water deposits of débris gathered at the ice front and partaking of the character of glacial deposits in composition, though the structure is fluviatile. So, while alluvium proper is generally confined to the flood plains of the rivers, and while the glacial alluvium commonly forms elevated terraces locally of enormous volume, the two sometimes intergrade in such manner that it is difficult to say where the one ends and the other begins, and their separation is accordingly semi-arbitrary.

In the driftless area the alluvium of the flood plains grades into the terrace deposits, and in the drift covered area it is thin, and in some cases apparently grades into the drift or loess. Accordingly, while the formation as a whole is distinct and definitely characterized, its boundaries are sometimes vague. The deposits are confined to the river valleys, and their volume varies roughly with the sizes of the streams.

The Mississippi.—The great river meanders in a main channel and a labyrinth of sloughs, through an alluvial bottom land 1 to 10 miles wide. The greater part of this bottom is a flood plain; it is swept by the expanded waters during each spring freshet, and frequently again during the "June rise," or at least during the memorable floods occurring once in a generation. But small parts of the plain are beyond the reach of the highest floods of historical time, and so belong rather to the terrace system than the flood plain system, even though they rise but a few feet above the highest water level. Sometimes these low and inconspicuous benches differ from the present river deposits, too, in that they are made up in part of fine loam, such as composes the terraces of the driftless area tributaries. There is a low bench of this character opposite Clayton, occupied in part by a group of prehistoric mounds which are built

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[1] Pl. XLIV (in pocket at end of volume) indicates the areal distribution of the alluvium as well as that of the Pleistocene deposits into which the alluvium merges.

of its yellowish loams and sands; but this late Pleistocene terrace is not beyond the reach of modern waters, for great freshets have occurred since the mounds were built, and deposited a layer of sands and dark brown loams of the modern alluvium about the bases of the mounds on the lower part of the bench, half burying some of their number.

Over the flood plain proper the river has repeatedly wandered and is still wandering, and its abandoned courses are amply marked by sloughs forming minor channels through which a part of the current passes; by meandering moats clogged with alluvial sands at one or both ends; by crescentic lakes completely dissevered from the main and minor channels; and by irregular depressions and morasses scattered here and there over its expanse. That these are the tracks left by the wandering river is shown by the observations of the river-pilot as well as by the inferences of the geologist. When the channel is first diverted during some great flood, a part of the waters flow for a time through the old channel; but the new was selected because offering a lower level or a shorter course, and so the new channel gains on the old until its volume is the greater; the new passage is

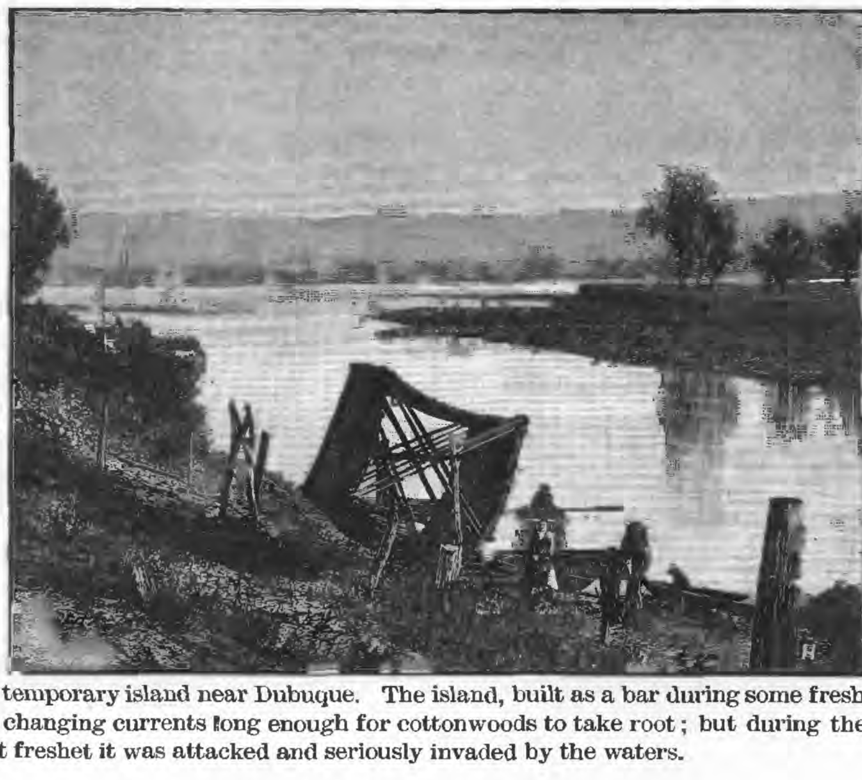

FIG. 36.—A temporary island near Dubuque. The island, built as a bar during some freshet, has withstood the changing currents long enough for cottonwoods to take root; but during the subsidence of the last freshet it was attacked and seriously invaded by the waters.

rapidly widened by the swift current, while the current grows sluggish and the idle waters drop sand and silt in the old. So the channel becomes a slough. Then, during some freshet, the shifting currents build a bar across an extremity of the old channel, and it is finally abandoned save during the highest floods; and as time goes on the other extremity is dammed, and the slough becomes a moat. Next, the ever wandering river shifts far upon its plain, and perhaps leaves the moat miles away from its main channel to be gradually transformed into a lake of clear water, perhaps fed by two or three streamlets and a dozen springs from the adjacent bluffs and drained through a deep-cut runnel in the alluvial sands and silts into the main river or one of its numberless sloughs. And finally the lake is filled with the sediment delivered by its streamlets, and brought over its banks during freshets, and only a faint, indefinite depression trenched by a meandering streamway remains to tell of its former existence. It is thus that the cycle is completed.

But sooner or later every minor channel, slough, moat, crescentic lake, and irregular depression is revisited by the capricious stream. During freshets the water is charged with detritus brought in from tributary streams and gathered from the channels near by, and in the swift current of the main channel this detritus is kept afloat by the endless boils, whirls, and eddies of the raging waters, and so transported freely; but as the flood rises and the waters escape from the channel over the flood plain the current is checked by the luxuriant undergrowth of the bottom lands, as well as by the shoaling of the water, and so the contained detritus is in part deposited. Now this deposition takes place most rapidly over the lands in the immediate vicinity of the main channel and in consequence the immediate banks are most rapidly built up and soon come to be the highest lands in the entire flood plain; and the lands may incline from the river banks to the bases of the bluffs, 1, 3, or 5 miles away, and the tributaries entering the flood plain may turn into the lowlands and wander many miles over the plain before joining their waters with those of the great river. Such is the case with the Oneota, whose waters are lost in a maze of sloughs and reach the main river only after many miles of idle wandering. Such is the case about Guttenberg, which stands high and dry on a slope descending from the river banks to an ill-drained marsh at the bases of the bluffs behind. Such is the case, too, at Sabula, which is built on the river bank, but from which the surface slopes down toward the western bluffs so steeply that the town is insulated during the great flood; and such is the case in scores of other localities. Unless restrained by man, the river will some day return to its abandoned courses at the mouth of the Oneota, at Guttenberg, and at Sabula, and its present channel will be abandoned; for the stream, flowing between levees of its own building, is eminently unstable.

The breadth of the alluvial belt along the Mississippi culminates about the mouth of the Wapsipinnicon. At Clinton the rocky bluffs characteristic of the river through the driftless area disappear, the immediate river valley widens, and with it the alluvium lining expands until at Comanche the flood plain is 4 or 5 miles wide. Then the equally broad flood plain of the Wapsipinnicon joins, or indeed may be said to cross, that of the greater river, and extends southeastward in a broad, lowlying, alluvium-lined valley, 5 to 10 miles wide. This valley was the Marais d'Ogée (the "willow marsh") of the French explorers. It is occupied by a channel now bearing the same name by which the freshet waters of the Wapsipinincon and the Mississippi are in part conveyed to Rock River to reunite with the Mississippi between Davenport and Buffalo, 30 miles below. But while a part of this vast mass of alluvium is scarcely if at all above the reach of the great floods of historical time, much of it accumulated as the ice-sheet was melting.

At no point in its course along the boundary of Northeastern Iowa does the Mississippi flow upon bed rock except in part about Dubuque and more notably between Le Claire and Davenport. At Dubuque the flood plain is exceptionally narrow, and, as will appear later, the surface was relatively lifted somewhat by a widespread warping at the close of the ice period, and so the river channel has been scoured energetically. The Le Claire rapids and the Rock Island rapids mark the extremities of a rock-bound gorge excavated by the Mississippi since the earlier ice-invasion, during which the stream was forced into this position from its old channel coinciding with the Marais d'Ogée and Rock River.

Within the driftless area the alluvium is generally of great depth, probably reaching fully 300 feet, and perhaps averaging 100 to 150; but the deposit thins toward Dubuque, and though it thickens somewhat below, is probably never more than 100 to 150 feet deep between Dubuque and Clinton. About the confluence of the Wapsipinnicon and down to the head of the newer gorge at Le Claire the deposits again thicken, but to an unknown amount; they are of insignificant depth in the small accumulations within the gorge; but below Rock Island they again increase, though to an unknown extent.

The volume and distribution of the alluvium show that, despite its magnitude, the behavior of the Mississippi is affected by every tributary. All of the tributaries have higher declivities than their principal,[1] and contribute annually a larger volume of detritus than the great river is well able to transport seaward; so only a part of the deposit made during each freshet in a tributary at the confluence is collected and conveyed seaward during the two annual floods. Moreover, in the northern part of the territory the valley is filling; so the deposits of the Oneota form a labyrinth of islands extending 25 miles down stream. Even the deposits of the Yellow form numerous islands and bars in the broader channel; the Wisconsin River has made a great delta and diverted the channel of the Mississippi against the western bluffs, leaving a broad, elevated bottom—the "Prairie du Chien"—on the eastern side; the Turkey has, in like manner, built a delta plain and has driven the great river quite to the Wisconsin side

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[1] The declivities are tabulated on p. 366.

of the cañon; and the other rivers have produced results similar in kind and varying in amount with their dimensions. Especially interesting are the relations of the Mississippi and Little Maquoketa. The great river cut into the western bluffs so far as to invade the channel of the smaller; but the latter then turned against the invader so energetically that he was forced to retreat, leaving an extensive slough-furrowed plain about the present mouth of the tributary.

The Oneota.—In its upper course this waterway belongs to the drift plain, and, like other drift-plain rivers, is flanked by a thin veneer of sandy alluvium grading into the drift from which it was derived. In its lower two-thirds it is a rock-bound stream of high declivity; it frequently ripples over bedded rock, though sometimes over bars and sheets of well rounded pebbles, partly washed in from the drift plain, partly derived from the contiguous terraces, and partly formed by the breaking up of the rocks over which it flows. It is commonly skirted on one or both sides by a shallow alluvial flood-plain, built chiefly of coarse sand and gravel, though occasionally finer loams occur. Within the last 10 miles of its course the river bottom widens, and some broad stretches of bottom land appear. About its mouth these may be a mile or two in width, though they are not sharply distinguishable from the lowest gravel terraces. These broader areas of bottom land are diversified by bars and moats, but contain few crescentic lakes or irregular depressions; for the Oneota is an energetic stream, and ever since the valley was clogged by the débris swept into it from the ice-margin it has been industriously cutting down its channel and clearing out the erratic débris.

Yellow River.—This is a typical driftless area stream in the character of its alluvium as in all other respects. True, the invading ice-king imposed a task upon its upper waters; but the stream falls 625 feet in the 30 miles of its length, and the strong current due to this slope has swept away nearly all of the ice-dropped detritus. Throughout its course the river flows either upon bedded rock or upon a thin sheet of coarse débris largely derived therefrom; its flood plain is narrow, and the alluvial deposits of the flood plain are thin and porous. Only near its mouth, where its activity is retarded by the sluggishness of its principal, are the alluvial deposits noteworthy either in thickness or extent.

Turkey River.—On the headwaters of this stream appears a thin veneer of sandy alluvium characteristic of drift plains. In the middle part of its course it is rock-bound like the Oneota and Yellow, but its declivity is somewhat less, and there is generally a greater development of alluvial sands and loams, sometimes reaching a considerable width. In the lower portion of its course the current is slackened by the backwater from the Mississippi, and the alluvial bottom lands are broad enough to accommodate farms. The materials consist of stratified sand and loam with a considerable admixture of pebbles derived from drift-born tributaries, the adjacent aqueo-glacial terraces, or the bed rock laid bare by the river in its upper courses. Some of its pebbles are fossils: silicified corals from the Niagara, well preserved gastropods washed from the friable Maquoketa shales, and characteristic brachiopods of the Devonian, are common; the largest known specimen of *Calymene niagarensis*, embedded in a nodule of chert, came from the alluvium of the Turkey River, near Millville; and a Cretaceous shark-tooth (*Otodus*, sp. und.), came from the alluvium of the Volga at Fayette.

The Maquoketa.—The widest alluvial flood plains of this river occur in the upper half of its course. Five miles north of Manchester the flood plain is nearly a mile in width, and both surface and deposits pass imperceptibly into the bounding drift plain. In the rock-ribbed, loess-crowned upland into which the waters turn 7 miles below Manchester, the flood plain quickly contracts from an average width of a mile or more to an average of about a quarter of a mile, and the deposits change from sandy loam to fine and coarse sand with some gravel. Below this upland, in the neighborhood of Monticello, the flood plain again expands to a mile and a half or two miles in width, and the deposits again become sandy loam. Farther downstream the flanking plains contract, and from Monmouth to the mouth the alluvial deposits are generally inconspicuous, though sometimes (as at the confluence of the North Maquoketa) reaching widths of a mile or more.

The Maquoketa has built a broad delta in the cañon of the Mississippi and forced that river against the Illinois bluffs, as has the Turkey and many other tributaries.

The Wapsipinnicon.—In the upper half of its course this river, like its drift-plain neighbors, is flanked by a broad belt of alluvial sand, which, though of limited depth, sometimes reaches 2 or 3 miles in width. Below Independence its immediate valley contracts, and the breadth and depth of the alluvial plain diminishes, while the materials grow coarser; yet occasionally, as at Central City, the alluvial belt widens to a mile. At Stone City the rocky bluffs converge, and the river itself occupies half its narrow ribbon of bottom; but below Anamosa the flood plain again expands; at Olin it is a mile wide, and at Oxford a mile and a half; below Massillon it is sometimes even wider; and thence to the confluence it is as broad as that of the Mississippi. The deposits are stratified sands and loams, and while some of them were evidently gathered directly at the ice-front by the glacier-swollen river it is impossible certainly to distinguish the modern from the ancient alluvium. In the immediate vicinity of the lower river, especially below Calamus, the surface is diversified by low-banked moats and crescentic depressions. Somewhat farther from the river and a little higher, the banks of the moats give way to bars and low ridges; and beyond the belt thus embossed, low terraces of great extent but irregular surface stretch toward the sloughy drift plain on the north and toward the prominent paha on the south; yet the deposits generally maintain the appearance of modern alluvium, and are indeed sheeted with a coating of débris carried in from the adjacent uplands during freshets.

The Cedar.—In respect to its alluvial deposits the Cedar is the homologue of the Wapsipinnicon. In its upper course there are broad, indefinite belts of alluvial sand; in its central portion the flood plain alternately contracts and expands as the river turns into and escapes from rocky uplands; and toward its mouth the bottom lands stretch from West Liberty southeastward for 5 or 10 miles. This bottom land, like that of the Wapsipinnicon, is diversified by moats, abandoned channels, and crescentic ponds at low levels and near the river, while at greater heights and distances from the channel it is terraced. The terraces definitely connect themselves with the history of the melting of the northern ice.

The Iowa.—The Iowa generally wanders through a considerable flood plain of alluvial loam and sand. At Marshall it is nearly a mile wide; at Montour it is a mile and a half wide, and the remnant of the Sac and Fox Indians residing in Iowa occupy its fertile acres; at Tama it is three quarters of a mile wide, and at Marengo it has expanded to more than a mile. At Amana it is a mile and a half wide, and so controlled by an artificial canal that the whole flood plain is under plow; below Roberts Ferry, in the great loess-crowned upland of Johnson County, the flood plain contracts to a quarter of a mile, and even two hundred yards. Just below Iowa City it emerges from the loess land, and at once expands from a quarter of a mile to 3 miles; still farther down stream it widens to 5 miles, and soon it merges with the wide-stretching semi-alluvial lowlands of the Cedar. Above Roberts Ferry the river never runs upon and probably never approaches the indurated rocks, and the alluvium probably reaches 50 to 100 or more feet in thickness in many places; between Roberts Ferry and Iowa City bed-rock is sometimes exposed in or near the channel; while below the latter point the depth increases greatly, but to an undetermined amount.

Minor streams.—In the driftless area the small streams are usually flanked by narrow flood plains thinly veneered with alluvium, which is largely made up of rather coarse local débris or, in the St. Peter and Oneota terranes, of loamy sand. About the margin of the driftless area the alluvial belts are more irregular in width and depth, but in general the volume of alluvium is greater than toward the center of the area; and erratic materials derived from the drift and fine loam coming from the loess are notable elements in its composition. The mill streams, like the rivers, are flanked by broad bottom lands of alluvial sand and loam, quickly passing into the subjacent drift; but the streamlets are frequently quite destitute of notable alluvial accumulations and wander through basins of bowlder-dotted drift in shallow channels, sometimes exposing pebbly drift undistinguishable from that revealed in artificial excavations in neighboring uplands. In the southern portion of the drift-covered area nearly all waterways are alluvium lined; the bottoms are generally broader and the deposits thicker than along streams of corresponding size in the north, either within or without the driftless area, and frequently the alluvial deposits flanking small streams are disproportionately extensive. In the southwest part of the territory, within which the prevailing superficial deposit is loess grading downward into bowlder-charged drift, the streamlets commonly occupied narrow, V-shaped ravines containing little or no alluvium; the brooks occupy equally steep-sided but broader-bottomed and U-shaped ravines, and their channels are flanked by flood plains varying in width with the stream volume and built of alluvium; the mill streams wander through broad-bottomed, alluvium-lined valleys; and the minor rivers—Bear, Old Man, and English—have disproportionately broad bottoms diversified by moats and bars, built of dark, silty loam of considerable but unknown thickness, sometimes rising above freshet level in low terraces; and upon these flood plains with their flanking terraces numberless fertile farms find place.

Résumé.—The great alluvial belt of the territory follows the Mississippi for 250 miles, with a mean width of fully 2 miles in Iowa and even more in Wisconsin and Illinois, and with a mean depth reaching and perhaps far exceeding 100 feet. Half of this great bottom is flooded by every vernal freshet and every "June rise;" another full quarter is swept by the great floods occurring at long but irregular intervals; and a scant quarter rises beyond the reach of the highest freshets, either in low terraces of late Pleistocene loams, or in more recent banks and bars of modern sands built beyond the present reach of the river between Dubuque and Muscatine, where alone the waters corrade at times the bed in which they flow. In the driftless area the secondary rivers are throughout most of their courses flanked by flood plains of alluvial matter, generally of limited thickness; but toward their confluence with the Mississippi these alluvial deposits broaden and deepen and reach great but generally unknown thickness and enormous volume. In the northern part of the drift-covered area the rivers flow through broad bottoms, partly within reach of floods, and these bottoms generally merge with the subjacent drift; but in the southern part the flood plains are wider and commonly clearly set off from the adjacent uplands, and the alluvial deposits are thicker, coextensive with the flood plains, and clearly set off from the subjacent deposits.

On reviewing the alluvial phenomena of the territory, two generalizations appear, one of which is perhaps local but probably applicable to glaciated regions in general, while the other is of wide-reaching application.

The first generalization is: Other things equal, the volume of alluvium is relatively the greater in the south (i. e., toward the periphery of the glaciated area) than in the north (i. e., toward the center of the glaciated area). The second generalization is: Other things equal, the volume of alluvial deposits is relatively the greater along the smaller streams.

Two noteworthy exceptions to this generalization appear. The first is the great depth and breadth of the alluvial deposits in the Mississippi Valley above Dubuque; but this vast accumulation is due to a general deformation, and is hence abnormal. The second is the absence of alluvium on many of the streamlets of the northern drift plain; but this is due to the incompleteness of the primeval drainage, which has been greatly extended by settlement, pasturage, and cultivation, but which has even yet barely transformed the primeval sloughs into tillable fields. The exceptions, therefore, do not affect the validity of the generalizations.

SECTION II.—THE RIVER TERRACES.

The Mississippi.—The great river is practically without well defined and continuous terraces, such as generally characterize the streams of glaciated regions. Throughout the 200 miles of its length along the eastern boundary of the territory, there is not indeed a single terrace rising so high above its waters as to indicate connection with the advent, subsequent action, or final melting of the great ice sheet; but several low, indefinite, and discontinuous benches, rising above the flood plain proper, are shown by their composition to be connected with the closing stages of that episode: and terraces of glacial materials flank the principal tributaries well down to their embouchures.

About the embouchure of the Oneota there are two or three low but extensive terraces belonging to the two rivers in conjunction. The village of New Albin is built upon such a terrace rising 10 to 20 feet above the somewhat irregular flood plain. Half a mile east of the village, the scarp of this terrace has been cut away for road metal and railway ballast. At this point it is wholly made up of coarse gravel, consisting occasionally of well rounded erratic pebbles from half an inch to an inch and a half in diameter, with a few intercalated layers of sand. In and west of the village the terrace materials consist predominantly of sand with intercalated sheets of gravel. The scarp of this terrace is generally sharply defined but quite sinuous; and its surface is generally so smooth and level that the low mounds of the aborigines, by which it is dotted, rise prominently in the fields and meadows into which it has been converted.

About the base of Oneota (or the "Minnesota Bluff," illustrated in Pl. v), and generally on the north side of the Oneota for several miles, there is a higher terrace of stratified sand containing local bowlders and angular rock fragments. This terrace is narrow, far less regular and continuous than its next lower neighbor, and its scarp is seldom definitely marked.

The next conspicuous terrace on the Mississippi lies on the Wisconsin side, opposite McGregor and just above the mouth of the Wisconsin River. This broad bench constitutes the "Prairie du Chien" of the early French voyageurs, and the name of the topographic feature has been perpetuated in that of the city located upon it. This terrace is made up chiefly of the "glacial flood drift of later epoch" as defined by Chamberlin.[1]

A few miles below the mouth of the Wisconsin there is another low bench of like origin rising but a few feet above the modern flood plain and distinguished from it chiefly by composition; for its materials are stratified loam, sand, and erratic gravel such as constitute the aqueoglacial terraces everywhere within and about the flanks of the driftless area. In this as in several other cases the modern alluvium has encroached upon the ancient terraces; and here the floods and their deposits have invaded an aboriginal village site and half buried some of the ancient tumuli.

Dubuque is built upon a narrow, sloping shelf of loam, sand, and gravel, with a considerable admixture of local rock fragments, the mass being generally stratified. These materials appear to represent collectively a preglacial talus, aqueoglacial deposits, and the postglacial talus; and they grade into the limited volume of modern alluvium along the riverside. Above the city this shelf expands into a more definite bench connected with the inconspicuous terrace system of the Little Maquoketa.

A few miles above Bellevue there is a low terrace of stratified gravel and sand 5 or 6 miles long and 2 miles in greatest width. Its surface is generally smooth and regular, though sometimes diversified by low sand-bars and shallow moats. Its materials are stratified and sometimes cross laminated sand with considerable quantities of well rounded gravel, from half an inch to 2½ inches in diameter, largely erratic, though nodules and fragments of chert from the Niagara limestone are abundant. About the somewhat sinuous scarp, gravel generally predominates over the sand and the material has been excavated largely for road and railway building. This terrace rises 10 to 25 feet above the contiguous flood plain.

On the opposite side of the river, and stretching thence downstream 15 miles, there is a lower and less conspicuous terrace of like but more finely comminuted materials mixed and sometimes interstratified with loam; and a still more extensive terrace, also on the Wis-

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[1] Sixth Ann. Rept. U. S. Geological Survey, Pl. xxvii.

consin side, extends from just below Savanna to a point nearly opposite Lyons.

Narrow, flat-topped and steep-scarped shelves generally skirt the bases of the bluffs about the mouth of the Maquoketa, on the Iowa side, and occasionally occur downstream nearly to Sabula. Two miles northwest of Sabula the shelf is well defined, 18 or 20 feet above the contiguous bottom land, and made up of sand and well rounded gravel, and its materials have been largely used in constructing the long causeway by which Sabula is connected with the upland.

About the mouth of Elk River, terraces reappear, skirting the bases of the low bluffs almost continuously for 8 miles; but the materials are more heterogeneous (containing a considerable admixture of loam and clay) and the scarps less definite than above, and the deposits are inconspicuous.

Below and opposite Lyons, and especially below Clinton, the bottom lands of the Mississippi expand enormously and send great arms off to the southeast to connect with the Rock River in Wisconsin, while the enormously expanded bottom lands of the Wapsipinnicon come in from the west; and a considerable part of these lowlands, which reach hundreds of square miles in area, consist of low terraces made up of stratified sand, loam, and some gravel. On the Iowa side there are two, three, and sometimes more terraces, the first scarcely beyond the reach of the highest freshets, and the uppermost 20 to 30 feet higher. In general the terraces are steep-scarped and smooth-surfaced toward the river, where gravel predominates in their composition; but inland their surfaces become irregularly scarred by moats and crescentic lakes and interrupted by swamps. The highest terrace is generally coarse toward its scarp, sometimes containing pebbles and bowlders up to a foot or two in diameter like those of the adjacent drift; and inland it passes gradually, both as to composition and as to conformation, into the drift plain. This transition from terrace to drift plain is well exhibited at Follets. On the south side of the Wapsipinnicon the terraces are as broad as on the north and more sandy in material, and commonly well drained as to surface.

Through the constricted gorge of the Mississippi extending from Le Claire to Davenport, no noteworthy terraces occur. From the western part of the latter city to Muscatine there is a more or less definite shelf, generally rising above reach of freshets, made up in part of aqueoglacial materials, though these sometimes constitute but a veneer concealing the Devonian subterrane.

Below Muscatine the river bottom quickly expands to a width of 8 or 10 miles; yet nearly the whole expanse was subject to overflow during the annual freshets until levees were constructed for the protection of Muscatine Island. A few inconspicuous terraces overlook Keokuk Slough, by which that island is divided from the mainland.

The Oneota.—In its upper course this river is flanked by a broad alluvial flood plain which gradually contracts and rises as the stream passes from the drift plain into the driftless area; and, now on the one side and then on the other side of the stream, remnants of older flood plains occur considerably beyond the reach of the highest freshets. About Bluffton, terraces of stratified sand and gravel derived from the drift occasionally appear; at Decorah they are conspicuous though discontinuous; and still farther downstream they increase in volume and height. About the west line of Allamakee County there is a discontinuous upper terrace 50 to 60 feet above the level of the river, and a more continuous but less regular one 30 feet lower. Still farther downstream these diminish in altitude, and the upper disappears about the mouth of French Creek. Obscure remnants or broader expanses of the lower terrace appear, at 35 or 40 feet above the river, in all reentrants below French Creek, and there is in addition a broad bottom land now standing a few feet above the level of the highest freshets. The discontinuous upper terrace is generally composed of fine stratified sand and loam with occasional sheets of gravel; and the lower consists of stratified and cross laminated coarse sand and gravel. Within the last 5 miles of its course the cañon of the Oneota expands and its terraces sink and merge into those of the Mississippi.

Turkey River.—Aqueoglacial terraces become conspicuous on the Turkey about Clermont, where broad benches of stratified sand and gravel, with intercalated sheets of loam, rise 50 or 60 feet above the flood plain, and a lower terrace system of coarser materials occurs at about half that height. These terraces are more or less continuous to the mouth of the river. At the confluence of the Volga the upper bench rises about 75 feet above the river, and is built of stratified and cross laminated sand and loam with occasional sheets of fine gravel; while the lower terrace is 30 or 40 feet in height, and composed of coarser sands with more abundant gravel. Similar terraces occur occasionally on the Volga from its mouth to Albany. Below Elkport the terraces diminish in altitude; at Osterdock they rise 60 and 30 feet above the river respectively; at Millville the upper rarely appears in inconspicuous remnants at 40 or 45 feet, and the lower is more persistent at 15 or 18 feet above the flood plain. Both benches disappear in the narrow gateway through which the river embouches into its principal; and without the gateway there are no terraces proper, though the delta deposits rise beyond the reach of freshets. Yet fragmentary shells of *Unio*, of species living in the river to-day, are lodged in the crevices of the rock half way to the summit of Estell's Point, 150 feet above the present waters.

The Little Maquoketa.—In the last 10 miles of its course this stream is flanked by discontinuous benches of stratified sand, gravel, and loam 30 or 40 feet in height. Midway between Durango and Dubuque the valley bifurcates, embracing between its arms the upland known as Eagle Point, and about the bifurcation (north of Thompson's Mill) the principal terrace expands to half a mile in width. It here rises about 55 feet above the ordinary water level, and its materials consist of fine sand and loam, similar to that of the loess by which the bounding hills are mantled.

Catfish Creek.—Toward the embouchure of this stream there are extensive deposits of stratified sand and loam, finest above and rising to a moderately uniform surface. Extensive exposures have been

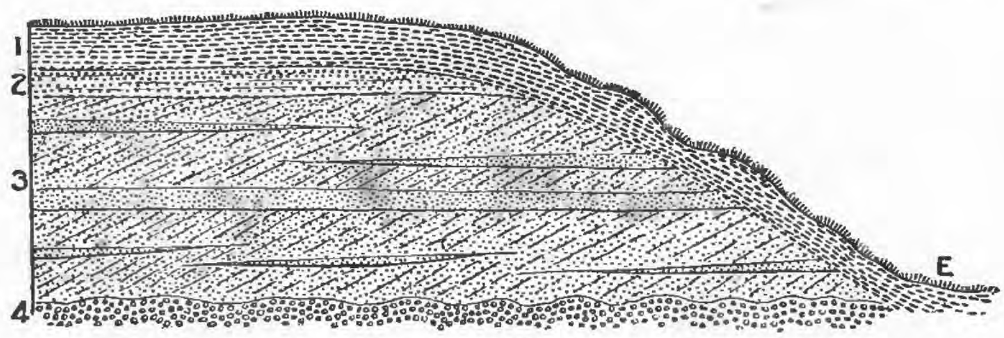

FIG. 37.—Structure of terrace on Catfish Creek, near Rockdale: (1) Sandy loam, without definite structure. (2) Horizontally bedded loam, loess like in color and appearance, but somewhat sandy. (3) Cross-bedded sand, generally fine, with intercalated sheets and lenses of fine, structureless sand. (4) Fine gravel, structureless or obscurely stratified, locally separated from the sand by a definite line, but elsewhere merging into it.

made in excavating the deposits for use as road material and building sand. The excavations display 10 to 30 feet of the loams and sands, the structure of which is illustrated in Fig. 37, and elsewhere the mass is probably 50 or 60 feet in thickness. The configuration of the deposit indicates that the gorge of the Catfish was once completely clogged, and that the stream has excavated an inner gorge within the old; and the composition of the deposit indicates that it grades into the practically continuous mantle of loess overspreading the whole of the region save the bottoms of the deeper cañons. The materials are generally cross laminated fine sand, with intercalated sheets either of fine gravel or loam.

The phenomena of the Catfish are duplicated in the Tête des Morts, Mill Creek, Pleasant Creek, and the lesser affluents of the Mississippi between the two Maquoketas.

The Maquoketa.—Terraces are not characteristic of this stream. Above Manchester it meanders through a broad bottom land which passes into a drift plain; in its lower course it flows through a cañon apparently too small for so considerable a stream, in which appear scant remnants of high-level terraces, something like those of the Oneota and Turkey; and even in the middle part of its course the terraces are generally narrow and inconspicuous.

Perhaps the best development is near Delhi and Hopkinton, where a considerable terrace rises some 50 feet above water level. Its materials are fine, stratified, and cross laminated sand, with intercalated sheets of loam, some of which are undistinguishable from the loess found at higher levels in the same vicinity. It is noteworthy that this terrace is considerably higher than the surface of the drift plain in "The Bay," the lowland which the Maquoketa avoided that it might enter the loess-capped upland through which its channel is carved.

About Maquoketa the valley widens and there is some development of terraces, the most conspicuous being of fine, stratified sand and loess (containing fossils), 50 feet above the level of the river. Less definite benches of coarser materials occur also at lower levels.

The Wapsipinnicon.—In its upper course this, like all other drift plain rivers, is flanked by broad alluvial bottom lands; but while these rise above the reach of the highest modern freshets and grade in form and materials into the drift, well defined terraces are rare.

In its middle course, from Independence to Massillon, the river generally flows in a constricted, rock-bound gorge excavated either in the axes of ridges or in elongated uplands; in this part its flood plain is much higher and narrower than in the drift prairies to the northward; and occasional remnants of elevated terraces appear in reentrants and about the mouths of tributaries at from 20 to 40 or 50 feet above the waters of the river. These terraces consist of stratified sand and buff loam. It is significant that the terrace materials differ from the loess of the neighboring eminences only in somewhat greater coarseness and more definite stratification—the terrace deposits in some cases being quite undistinguishable from the basal portion of the loess. It is equally significant that the terraces within the cañons sometimes stand higher than the drift plain from which the cañon-cleft ridge rises. This is the case near Quasqueton; and again near Anamosa there is a terrace whose materials are undistinguishable from the basal loess of the adjacent hills standing 50 feet above the river, or about the same height as the drift prairie on the south side of the upland through which the Wapsipinnicon has cut its cañon.

Below Massillon the river-bottom expands greatly and is flanked by low and sometimes indefinite but wide-stretching terraces which merge with those of the Mississippi. Those on the north consist of sand and clay intermixed with pebbles, and sometimes bowlders, and approach in composition the drift from which they are evidently derived; while those on the south are of finer materials, chiefly stratified sand and loam, resembling much the basal portion of the loess of the upland overlooking the stream.

The Cedar.—Throughout its whole course the Cedar is terraced; but except when its bounding bluffs are high and steep and its cañon narrow, the terraces are indefinite. Between Otranto and Newburg there is a broad bottom of pebbly sand quite beyond the reach of the highest floods, and about St. Ansgar definite scarps are sometimes exhibited; in the relatively narrow and deep cañon of the river near Osage, occasional flat-topped remnants of stratified sand passing up into loam appear in reentrants and tributary ravines ; and at Floyd there is on the north side of the river a fairly well defined terrace 25 feet high, or somewhat beyond the reach of the highest floods. In section this exhibits 15 inches of brown loam much like modern alluvium resting on 12 feet of light brown, sandy loam with obliquely laminated lenticular intercalations of clean, whitish, or golden yellow sand; and this in turn rests upon 3 feet of water-worn pebbles from a quarter of an inch to 8 inches in diameter, both local and erratic (the former predominating among the larger and the latter among the smaller specimens), irregularly bedded above. Near the base of the light brown loam, univalve shells of recent species and partially mineralized wood resembling that found to-day in the neighboring forest were associated with fragmentary crania and teeth of a bison, probably *B. americana.*

Fairly well defined terraces of stratified sand and loam occur in the cañon of the Cedar west of Center Point ; and here as on other rivers the terraces rise above the level of neighboring drift plains tributary to the river.

Southwest of Mount Vernon there is on the south side of the river a broad bench some miles in length and 10 or 15 feet above the reach of freshets, made up of stratified sand and loam, intermediate in composition and appearance, between the loess of the adjacent hills and the sandy alluvium of the flood plain.

At Rochester there are, on the east side of the river, several narrow benches of stratified sand and loam, sometimes containing pebbles and bowlders (particularly in the higher members), extending up to 40 or 50 feet above the level of the river; and in general the escarpment of each is marked by a ridge of sand.

A few miles below Rochester the river bottom expands to 3, then to 5, and finally to 8 or 10 miles in width, most of which is above the reach of the highest freshets and is definitely terraced. The modern flood plain is interrupted by sloughs, moats, and crescentic lakes, all nearly as conspicuous as, though less extensive than, those in the Mississippi bottom. The first terrace, which is composed of stratified sand, rises 20 feet above the flood plain, generally in a steep and definite though sinuous escarpment. Toward the escarpment the terrace-plain is as smooth as a floor; but inland it gradually becomes diversified by irregular depressions, sometimes holding water, and by shallow moats, as well as by low banks and hillocks of current-bedded sand. It is sometimes miles in width, and is overlooked by a less definite escarpment, 15 or 20 feet in height, which forms the margin of the upper terrace. The surface of the upper bench is somewhat less smooth than that of the lower; its materials are fine sand and loam; and both surface and materials pass into those of the loess-drift of western Muscatine County.

A phenomenon doubtless related to terracing, displayed in some degree by all the rivers of the territory, is best exemplified by the Cedar. Here and there stratified sands similar to those of the lowest terraces or even of the modern alluvium extend over the drift deposits of the uplands far above the level of the river and even over the highest lands in the vicinity. This is the case near Janesville, where a broad belt of sand extends southeastward for some miles over the drift plain. It is the case also at Brandon, where stratified sands run from the river banks well on the divides, 300 feet above the river, and stretch off in an irregular belt half way to the Wapsipinnicon and southward most of the way to Vinton; and the same thing occurs in the vicinity of Cedar Rapids, where a wide belt of sand skirts the river on the northeast for many miles. Another example, displayed on the south side of the Maquoketa, near Onslow is illustrated in Fig. 55. In all such cases there are neighboring deposits of loess and topographic and other indications that a part of the sand was exposed by denudation of that deposit; but in all cases the sands are not only more extensive than the loess ever could have been, but are definitely connected by complete stratigraphic continuity with the lowest terraces or even the alluvium.

The Iowa.—The terraces of the Iowa resemble those of the Cedar in material, height above the river, distribution, and extent. Tama occupies a terrace 60 feet above the river and 25 feet beyond the reach of freshets. Marengo is built on a broad bottom land well beyond the reach of the highest floods. An artificial canal alongside the river at Amana marks the scarp of a terrace 20 feet above the level of the river and composed of sandy loam. The principal part of Iowa City, including the university campus, is on an elevated terrace of loess 60 feet above the river, and there is a narrow terrace just beyond the reach of floods; and as the bottom lands expand below Iowa City they divide into terraces similar to and eventually merging with those of the lower Cedar.

SECTION III.—RELATIONS BETWEEN ALLUVIUM AND TERRACES.

It is noteworthy that along the Mississippi, as well as on the principal streams tributary to that river, it is sometimes impossible to discriminate the modern alluvium and loess save by differences in composition, and that in some cases even this criterion fails. It is equally noteworthy that along all of the rivers the height of the flood plain above the water level of the river varies greatly and is not always proportionate to the width of the cañon. Less conspicuous, but equally significant, is the fact that the altitudes of the terraces along the greater as well as the minor streams are inconstant.

The higher terraces, composed of materials grading into loess and drift, and the alluvium deposited by the river during the last vernal freshet, are widely different in composition, color, and other features; even the lower terraces and the alluvium of the higher parts of the flood plain, reached by only one flood in a generation, may also be discriminated at a glance in most cases; yet through out the territory the lower terraces and the higher portion of the alluvium frequently intergrade in such manner as to indicate that they do not represent distinct sequences of events and series of deposits, but rather the extremes of a single unbroken sequence of events and series of deposits.

At the mouth of the Oneota the lowest considerable terrace is smooth surfaced and level toward its scarp, but somewhat broken within; and it overlooks a tract of bottom land diversified by moats and crescentic lakes which is beyond the reach of all but the highest freshets, which itself has a scarp overlooking the annually flooded plain, and toward which it is as smooth surfaced as its higher neighbor. At Prairie du Chien the deposits of the glacial flood are indeed beyond the reach of recent freshets; but the southern continuation of the same deposits below the mouth of the Wisconsin have been invaded by the floods of the Mississippi River since the Red Man occupied their level surface; at Dubuque the shelf of aqueoglacial deposits inclines toward the river and passes imperceptibly into the modern alluvium; at Guttenberg and again at Sabula the river has built bars of modern alluvium so high above its own level that permanent cities have been located upon them. About the mouth of the Wapsipinnicon it is impossible to discriminate the Pleistocene terraces from the post-Pleistocene alluvium by configuration, by inequality in altitude, or by composition. At the confluence of the Turkey and the Volga there are two well defined terraces, 35 and 75 feet respectively, above the modern flood plain and composed of materials brought in when the rivers were flooded by melting ice and flowed far above their present level; but downstream these terraces diminish in altitude until the lower merges into the modern flood plain and assumes its composition, while the upper descends almost within reach of the modern floods; and beyond the narrow gateway through which the stream embouches the delta comprises Pleistocene and modern materials intermixed indiscriminately at depths and passing imperceptibly into the latter near the surface. Along the Little Maquoketa there is a series of flood-plain deposits yet in process of deposition during every vernal freshet, yet 5 miles above the mouth of the river they grade into a terrace composed in large part of fine sand and loam distinguishable only with difficulty from the loess of the neighboring hilltops. On the Maquoketa at Delhi and between Delhi and Hopkinton there are terraces of fine stratified sand rising above the level of the drift plain that lies just beyond the base of the ridge in which the river is confined; but downstream these terraces diminish in altitude as the cañon expands and pass both morphologically and structurally into the broad terrace of dark, sandy, and gravelly loam of modern aspect near Monticello, which is barely beyond the reach of annual freshets. Toward the mouth of the Wapsipinnicon the extensive system of terraces connects the river deposits of to-day with the Pleistocene drift, and it has not been found possible to definitely divide the series. On Old Man Creek and English River there are terraces of materials closely approximating the modern alluvium, though containing a slightly greater proportion of unoxidized loam, at various levels from that of the flood plain to 20 feet beyond the reach of the highest freshets. And along the streams of the northern part of the drift plain there is a thin coating of loam, sometimes irregularly terraced, grading into drift on the one hand and into the modern deposits on the other, with never a line of distinct demarkation. In these and scores of other cases the sequence from Pleistocene espisodes to modern espisodes is unbroken.

Along the smaller streams, and particularly about their confluences, low terraces of modern alluvium frequently occur far beyond the reach of the freshets of to-day. Such terraces frequently flank the stream on both sides, and the stream flows in a narrow gorge, evidently excavated in the plain of which the pair of terraces are remnants, and may have no considerable flood plain; and upstream or downstream a few miles, or perhaps even a fraction of a mile, the stream may wander over a plain evidently homologous with that elsewhere carved into terraces, and the whole plain may be annually flooded. In these cases it is evident that there has been a local and perhaps temporary change in altitude of the river channel—that in its frequent wanderings it has sometimes gone up and again gone down, and alternately formed and destroyed flood plains which in a certain stage in the process of destruction constituted low terraces. Indeed the valleys of the streamlets generally consist of a series of alternating alluvial plains, over which the waters meander sluggishly, and alluvium-free gorges, through which the waters rush rapidly; and it is equally evident that gorge and plain continually shift their places at a rate depending upon the size of the stream and perhaps other conditions, and thus alternate in time as well as in space. The manner in which the movement takes place is discussed elsewhere (chapter II, section 3).

CHAPTER VI.

THE LOESS.

SECTION I.—THE LOESS OF THE NORTHERN AREA.

The most extensive unbroken body of loess in the territory is that occupying the Iowa portion of the driftless area and overlapping the contiguous drift border upon the southwest.[1]

Within this area the deposit departs somewhat from its normal characteristics. It is exceptionally argillaceous, so much so indeed as to be commonly called clay by agriculturists and artisans. At the same time it is exceptionally poor in lime, effervescing but feebly under acid, while the characteristic calcareous nodules (loess-kindchen) and the equally characteristic calcareous tubules of more southerly areas occur only rarely. It is also poor in comminuted silica, the principal siliceous element consisting of quartz sand (found in greatest abundance either toward the base of the deposit or in high level terraces inseparable from it), which is seldom reduced to the finely divided condition characteristic of the deposit in the bluffs of the Missouri. Moreover, fossils are not found in the northern portion of the area, and in the southern portion they are generally rare and some forms are more or less depauperate. These departures from the normal type are specially notable only in the northern half, particularly in the northern third, of the area; for here, as elsewhere, the deposit is variable, even in adjacent exposures. When compared by groups of sections, it is found gradually to change with the latitude until in eastern Jones and northern Clinton Counties it closely approaches the normal type of the Mississippi and Missouri valleys—the materials are fine, homogeneous and pulverulent; partially undecomposed carbonate of lime and impalpably fine siliceous matter are notable elements; loess-kindchen and tubules abound, and the mass is charged with shells of pulmoniferous mollusca.

There is an external feature, depending upon composition and structure, by which the northern loess is distinguished. The characteristic habit of standing long in vertical walls fails in this area; when a face is exposed by erosion or artificial excavation and not kept free of talus by stream-work, the materials crumble and the vertical face is within a few years converted into a slope; yet the

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[1] The distribution of the loess and other Pleistocene deposits is indicated on the map forming Pl. XLIV (in pocket at end of volume).

mass mats (or undergoes partial cementation) to such a degree that the slope remains steep. So the area of the deposit is one of distinctive topography, made up of steep-sloped hills and narrow ravines. But this feature, too, varies from north to south, and in southern Jackson and northern Clinton Counties vertical loess walls stand for years.

There is an attendant feature of the northern loess which appears to be unusual. The deposit is approximately homogeneous from summit to base; but below it passes quickly yet by imperceptible gradation into a sheet of sand, gravel, and bowlder-charged clay, which differs from the upper drift sheet only in the preponderance of coarse materials and in the smaller size and better rounding of the pebbles and bowlders. This basal pebble-bed is characteristic alike of the driftless and drift-sheeted portions of the northern loess area; yet, like the other distinctive features, it weakens and sometimes fails to the southward—for about Baldwin and Monmouth, and in the exposures south of Charlotte, the homogeneous upper portion of the deposit grades downward into silt or laminated and stratified sand, just as do its homologues on the Mississippi at Muscatine and St. Louis, and on the Missouri at Council Bluffs, St. Joseph, and St. Charles.

Thus the loess of the northern area diverges from the normal type in many ways; yet certain features of composition, structure, and geographic distribution ally it to the deposit as typically developed elsewhere, and prove that this is but one of the multifarious divergent phases of an ever varying but always distinctive deposit.

In areal distribution the northern loess extends over practically the whole of the driftless area in Iowa, although in the extreme northeastern part of the State, and especially upon eminences and divides, it is so thin as to be inconspicuous, and so largely made up of local materials as to be scarcely distinguishable from the subjacent residuary clays; it also overlaps the margin of the drift sheet to a variable distance, generally increasing from north to south; and at various localities tongues and spurs extend from the main body westward or northwestward still farther upon the drift sheet, their length generally increasing from north to south.

In hypsographic distribution its range measures that of the relief of the territory. It lines the valleys of the Oneota and the Turkey, the Yellow, the Little Maquoketa, the Tête des Morts, and the Maquoketa, and clogs their tributaries save where removed by erosion; and it also crowns the crests and divides of the great ridge stretching from northeastern Howard County to the Mississippi at the tip of "Cromwell's Nose."

Its thickness is variable, but in general increases from north to south, and also from the Mississippi nearly to the southwestern margin, where it again attenuates. On the eminences of the extreme northeast it is but an inconspicuous veneer; on the gentler slopes at low levels it thickens greatly, the maxima ranging from perhaps 25 feet in the lower Oneota basin to 75 feet or more on the Little Maquoketa, the Catfish, and the Tête des Morts; along the base of the Niagara escarpment it thickens from maxima of 30 or 40 feet in northeastern Howard County to 100 or more feet in the vicinity of the larger mill streams falling over the escarpment into the Volga and the Turkey; and along the culminating crest of the territory just within the escarpment it generally maintains a thickness of 10 to 50 feet to its very verge, and overlooks the contiguous drift plain in a definite but sinuous scarp.

Some of the minor and constantly varying features of the driftless area loess are noteworthy.

While the deposit is in general approximately homogeneous from within a foot or two of the weathered surface to within a few inches of its base, careful examination commonly reveals diversities in composition and structure. The prevailing color is light drab or brown, but it sometimes assumes a light blue below. When this is the case (and occasionally when no change in color appears) the mass may be rectangularly jointed, the jointage planes usually showing a ferruginous stain. Again, jointing may be absent, and the bluish portion may be obscurely laminated; and it is in the blue tinted, laminated phase alone that fossils are commonly found within the northern loess. Such is the character of the deposit at the three northernmost fossiliferous localities in Dubuque County. It is in this phase of the deposit alone, too, that loesskindchen have been found north and east of the Maquoketa River; e. g., in NE. ¼ NE. ¼, Sec. 12, T. 88 N., R. 1 W., Dubuque County, and in NW. ¼ SW. ¼, Sec. 3, T. 92 N., R. 4 W., Clayton County. In the extreme southern portion of the area, however, both fossils and loesskindchen appear in all parts of the deposit, as in the southeastern part of Maquoketa, where shells of the prevailing species of *Succinea*, *Pupa*, and *Helix* are disseminated through the homogeneous, buff colored mass of the deposit from near the surface to the base of a 12-foot exposure, and in the SW. ¼ SW. ¼, Sec. 27, T. 84 N., R. 6 E., where solid and almost perfectly spherical concretions of carbonate of lime are distributed through a large exposure.

A characteristic feature of the northern loess, and indeed of the loess of the territory generally, is found in irregularly cylindrical ferruginous concretions, commonly approaching verticality in attitude, particularly in the upper part of the deposit. These concretions may have been formed about decayed rootlets. Sometimes they are so loose in texture as to amount to little more than concentric yellow and brown stains, deepening in color toward the center; but again they are firmly cemented, and it is noteworthy that the degree of cementation appears to depend upon weathering. In fresh excavations only broad stains may appear, but these gradually contract in area and harden in texture until, in long-weathered exposures, the concretions are firm; and solid concretions exposed in natural gullies are found on examination to gradually expand and become friable within a foot or less beneath the surface.

The materials of the deposit are commonly fine and easily reduced to impalpable powder between the fingers; and, wherever the usual clayey consistency prevails, to such a degree is it compacted by pressure that when freshly turned over by the polished plowshare or compressed in the roads beneath steel-shod hoofs and wheels the smooth surface reflects the rays of the sun like planished metal and dazzles the eyes of the beholder. Yet coarser particles, either concretionary or of crystalline rock, sometimes occur, and perhaps once in each week's examination a pebble or small bowlder, like those in the basal pebble-bed, may be found within the deposit.

By reason of its habit of crumbling and breaking down into talus slopes on weathering, good exposures, revealing the deposit from base to summit, are rare. Artificial excavations are commonly unsatisfactory, too, since the minuter characteristics of the deposit are obscure during the life of an evanescent exposure and become conspicuous only when brought out and emphasized by moderate weathering, so that a mass really abounding in significant detail may long appear uniform and homogeneous throughout. The most satisfactory exposures are found in roadside gullies, in the sides of storm-washed ravines, and in the precipitous falls formed at the heads of the smallest ravines by rain-born rills; for in such outcrops the minutest features are commonly revealed, and what the single cutting lacks in depth is made up in the multitude of cuttings at all horizons.

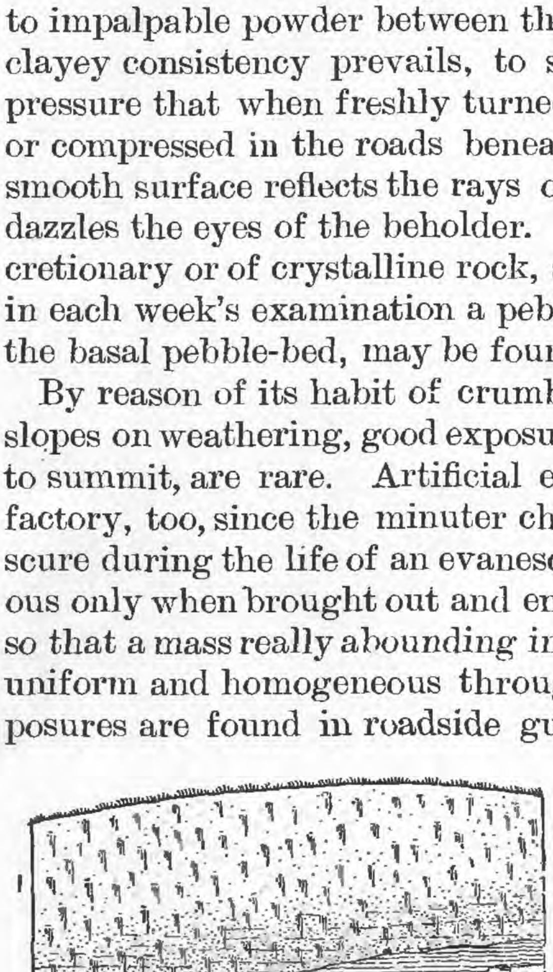


FIG. 38.—Relation of the loess to subjacent deposits in Winneshiek County: (1) Loess, somewhat clayey, homogeneous, and free from coarse material save sparsely disseminated sand grains in its upper portion, becoming decidedly sandy and somewhat pebbly at base, 12 feet. (2) Plastic red clay (geest), granular in texture, containing a few fragments and nodules of chert, with a dark line at base, 1½ feet. (3) Trenton limestone.

An exceptionally complete exposure in the extreme north is that displayed in a deep roadside cutting in the NE. ¼ NE. ¼ Sec. 26, T. 98 N., R. 8 W., Winneshiek County. Here the conditions of drainage are such that the compact residuary clay and the sandy or pebbly base of the loess are carried away by storm floods much more rapidly than the loess recedes by crumbling; and so the cliff is sapped and falls down in vertical slabs a few inches thick, perhaps 3 or 4 feet wide, and 12 feet high. Frequently these slabs cleave off without toppling over, and are gradually let down by the erosion of their bases. The loess in this exposure is, for its latitude, exceptionally rich in lime and poor in clay.

In the deeper sections the northern loess, like that of the other Iowa areas, exhibits an obscurely banded or stratified appearance after some exposure, particularly on the gradual drying of the surface in spring or after a rainstorm. Commonly no difference in the composition or texture of the bands can be detected, and they even disappear if an inch or two of the face be removed. The banding appears simply to betray a slight difference in porosity of successive strata; but sometimes the drier and lighter colored layers are found under the glass to be made up of groups or floccules of particles, while the particles of the wetter layers are not so arranged; and the hygroscopic inequality of the successive bands appears to be due to inequality in degree of flocculation. The phenomenon thus appears to illustrate the effects of the flocculation of fine particles, first recognized by Hilgard.[1] Analogous phenomena have already been noted by Todd in southwestern Iowa.[2] Commonly the darker bands are the thinner in the ratio of 1 to 2 or 1 to 3, and range from 8 inches in thickness downward; and commonly the thickness of the bands is uniform and the attitude sensibly horizontal or slightly inclined toward adjacent lowlands throughout each exposure, as illustrated in Fig. 40; but now and then the bands are curiously contorted. One of the best examples of such contortion (represented in Fig. 39) was observed in a deep roadside gully in the SW. ¼ NE. ¼ Sec. 36, T. 95 N., R. 9 W., in Fayette County. Such contortion has never been observed save on slopes. It is probably due to simple settling of the deposit, accompanied by both compression and slight slipping in the direction of the slope, as in the case of the much more profoundly contorted laminæ of the lower members of the Albany clays on the banks of the Hudson. Contorted laminæ of this character are not confined to the northern loess, but occur occasionally in the deposit throughout the territory.

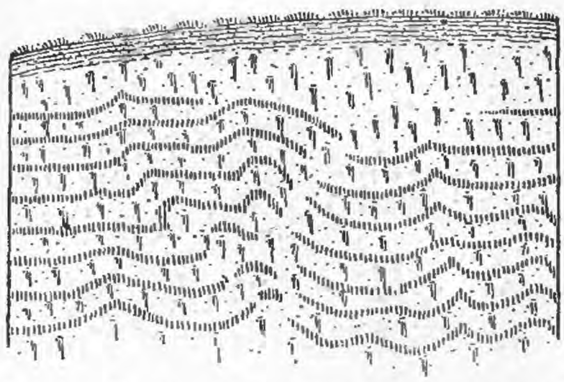


FIG. 39.—Hygroscopic banding and contortion of the loess, Fayette County.

Definite stratification of the deposit is uncommon, and practically confined to the basal portion in a few localities and to the high level terraces into which the loess appears to grade.

It has already been shown that no constant demarkation in altitude, geographic position, or time can be drawn between the Pleistocene and post-Pleistocene deposits in Northeastern Iowa; and the loess

[1] Amer. Jour. Sci., 3d ser., vol. 17, pp. 205 et seq.; ibid. vol 18, p. 110.
[2] Proc. Am. Assoc. Adv. Sci., 1877, vol. 26, pp. 287, 288.

of late Pleistocene terraces sometimes grades up into or is overlain by alluvium, as in the cutting in the SW. ¼, Sec. 14, T. 93 N., R. 5 W., Clayton County, illustrated in Fig. 40. The horizontal banding is

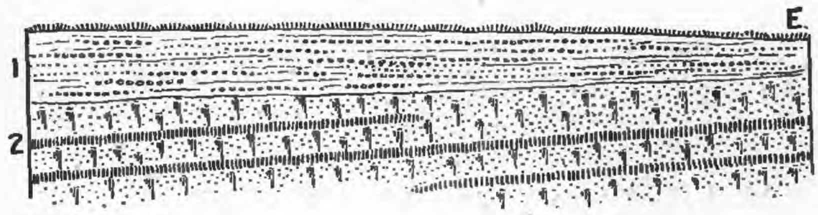


FIG. 40.—Hygroscopic banding of loess and superposition of alluvium, Clayton County: (1) coarse sandy and pebbly loam, irregularly bedded, 4 feet; (2) exceptionally calcareous loess, fine and generally homogeneous, but horizontally banded.

much like that displayed at Muscatine and illustrated in plates XLVIII, and XLIX. This section exhibits the structure of a broad strath, perhaps a square mile in extent, overlooking Turkey River just north of Elkader. The strath is nearly circumscribed by precipitous bluffs of Galena limestone; and although 60 feet above the river level, or about the average height of the upper terraces of this part of the stream, the enfeebled drainage of post-glacial times has apparently been unable to commence the destruction of this part of the terrace, and has indeed only buried it beneath débris gathered from the bounding bluffs.

Everywhere beyond the Niagara escarpment and the coincident drift margin, the northern loess appears to be made up in part of the residuary clays which formed the surface deposit during the ante-Pleistocene time. This intermingling of deposits is shown in various ways: (1) The element of clay in the loess varies inversely with the extent of residuary clays in its vicinity. Thus in the north, where its volume is slight in proportion to the volume of subjacent residuary clays, the loess is especially rich in clay; the clay element increases from the drift margin eastward toward the interior of the driftless area under each parallel; and the same element diminishes under each meridian southwestward from the interior of the driftless area until it becomes inconspicuous in Jones and Clinton Counties. (2) The incorporation of geest within the northern loess is indicated by the high proportion of iron found in the deposit; for the residuary clays are always ferruginous, and most of the other components of the loess are non-ferruginous. The distribution of the iron in this as in other deposits is determined by various conditions, one of the most important of which is weathering; so a ferruginous band is frequently found a few feet beneath the surface of the deposit within the driftless area. Commonly this band is parallel with the surface, as in the accompanying section (Fig. 41) observed in a roadside gully in the SW. ¼ NW. ¼ Sec. 3, T. 90 N., R. 2 W., Dubuque County. Here the incorporation of residuary products is indicated not only by the prevalently argillaceous character and the pronounced ferruginous staining, but by the presence of two rounded pebbles of jointed red clay identical with that of the prevailing mantle of the rocks within the

FIG. 41.—Ferruginous banding of the loess, Dubuque County: (1) Somewhat incoherent loess, brownish drab in color, 2 feet; (2) brownish red band, partially indurated, 3 inches; (3) clayey loess of the usual aspect, containing two rounded lumps of dark red plastic clay, similar to residua of Niagara limestone exposed a few rods away, 5 feet.

driftless area. Sometimes, however, the ferruginous banding is not parallel to the surface but approximately horizontal, and probably coincides with the hygroscopic banding already noticed, as shown in Fig. 42 (roadside gully in NW. ¼ SE. ¼ Sec. 28, T. 91 N., R. 2 W.,

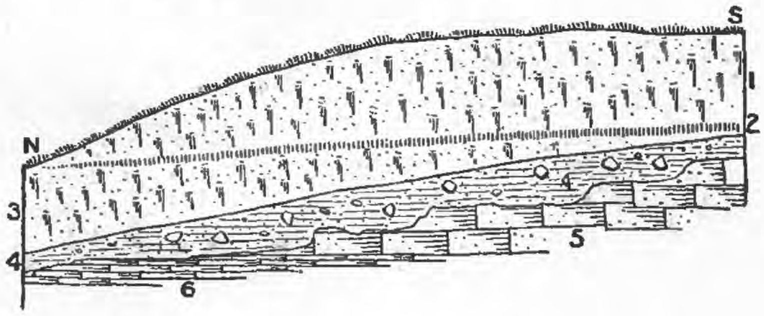


FIG. 42.—Ferruginous banding of the loess, Clayton County: (1) Brownish drab loess, 6 feet; (2) partially cemented ocherous band 3 inches; (3) homogenous loess with small cylindrical concretions, 3 feet; (4) brownish red clay, compact, tenacious, with a few fragments of local chert and erratic pebbles, 1 foot; (5) Niagara limestone; (6) Maquoketa shale.

Clayton County). More rarely the ferruginous staining is irregular, and associated with firm nodular concretions like those of the drift. This case is illustrated in Fig. 43, observed in the NW. ¼ SW. ¼ Sec. 33,

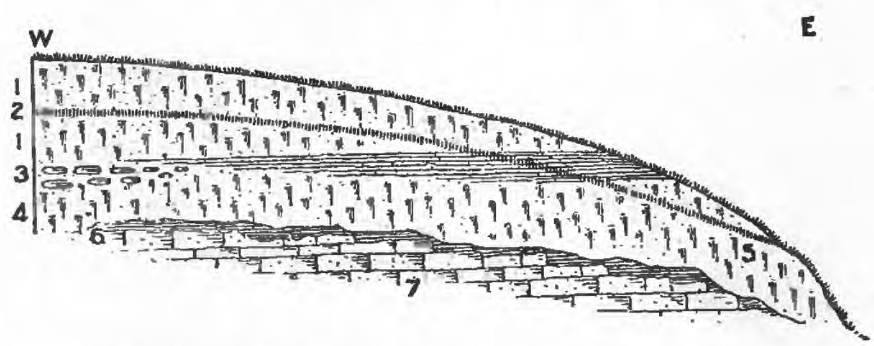


FIG. 43.—Ferruginous banding of the loess, Clayton County: (1) Loess, homogeneous, light drab in color, 7 feet; (2) ferruginous band; (3) loess, homogeneous, somewhat silty and unusually light colored and calcareous, thinning westward and giving place to a bed abounding in loess-kindchen and large calcareous concretions, 2 feet; (4) somewhat silty loess with a bluish tinge, containing loess-kindchen and branching tubules of lime carbonate, 4 feet; (5) the same with the calcareous concretions replaced by cylindrical ferruginous concretions and irregular ferruginous nodules, 4 feet; (6) unctuous red clay; (7) Galena limestone.

T. 92 N., R. 4 W., in Clayton County. The exposure is of additional interest in that it is the northernmost in which loess-kindchen have been noted, in that there is a moderately definite bedding through which the ferruginous band passes, and in that one of the beds is exceptionally calcareous, running into large calcareous nodules in a part of the section.

In general the northern loess forms a mantle of varying thickness stretching from interior drift plain to the Mississippi bluffs—a mantle thickest over the greatest topographic crest which balked the ice-sheet, and thence thinning over divides and thickening in valleys toward the great river. But the mantle has been rent by erosion, completely asunder in the valley of the larger streams, half through in the smaller valleys; and there are some tracts on divides within the area sub-mantled by drift in which the loess mantle fails. In some such cases the loess was never deposited, and in others it has been removed by erosion; yet in the last case it has always left an unmistakable record of its former presence, however wide the area from which it has been swept. The northern loess is never without a basal pebbly layer or sand bed, and when the finer materials are transported by the waters, pebbles and bowlders or coarse sands remain, giving a surface deposit quite unlike the drift. Moreover, loess develops a distinctive topography, in which the horizontal elements are small, the hills pygmy, the divides narrow, and the ravines frequent; and after the removal of the deposit the crowding of drainage lines persists, and there is developed a topography possessing the flatness of the drift but not its sparse distribution of waterways. Again, the scarp in which the remnant of the loess overlooks such denuded areas has the characteristic slopes and contours of modern erosion, while the normal loess scarp is characterized by its own distinctive and unmistakable slopes and contours which are not determined and only slightly modified by modern erosion. This distinction between primary and denuded drift surfaces is valid not only about the driftless area, but throughout Northeastern Iowa; it can not be too strongly emphasized that the primary drift surfaces and those surfaces from which the loess has been removed are so distinct that the two need never be confounded even by casual observers. So the original as well as the present distribution of the loess mantle may be ascertained with high accuracy.

The pebble-bed at the base of the northern loess is a noteworthy and essentially constant feature. This stratum is so unlike the mass of the loess and so like the upper drift sheet in composition and texture that in a taxonomy based on these characters it might with propriety be classed with the latter deposit; yet it is a universal associate of the loess within and about the driftless area, accompanying it over divides and through valleys in the area untouched by ice, and separating it from the drift sheet where the two are associated southwest of the great Niagara escarpment; into it the loess invariably grades, sometimes so rapidly as to suggest unconformity, but generally by imperceptible transition or interlamination; and it reposes unconformably alike upon the Paleozoic rocks, the residuary clays derived from them, the older drift sheet where it extends beyond the newer in the northern counties, and (generally) the newer drift sheet in the central and more southerly counties. In structure the deposit is distinct from the loess, yet the two intergrade; in distribution they are conterminous; in composition they are indeed diverse, but the diversity is chiefly in degree of comminution; in time of formation they are evidently immediately successive; and in genesis they are unquestionably related.

So prevalent is the basal pebble bed that it appears in greater or less volume in nearly every section exposing the base of the loess. In Fig. 44 (well, in NE. ¼ SW. ¼, Sec. 31, T. 89 N., R. 1 W., Dubuque County) it is bitartite, the lower portion consisting mainly of local chert irregularly disseminated throughout an unstratified reddish yellow, sandy clay, while the upper portion consists of erratic bowlders and pebbles closely packed in a similar matrix. In this section the erratics are large, sub-angular, and rounded, comprising granite of two or three varieties, hornblende schist, hematite, quartzite, etc., 2 feet and less in diameter, none distinctly striated, but one polished; and a similar bowlder bed is exposed in an adjacent road-cutting as shown in Fig. 65. Here the loess, with its basal pebble bed, rests upon the newer drift sheet.

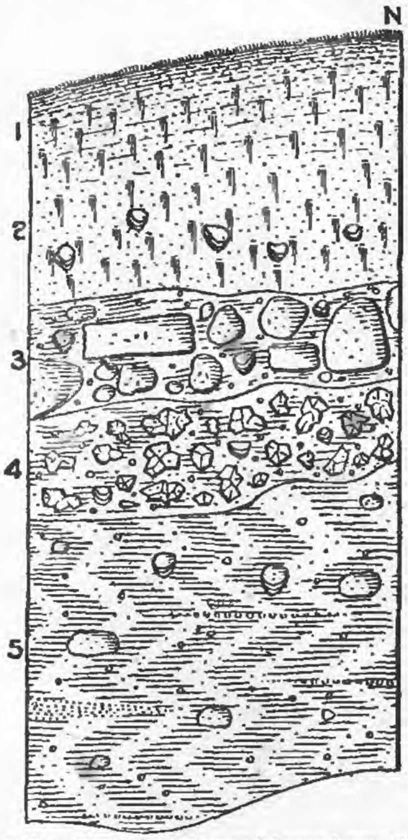


FIG. 44.—Bowlder-charged loess-base, Dubuque County: (1) black surface soil; (2) loess, stained dark blue; (3) yellow sandy clay with great numbers of erratic bowlders (the larger of which are drawn to scale) and a few cherty fragments; (4) similar clay packed with nodules and fragments of chert; (5) unstratified yellow clay with a few small bowlders and striated pebbles. Exposure, 10 feet.

Quite beyond the drift margin the relations are similar. In a specific case the basal deposit consisted of sandy and gravelly yellow clay containing numerous erratic pebbles and bowlders, including one of brown quartzite, sub-spheroidal but unworn, 18 inches in mean diameter; one of hornblende slate, angular and unworn, 8 by 15 by 30 inches; one of coarse-grained hornblende granite, angular, 6 by 8 by 10 inches; and several of smaller sizes. The whole reposed unconformably upon obscurely laminated blue plastic clay, containing a few small local pebbles at its base. This exposure was observed some miles from the Niagara escarpment and within the driftless area proper, in the SE. ¼ NW. ¼, Sec. 12, T. 88 N., R. 2 E., Dubuque County. It is, however, exceptional to find the included bowlders so largely erratic in the interior of the driftless area—indeed, outside the drift margin the pebbles are smaller and more largely local in most cases than those of the subjacent drift; and within the driftless area they are still smaller and more largely local.

While in general the pebble bed is more or less distinctly separable from the newer drift sheet, this relation is not invariable; for, as in the section represented in Fig. 45 (observed in the NE. ¼, Sec. 20,

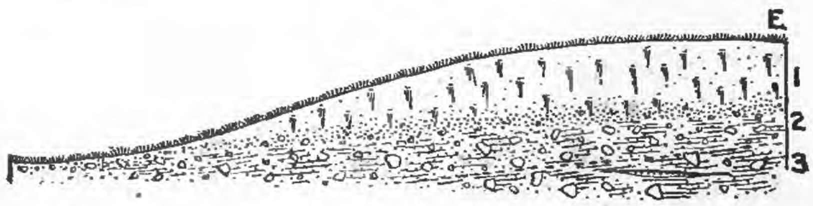


FIG. 45.—Relation of loess to basal pebble bed, Dubuque County; (1) brownish drab loess, 6 feet; (2) yellowish brown loam, charged with fine gravel and larger pebbles, both local and erratic, 5 feet; (3) brownish yellow clay with worn erratic bowlders (some polished) and lenses of sand and gravel, 4 feet.

T. 90 N., R. 2 W., in Dubuque County), no other than an arbitrary line can be drawn between the deposits, though the bowlders decrease in size and increase in number and degree of rounding upward. Despite the rapid and complete change in appearance between loess and drift displayed in this section, there is no indication of unconformity, no mark of erosion, no oxidation, no ancient soil, no ferruginous stain; and in some cases intergradation is evident. A natural gully in the SE. ¼ of the SW. ¼, Sec. 5, T. 87 N., Dubuque County, displays distinctive loess above and distinctive drift below, separated by a bed of composite character, into which the former

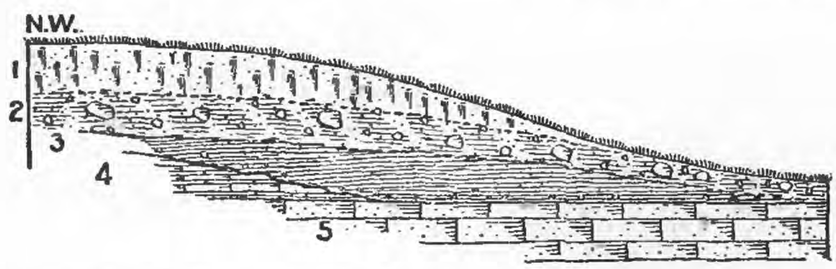


FIG. 46.—Relation of loess to basal pebble bed, Dubuque County: (1) loess: (2) stony, sandy, and gravelly yellow clay; (3) plastic blue clay; (4) Maquoketa shale; (5) Galena limestone. Mean exposure, 10 feet.

grades by imperceptible stages, while the demarkation from the latter is even less easily found. In a neighboring gully the pebble bed is fairly distinct from the loess, and sharply demarked from the subjacent blue clays representing the marginal and superior phase of the older drift sheet (Fig. 46).

The basal bed of the loess is protean in composition as in structural relations. Sometimes pebbles are altogether absent, and the loess simply becomes sandy toward the base, as in the section forming Fig. 47 (observed half a mile south of Cascade, within a few yards

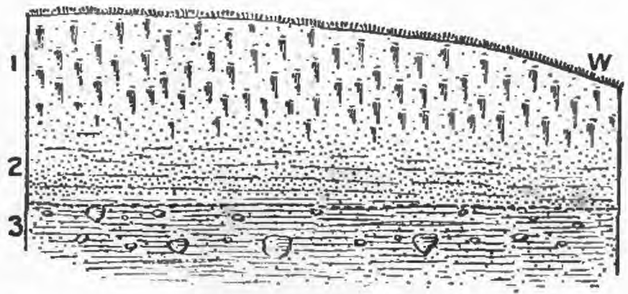


FIG. 47.—Transition of loess to sand, Jones County; (1) Loess, slightly silty above, grading into sand below, 12 feet; (2) obscurely stratified sand, fine above, coarser below, 5 feet; (3) dense, tenacious blue clay, with ferruginous nodules above and sparsely disseminated greenstone pebbles below, 5 feet.

of the Dubuque-Jones County line). Here the newer drift sheet is absent, and the loess rests unconformably upon an old soil representing the interglacial forest bed, and at lower levels upon a bed of gravel representing the older drift sheet.

The basal member of the northern loess is as variable in thickness as in the degree of comminution of its materials. In a railway cutting through one of the characteristic narrow divides of the area (in

FIG. 48.—Relation of loess to basal pebble bed, Dubuque County; (1) Loess; (2) brownish yellow, pebbly sand and clay with erratic bowlders; (3) yellow drift clay containing large erratic bowlders. Maximum exposure, 20 feet.

SW. ¼ NW. ¼, Sec. 9, T. 88 N., R. 1 E., Dubuque County) exhibited in Fig. 48, both members of the deposit mantle a still narrower ridge of drift, attenuating over its crest and thickening along its flanks, save where reduced by degradation.

All the foregoing variations in the basal member of the northern loess occur within a radius of 10 miles. They exhibit well its leading features and its protean character; for little greater or little different variations can be found within the entire area.

While the loess with its attendant pebble bed forms a nearly continuous mantle over the driftless area and the adjacent drift margin, and while its surface is (save in the minor features due to post-Pleistocene erosion) conformable in a general way to the older surface upon which its rests, there are a few cases in which the old surface and the new are discordant, and in which the relations of the deposit betray slight geographic changes, usually the abandonment of old and the selection of new waterways. An example of such geographic change is illustrated in Fig. 49, observed in the SW. ¼, Sec. 27, T. 88 N., R. 1 E., Dubuque County. It is noteworthy, too, that here, as well as farther southwestward, the loess displays a

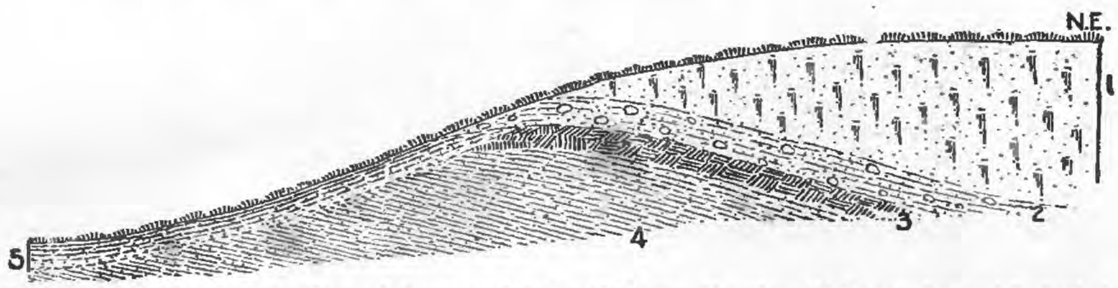
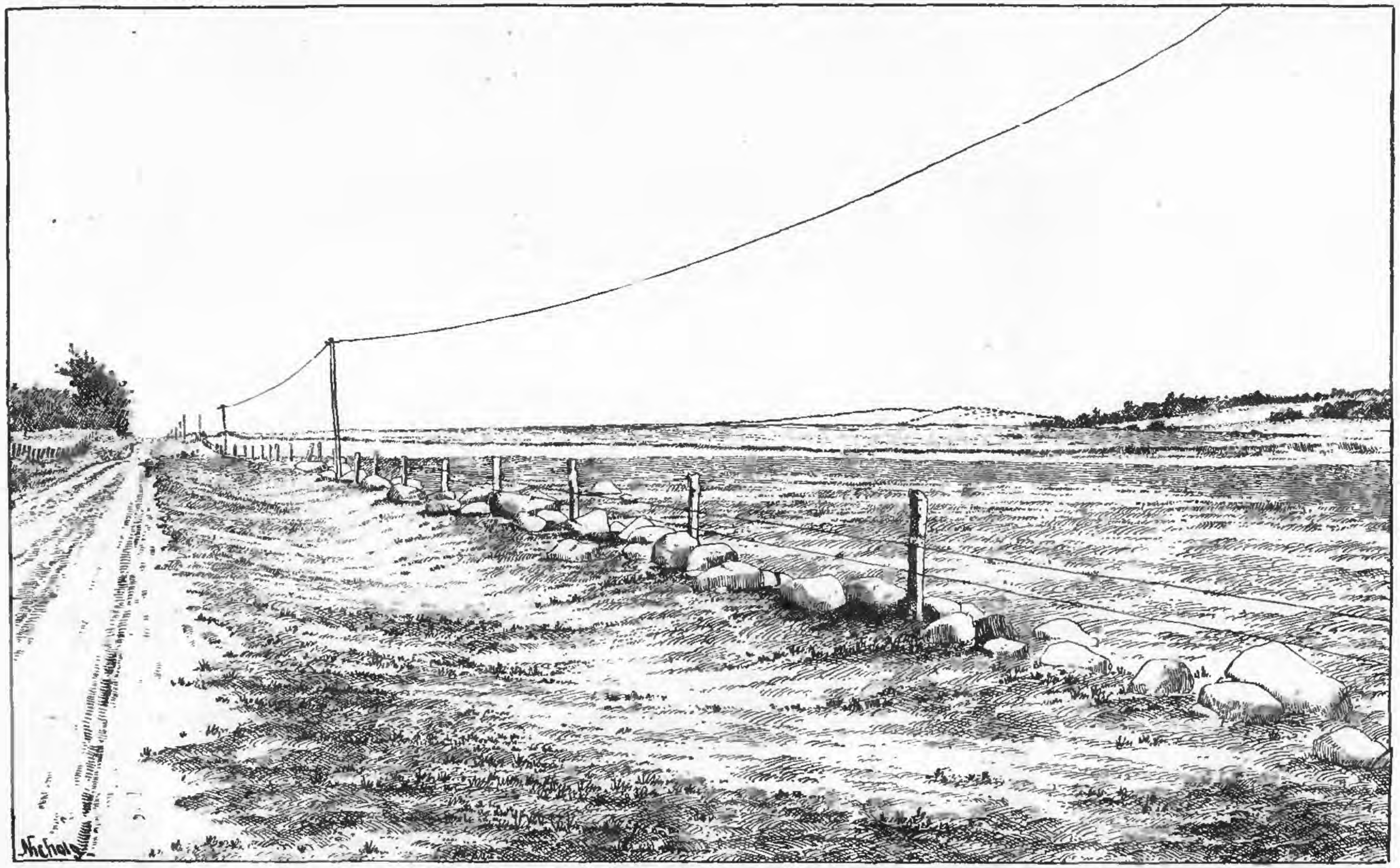


FIG. 49.—Discordant deposition of loess and drift, Dubuque County: (1) Loess, brownish drab in color, 6 feet: (2) obscurely stratified sand and pebbly clay, 1 foot; (3) dark brown friable earth with ferruginous nodules and traces of wood (forest bed), 1 foot; (4) clean, finely laminated plastic blue clay, weathering whitish drab (lower till), 5 feet.

tendency to accumulate on southerly slopes of summits and on northerly slopes in valley bottoms; but this tendency is best marked among the paha.

In brief, while the basal pebble-bed is protean, it is a (if not *the*) distinctive feature of the northern loess; yet it is, perhaps, not altogether superfluous to point out that the feature is not wholly unique. Throughout Northeastern Iowa the loess everywhere grades downward into (1) a bed of water-laid sand and gravel like that exhibited in most of the foregoing sections; (2) stratified sand, like that exhibited in Fig. 47; or (3) modified glacial drift. The same proposition is true of the loess of the Missouri and the Mississippi Rivers generally. About Sioux City the loess is sandy below, and the sand frequently passes into a pebble bed; in southwestern Iowa the drift thins as the loess thickens toward the Missouri River (as shown by White and St. John), and at Council Bluffs and Omaha beds of sand and pebbles occur near its base. At St. Joseph the city is supplied with sand taken from the lower part of the loess; no line can be drawn between the homogeneous deposit above and the sand below, and the same fossils run through both. The deeper excavations at St. Louis generally reveal a bed of sand and pebbles or both at the base of the loess, and the two classes of materials intergrade; and the prevailing relation holds still farther southward. The relation between the homogeneous upper member and the heterogeneous lower member of the loess, not only in Northeastern Iowa but throughout the upper Mississippi Valley, is identical with that existing between the homologous (but probably much older) members of the early Pleistocene Columbia formation of eastern and southeastern United States.

Perhaps the most striking attribute of the northern loess is the great altitude at which it occurs. The highest lands in Northeastern Iowa are found in the neighborhood of the Niagara escarpment. The Paleozoic terrane here is commonly covered with the ground moraine



A TYPICAL LOESS MARGIN, FAYETTE COUNTY.

of the Pleistocene glacier, and the land is thus further elevated; but over the obdurate Paleozoic strata, over the dense tenacious drift sheet, up to and over the culminating summits and crests of the entire territory of 16,500 square miles, the fine, friable, readily pulverulent materials of the loess are heaped; and the real altitude is emphasized and exaggerated by the nearly universal forest covering. Along its southwestern boundary the deposit, in its main body and in its digitate spurs, and outliers as well, invariably overlooks the contiguous drift plain; and isolated basins of drift are sometimes found along the loess margin, or even miles within the loess area. The most notable of these completely isolated drift basins is that of southern Dubuque County, between Fillmore and Bernard; but the nearly isolated basin in the western part of the same county, between Dyersville and Epworth, is nearly as striking. The intermediate village of Farley is located on a drift plain, smooth, level and bowlder-dotted as those of 50 miles northwestward; and this drift plain is overlooked from north and south, and less prominently from east and west, by the elevated rim of loess hills, which is barely broken eastward and westward by streams leading respectively into the Little Maquoketa and the North Maquoketa. The hypsographic relations of loess and drift in the southern rim of this basin are shown in Fig. 7 (p. 218); and a profile through it forms Fig. 50. Another noteworthy drift basin is that lying east of Lima, in eastern Fayette County, where the drift floor represents the lower till.

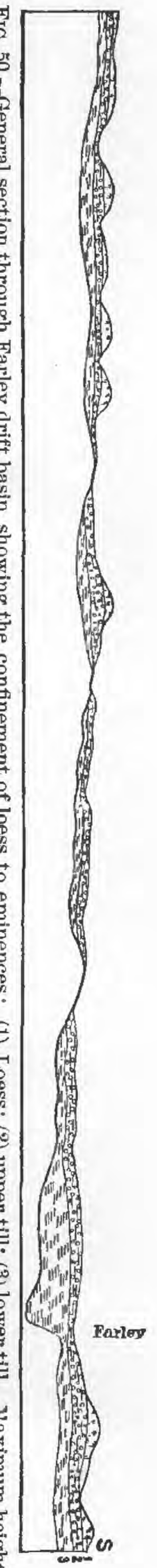


FIG. 50.—General section through Farley drift basin, showing the confinement of loess to eminences: (1) Loess; (2) upper till; (3) lower till. Maximum height from base line, 200 feet; length, 6 miles.

Viewed as a unit, the northern loess varies notably from the well defined margin skirting the drift border belt to the vaguely defined eastern margin traversing the interior of the driftless area a few miles beyond the Mississippi. On the west the deposit maintains its thickness to its very verge, crowns the highest crest within scores if not hundreds of miles in scarcely diminished thickness, and overlooks the drift plain in a prominent scarp; while northeastward the deposit thins rapidly to and still more rapidly beyond the Mississippi, becoming in Wisconsin a sediment-like mantle, thickest in valleys and thinnest over divides, failing or blending with the subjacent residua over the greater eminences and dying out so gradually that its margin can not be traced; in the one case the loess-border is marked by a conspicuous topographic boundary, while in the other it is not only unmarked topographically, but is too vague for structural demarkation.

Within the northern loess area fossils are moderately abundant in many southern localities, rare in the middle latitude localities, and practically absent north of latitude 42° 30′. The forms are sometimes more or less depauperate in the south and commonly either depauperate or of boreal species in the most northerly localities in which they have been found. Two of these localities are: (1) A railway cutting in NW. ¼ SE. ¼ Sec. 15, T. 89 N., R. 1 E., Dubuque County; and (2) a road cutting in NE. ¼ NE. ¼ Sec. 12, T. 88 N., R. 1 W., Dubuque County.

The collections from these and some other localities in the northern area (which were unfortunately lost) are fairly represented by collections made just beyond the Mississippi in Galena and Fulton (opposite Dubuque and Clinton respectively). These have been identified and briefly discussed by R. Ellsworth Call, as follows:

Galena.	No. of specimens.	*Fulton.*	No. of specimens.
Succinea avara	31	*Succinea avara*	6
Succinea obliqua	8		
Patula striatella	17	*Patula striatella*	2
		Patula strigosa	1
Vallonia pulchella	1	*Vallonia pulchella*	5
Limnophysa humilis	2	*Limnophysa humilis*	1
Limnophysa desidiosa	2		
Pupa contracta	1		
Pupa muscorum	1	*Pupa*, sp. und	2

Of the five genera, four (*Patula, Vallonia, Pupa,* and *Succinea*) are land forms, and one (*Limnophysa*) is fresh water; but one of the land forms is commonly found near the water's edge, or in other moist stations. All of the species save one (*Patula strigosa*) are known to now live east of the headwaters of the Missouri, or in a general way within the region in which the fossils are found. Several of the shells diverge more or less from the living forms, but the most notably depauperate species is *Succinea obliqua,* from Galena, nearly all of the shells of which are considerably less than the normal size of those now living in adjacent parts of Illinois. The relative abundance of species is approximately indicated by the numbers of individuals comprised in the collections.

It should be observed that the collections from the Illinois localities come from low levels and near the surface, while those from Iowa were found upon uplands and in the lower portion of the deposit, and that the former are thus somewhat newer than the latter.

Perhaps for this reason the individuals of the Illinois collections are perceptibly larger and much more abundant than those of Iowa.

Another fossil-yielding locality in the northern area is found in the NE. ¼ SE. ¼, of Sec. 5, T. 87 N., R. 1 W., Dubuque County, 5 miles south of Farley; and a few fossils have been found still farther northward in one of the northernmost of the isolated loess areas along the Cedar River, viz, near the center of Sec. 27, T. 91 N., R. 13 W., Bremer County, 6 miles southeast of Waverly. Small collections from these localities were studied by Prof. B. Shimek, of the State University of Iowa, with the following results:

Farley.	No. of specimens.	*Waverly.*	No. of specimens.
Helicodiscus lineatus Say	7	*Helicodiscus lineatus*	1
Succinea avara Say, (var.)	20	*Succinea avara*	19
Pupa decora, Gld	1		

The Farley fossils.—Three of the specimens of *H. lineatus* are mature, four young and imperfect. They "differ in no way from recent shells from Iowa and Nebraska. This species now has a very wide distribution in this country, being found throughout the United States and British America, and is remarkably constant under the various conditions of climate and environment incident to its wide distribution." Only four of the specimens of *S. avara* (var.) are perfect adults. "This form answers in all respects to the description of the shell of *S. verrilli*, Bld. (Binney's Terrestrial and Air-breathing Mollusca of the United States and adjacent Territory, vol. v), which is probably a variety of *S. avara*, Say. It is now credited to the *northern region* of the *eastern province* of Binney, though a form apparently identical in the character of the shell is common about Lincoln, Nebraska." The specimen of *P. decora* represents an adult of about the usual dimensions of the living form. "The species is now restricted to the *northern region* of the *eastern province*."

The Waverly fossils.—The single specimen of *H. lineatus* "is precisely like the Dubuque County specimens." Of the nineteen specimens of *S. avara*, eight are mature, eleven immature. The form "is much like the *S. verrilli* mentioned above, but the specimens are larger and approach a little more nearly the typical *S. avara* of Say than do the Farley fossils. The difference, however, is slight; and what has been said above of the distribution of this form will apply equally well here."

"Of the three species from Farley and Waverly, two (viz, *Pupa decora* and *Succinea avara*, var. *verrilli*) are restricted to, or, if proper allowance be made for the variability of the *Succinea*, at least are prevalent in northern latitudes, while the third species (*Helicodiscus lineatus*) has an exceedingly wide distribution. The fossil specimens of *H. lineatus* and *P. decora* do not differ in any way from recent representatives of the same species. The fossil specimens of *S. avara*, var. from Farley are smaller than the recorded average dimensions of *S. verrilli*, while those from Waverly average larger. Both can be duplicated, however, by unusually slender living forms from Iowa and Nebraska. The great variability of this species, both fossil and living, makes it unsatisfactory as a basis for conclusions concerning habitat, etc."

SECTION II.—THE LOESS OF THE RIVER RIDGES AND PAHA.

The area within which this phase of the loess is developed lies southwest of the driftless area and northeast of the Iowa River, except about its great elbow. While this area is large, forming a broad zone extending from the northern and western boundaries of the territory nearly to the Mississippi, but a small part of it is actually loess-covered; for the deposit is commonly distributed over it in flecks and strips, each of little extent, and only reaches notable volume in the southeastern half of its zone. The accumulations in the northwest are confined to a few plateaus and ridges in the vicinity of rivers, the most noteworthy being those in northern Mitchell County in the neighborhood of Osage, in eastern Floyd and western Chickasaw Counties about Charles City, and in western Bremer County near Waverly. It includes in its southeastern portion the loess belt skirting the Iowa River toward and about its great elbow in northern Iowa and Johnson Counties, the similar belts fringing the Cedar, the Wapsipinnicon, the upper half of the Maquoketa and their tributaries, and the various outliers over the divides separating these rivers.

Throughout this zone the composition, texture, structure, and general aspect of the loess is fairly uniform. It is decidedly more calcareous than the northern loess, effervescing freely under acid and frequently containing sparsely disseminated loess-kindchen[1] and tubules,[2] and it is decidedly less clayey, and accordingly is neither notably tenacious when wet nor intractable when sun dried. It is more uniform in texture than the northern loess, seldom exhibiting the peculiar jointed or granular character normal to the driftless area, but breaking down in fine dust and isolated coarser particles rather than grains and masses on weathering. At the same time its component particles appear more heterogeneous; when rubbed dry between the fingers it is readily pulverulent, and the greater part of the mass is found to consist either of impalpable particles or of rounded and subangular grains, ranging in size from coarse sand downward in a continuous series; the whole mass, when highly mag-

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[1] Spheroidal or irregular nodules of carbonate of lime.

[2] Irregular, hollow, twig-like concretions of carbonate of lime.

STRIATED BOWLDER FROM LOESS OF THE NORWAY PAHA.

nified, simulating an aggregation of bowlders, cobbles, pebbles, and coarse sand grains embedded in a matrix of finer sand and silt.

In structure the deposit is usually homogeneous and massive, particularly in its upper portion, while its lower half is sometimes banded like the northern phase of the deposit under certain conditions of wetness, though seldom definitely bedded; and toward the base it is commonly laminated and sandy or interstratified with sand beds and passes down into stratified coarse sand or fine gravel. Foreign materials are rarely found within it; in perhaps one in twenty of the sections commonly exposed in railway or roadway cuttings, cellar excavations, and roadside gullies, bowlder-like masses of drift clay, ranging from an inch to a foot or two in diameter, may be found; in one section in a hundred an erratic pebble (generally well rounded) may appear; in one section in five hundred a bowlder a foot or more in diameter may be found; and in one section of the many thousands examined a limestone bowlder (represented in Pl. XLVI), so beautifully striated as admirably to illustrate this class of icework, came to light.

In color, in erosion habit, and in other external characteristics, the loess of the river ridges and paha is intermediate between the northern phase and the typical deposit in the bluffs of the Missouri River. Its color is yellowish or brownish drab, while the prevailing colors on the upper Mississippi and on the Missouri are reddish drab (or brown) and pale drab respectively. Vertical faces of it formed by artificial excavation or erosion stand long, as in the latter region, while the winds bear away the fine dust, leaving the coarser particles gradually to accumulate in taluses, as in the former; and its topography is one of steep slopes and narrow ravines, as on the Mississippi, and in the sides of these rise miniature scarps and cliffs of the undisturbed deposit, as in the Missouri bluffs.

The characteristic topography of the loess is, however, exhibited only in the interiors of the more extensive plateaus and on the broader ridges of the deposit. The loess scarps overlooking the drift plain are generally so steep and high as to be conspicuous in a land of low relief, yet so gentle and of so limited height above base level as to be scarcely attacked by erosion. The river ridges are indeed sharply incised by miniature dendritic drainage systems on the riverward slopes, yet the gentler slopes toward the drift plain divides are smooth and soft contoured, and the narrower ridges and smaller paha traversing the divides may show no trace of erosion; and the soft and peculiarly graceful contours by which they are characterized may betray no semblance to the equally characteristic contours of the broader tracts.

But the loess of the paha gives a distinctive topography. The isolated hills are in plan elliptical and more regular than any other topographic forms save possibly the drumlins of Massachusetts and central New York, and in profile their curves are flattened double sigmoids, and the smooth convexities of their upper halves shade off into gentle concavities blending with the plain; and in the compound paha, made up of series of nearly isolated or closely joined swells, the curves of the profile unite in a sinuous line of peculiar grace—a continuous chain of Hogarthian curves of beauty, as distinctive as the deposit it bounds. The sweeping curves are too long and low to be well caught by the camera; but imperfect examples appear in Pls. XVIII and XL. The distinctive paha profile is readily recognized at any distance; and within much of the region of river ridges and paha it is never out of sight.

The geographic and hypsographic distribution of the loess of the middle zone is unique. In general the deposit seeks waterways and forms the plateaus through which the rivers run or the ridges in whose axes the cañons are carved; from the principal plateaus long fingers extend perhaps miles upon the drift plain, giving the isolated areas peculiarly digitate outlines; and occasional isolated or nearly isolated ridges sprinkle and sometimes span the divides. And the longer axes of the plateaus, the ridges cleft by the rivers, the narrower ridges upon the divides, and the larger axes of even the smallest isolated paha upon the drift plain, fall into the peculiar radial and curvilinear system which characterizes the topography of the central part of the territory; for all the higher ridges of the ridged-drift region are of loess. The remarkable linear arrangement of surface forms and deposits is imperfectly illustrated in the maps showing hypsography and superficial deposits (Pls. XXX, XLIII, and XLIV).

In hypsographic distribution the deposit everywhere seeks eminences. There is no prominent plateau, or ridge, or knob within the region of this phase of the loess that is not crowned by the deposit; and there is no considerable accumulation of the deposit except at a relatively high level. No single profile line covering both deposits has ever been seen in the entire zone that does not curve downward in passing from loess to drift, save where the contours are manifestly determined by modern erosion; and even the smallest outlier of the loess overlooks the drift plain in all directions. And here, as in the driftless area, the student readily recognizes drift areas from which loess has been removed by erosion; the eroded scarp of the loess loses its graceful curves and takes on the sharper erosion contours; the close-branched dendritic drainage system of the loess (which is altogether unlike the lax and fortuitous arrangement of waterways upon the unmodified drift plain) is superimposed upon the subjacent deposits; and remnants either of the loess or of its basal sands remain to mark the area of the superimposing deposit.

In certain localities, remnants of the basal sands of eroded loess are conspicuous. Southwest of Rockville, in eastern Delaware County, and west of Delhi, in the same county, there are limited tracts of wind-blown sand marking the positions of partly or wholly eroded paha; and in the first locality these sands are exposed to the sweep of the winds passing over miles of gently ascending prairie land, which heap up the loess sand in the lee of fences in banks and drifts like those of winter's snow. South of Brandon, in southwestern Buchanan and northern Benton Counties, there is an extensive tract of similar sands rising at one point into commanding eminences, and everywhere exhibiting characteristic eolic configuration, though now wooded here and there; north of Oxford and south of Tiffin, in western Johnson County, there are tracts of sand hills interspersed with ponds, by which the erosion of the northern boundary of the southern loess may be measured; a few miles northwest of Princeton, Lost Creek has deeply dissected the upturned northern rim of the loess tract of eastern Scott County, removed the homogeneous upper part of the deposit in whole or in part over a considerable tract, and left the basal sands to form water-cut hillocks and wind-carved drifts and dunes, interspersed as usual with ponds and lakelets; and in many other parts of the territory there are similar stretches of shifting sands heaped up in irregular drifts and mounds and impressed with irregular pits and troughs (sometimes partly filled with water), all assuming the peculiar chopped-sea aspect of eolic sculpture. In a score of cases the loess has indeed been locally removed by erosion, but there are no more distinctive and easily discriminated areas in the entire territory than these; and the paha and the plainward sides of the river ridges have seldom been appreciably modified by modern water work.

It can not be too strongly emphasized that the peculiar distribution of the loess of this region is essentially primary, and so that the deposit is now almost as nearly continuous as at the time of its formation. This is illustrated by the representative paha depicted in Pl. XLI, which represents detailed surveys by W. J. Peters and C. T. Reid. In addition to the larger loess areas, which as usual are characterized by rugose configuration, there are within the tract covered by the map two isolated paha rising sharply from the drift plain. Now a glance at the map suffices to show, and a glance at the tract itself shows still more clearly, that there is a dearth of well defined waterways upon the plain from which the paha rise, that a considerable part of the area consists of sloughs, and that still larger areas are gentle slopes from which the water of storms and snows seeps slowly away through and over the sod, and consequently that no considerable aqueous erosion and transportation can have taken place under existing conditions of base level, etc. Moreover, inspection of maps, even without study of the ground, indicates that the base level, local or general, has never been materially lower than now since the shaping of the drift plain; for both the Wapsipinnicon and the Cedar, into which the waters of the tract drain, sometimes flow upon rock bottoms and are now gently corrading their channels, while the smaller streams flow commonly upon drift and never in drowned valleys, and there are no other channels such as a stimulated drainage would inevitably develop. Again, while the drift plain from which the paha rise betrays only the feeblest traces of water sculpture, it displays the most conspicuous marks of ice molding; at the same time the profiles and contours of the paha are those characteristic of such elevations, and not those produced by water carving, either in loess or in any other known deposit; and accordingly inspection of the map, even without examination of the ground, shows that the configuration of plain and paha alike is unlike that which would result from nearly complete removal of a once continuous mantle of paha materials. Once more, the material of the drift plain is unmodified glacial drift, without the slightest remnant of superincumbent water-laid deposits save in the loess areas and paha. Finally, the paha in general are intimately related to local accidents of the subterrane and local peculiarities of the drift mantle, and are not found where these accidents and peculiarities fail. In short, if geologic history can ever be read from land configuration, it is evident that the Stanwood and Olin paha are not remnants of a once continuous formation, but that the configuration of the tract of which they form a part is essentially primary; and these paha are types of a class, every member of which gives coincident testimony. The structural testimony is of like tenor, yet even by itself the morphologic relations clearly indicate that the paha and the plains to-day retain approximately their original forms and dimensions.

It is noteworthy that the loess of the river ridges and paha is usually but a mantle, and sometimes only a veneer, over a nucleus of glacial deposits. This relation is illustrated in a railway cutting in the northeastern quarter of Sec. 24, T. 85 N., R. 4 W., Jones County, where the 10-foot sheet of loess passes downward into a bed of stratified sand 8 feet thick, and this in turn into drift which is irregularly bedded above but massive below.

It frequently happens that when the loess veneers a ridge the coating is not concentric with the nucleus. Such eccentricity is exhibited by the sections illustrated in Figs. 51 and 52, the former exposed in the SE. ¼ NE. ¼ Sec. 35, T. 82 N. R., 11 W., Benton County, and the latter in the SW. ¼ NE. ¼ Sec. 9, T. 82 N., R. 8 W., in Linn County. In like manner, when ravines developed upon the surface of the loess coincide with depressions in subjacent drift or rock (indicating that the deposit forms a mantle of approximately uni-

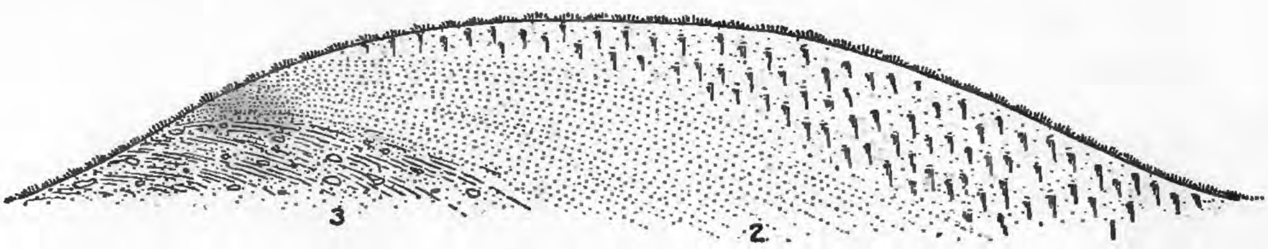

FIG. 51.—Discordant deposition of loess and drift, Benton County: (1) Firm-textured homogeneous loess, drab in color, rather calcareous, 0–8 feet; (2) fine brownish drab sand, rather obscurely laminated, 2–8 feet; (3) coarse sandy brown clay, with local and erratic pebbles, 3 feet. There are no distinct lines of demarkation.

form thickness), it generally happens that the new depression is not quite coincident with the old. Such is the case in the section illus-

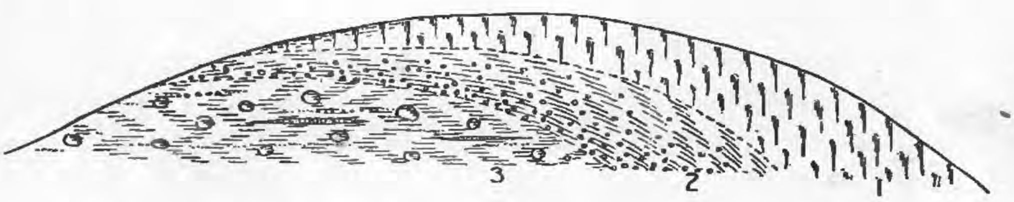

FIG. 52.—Discordant deposition of loess and drift, Linn County: (1) Loess; (2) laminated sand, pebbly below; (3) yellowish-drab drift clay, with obscure horizontal structure, containing local and erratic pebbles. Height, 12 feet.

trated in Fig. 53, observed immediately above the bridge of the Chicago, Milwaukee and St. Paul railway over the Wapsipinnicon

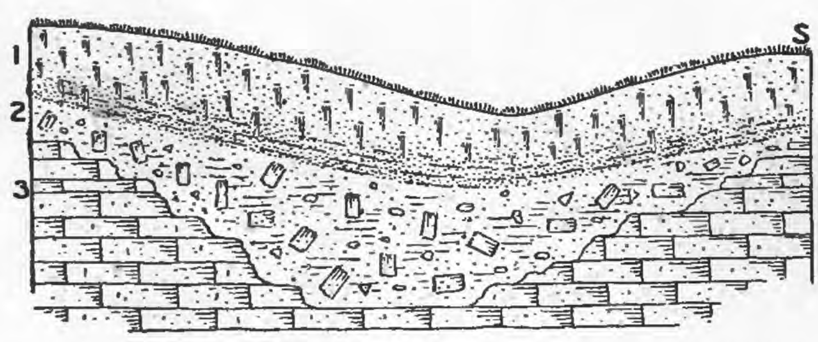

FIG. 53.—Discordance between loess surface and rock surface, Stone City: (1) Homogeneous loess, slightly silty but standing long in vertical walls, light drab, fossiliferous, passing into stratified fine sand, with fragments of *Unio* shells, 10–15 feet; (2) brown and yellow clay and loam containing angular fragments of Niagara limestone like that of immediately adjacent exposures, 1–20 feet; (3) Niagara limestone.

River at Stone City. The section is of additional interest in that the loess grades downward into stratified sand in the manner common to this region; also, in that no erratic deposits appear between the stratified sand and the rock below, although the locality is well within the glaciated area, the mass of clay above the limestone simulating the glacial talus described elsewhere; and moreover, in that, while the homogeneous upper part of the loess here yields only the characteristic pulmoniferous mollusca—*Succinea*, *Pupa*, etc.—in slightly depauperate condition, the subjacent sands contain decomposed shells of undetermined species of the freshwater genus *Unio*.

The behavior under weathering of the loess faces formed by artificial excavation, the relations of the homogeneous upper member

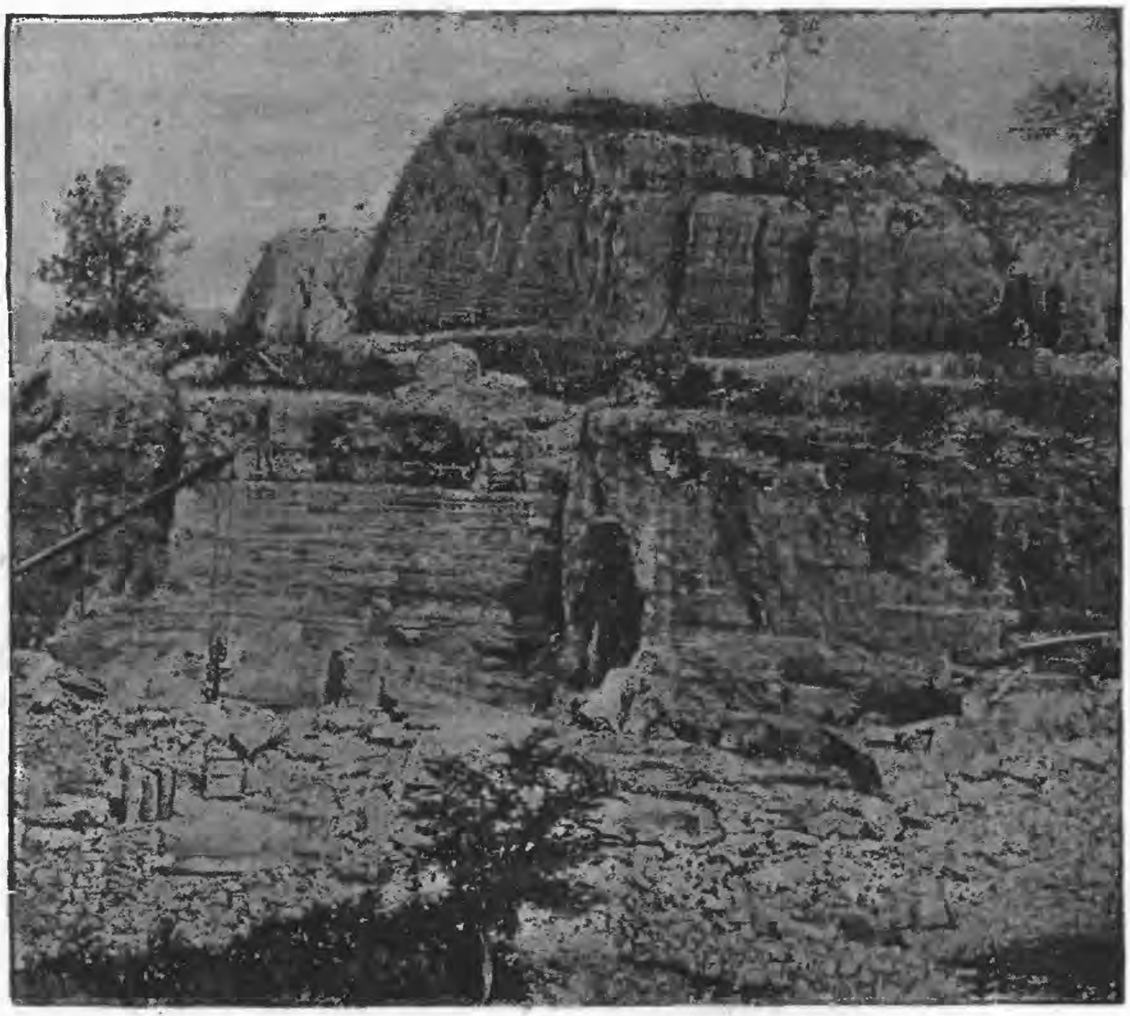

FIG. 54.—Relation of loess to basal sands and subjacent limestone, J. A. Green's quarry, Stone City.

to the stratified lower part, and the relations of both to the subjacent Niagara limestone at Stone City are illustrated in the photograph reproduced in Fig. 54. Here the loess is generally destitute of loess kindchen, though there are scattered throughout it indurated lumps made up of its own materials cemented by carbonate of lime, ranging from a quarter of an inch to 2 or 3 inches in diameter. Calcareous tubules also occur occasionally, particularly between 5 and 10 feet beneath the surface.

The prevailing relations between loess and drift in the region of river ridges and paha are exhibited graphically in the section extending from Onslow northward to the Maquoketa River, forming Fig. 55. Onslow is situated at the south side of one of the most extensive drift lobes extending into the loess area. This lobe is fully 35 miles in length from the drift plain near Prairieburg to its eastern termination near Monmouth. It is nearly isolated by the river ridges flanking the Maquoketa at Monticello and the Wapsipinnicon at Anamosa, and by a series of paha originating on the divide; but east of Langworthy its average width is 3 or 4 miles. On both margins the loess rises in a scarp, sometimes continuous for miles, as in the vicinity of Onslow, but again sinuous and digitate, as in the vicinity of Scotch Grove, ranging from 10 to fully 100 feet in height. The basin is imperfectly drained northward and eastward by streams originating within it, which break through the prominent loess rim into the Maquoketa, and in the days of the pioneer much of it was marshy. Its surface is a uniform plain, dotted with bowlders and destitute of trees, so level that the fences can be followed by the eye for many miles from any part of the bounding loess rim.

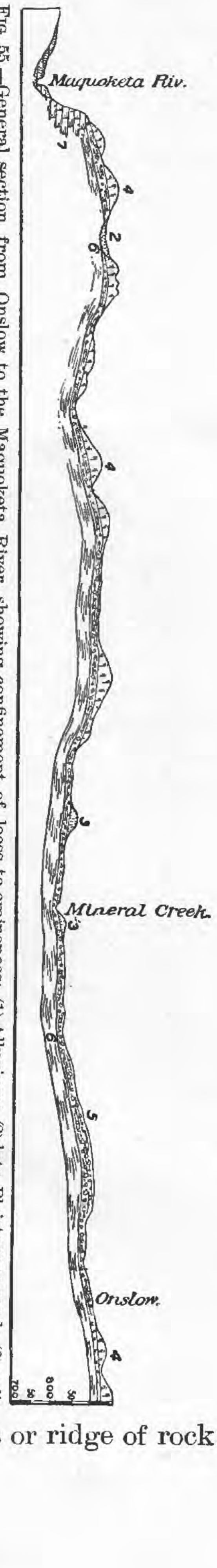

FIG. 55.—General section from Onslow to the Maquoketa River, showing confinement of loess to eminences: (1) Alluvium; (2) late Pleistocene sand; (3) eolic accumulations of sand from base of loess where removed by erosion; (4) loess; (5) upper till; (6) lower till; (7) Niagara limestone.

It frequently happens that the bluffs and ridges of the loess of the middle region have nuclei of rock rising well toward their summits. This relation is exhibited by nearly all of the ridges cleft by rivers. On the Maquoketa between Delhi and Hopkinton, and again north of Onslow; on the Wapsipinnicon at Quasqueton, and near Anamosa; on the Cedar at Osage, below Vinton, and near Moscow; and on the Iowa at its great elbow, and in many other localities, the indurated rocks of the Paleozoic subterrane rise not only to unusual heights, but even above the level of the drift-plain surface on either side of the ridge. So, in a general way, the cross section through a paha exhibits at the base a boss or ridge of rock; next in order a local thickening of the glacial drift; and finally a nearly coincident cap of loess, fine and homogeneous above, sandy and stratified below, and thinning out and quickly disappearing laterally. But in longitudinal section the boss or ridge of rock usually appears toward the northwestern extremity of the loess ridge. This is notably so of the ridges originating in the northwest corner of Sec. 29, T. 87 N., R. 4 W., and in the western part of Sec. 14, T. 89 N., R. 3 W., in Delaware County, and in the triple paha near Monticello, illustrated in Pl. XL and Fig. 35. In all of these cases the ridges extend southeastward from prominent knobs of Niagara limestone, whose ledges are utilized by the quarryman; they are Titanic examples of the common glacial phenomena of "crag and tail," illustrated by Geikie,[1] and they illustrate on an equally magnified scale the peculiar phenomena of rock scoring described by Chamberlin, in which a fossil or siliceous nodule in limestone gives origin to a ridge extending far in its lee;[2] but while in the case of the Monticello paha the loess quickly dies out in the lee of the crag, in the other cases the ridge increases in width and height for miles: in the one case the effect of the obstruction was local and temporary, and in the other far reaching, long continuing, and cumulative.

Another relation between preglacial or glacial topography and the distribution of the paha is equally significant but more rare: sometimes the loess is accumulated in the lee of a depression. This is notably the case of the paha at Rockville, Delaware County, illustrated in Figs. 32 and 33 (pp. 388, 389). Here the North Maquoketa River hugs the western margin of the upland crest of the territory, sometimes turning out upon the lowlying drift plain only to quickly return into the elevated rocky plateau. Half a mile northwest of Rockville the river so deserts the lowland and turns into the upland forming a rather narrow cañon occupied in part by the village mill-pond, thus cutting off a minor outlying plateau; and nearly parallel with the course of the main cañon there is a little ravine, dry save after rains and during vernal snow-melting, dividing the pygmy plateau. Now, after entering the upland the river quickly turns to the southward parallel with its margin; and in the line of the gateway by which it enters and only a few rods beyond its bend there rises a conspicuous but indefinite ridge of loess exhibiting the typical paha contours over its crest and about its western extremity as well as on the south; while on the north it passes into the prevailing loess mantle of the region, and on the east breaks up, after the fashion of many paha, into a series of indefinite outliers modified by erosion. Just opposite the village and in the line of the smaller ravine stands the Gem of the Paha. It is only 100 yards broad and 200 yards long; but its slopes are so steep that it is 50 feet high. It is formed of sandy loess, found by means of an excavation to be laminated; and it rests on a surface of sandy and pebbly drift. It is the gem of the series, not only because of its perfection of form and miniature size, but because it

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[1] Great Ice Age: New York, 1877, p. 18.

[2] Seventh Annual Report U. S. Geological Survey, 1888, pp. 194, 195.

tells the story of its own origin and so betrays the paternity of its kindred and gives a clue to the Pleistocene history of the entire territory.

But, intimately as the loess of the paha is related to the ante-Pleistocene configuration, it is still more intimately related to the configuration of the drift surface; for while the connection between the larger loess plateaus and the broader loess ridges and the prevailing drift is sometimes obscure, yet this is not true of the smaller and isolated paha. The drift of a considerable part of the territory is beautifully corrugated, the ridges rising perhaps only a few feet above the general level of the drift plain yet extending for miles in southeasterly directions. In general these ridges increase in height and width toward the southeast; and nearly all of the more conspicuous gradually become veneered and at length deeply coated with loess. This is notably true of the drift ridges of eastern Cedar County, which, toward the Wapsipinnicon, are all loess crowned. It is even more strikingly true of the peculiar system of ridges rising from the northern drift plain in central Benton County and stretching many miles to the southeastward to terminate and culminate in prominent cusps and spurs overlooking Prairie Creek, as illustrated in Pl. XLIII. Throughout the greater part of their length these ridges are of drift absolutely undistinguishable from those of the lower lands between; yet all of the higher members, from Watkins to Cedar Rapids, are loess crowned at their extremities. The structure of all these is represented by that near Watkins in the NW. ¼ SW. ¼ Sec. 24, T. 82 N., R. 10 W., whose summit is 85 feet above the drift plain to the north. An excavation in its north slope exposes loess 5 or 10 feet thick passing down into cross-bedded sand, within which there are considerable layers and pockets of pebbly drift clay containing loess kindchen; and near the base of the loess, surrounded by loess kindchen and calcareous tubules, was found the beautifully striated limestone bowlder illustrated in Pl. XLVI. The loess and the stratified sand, with the intercalated layers of pebbly clay, appear to constitute the upper third of the slope; while below, the materials are unmodified glacial drift, similar to that of the lowlands stretching northward beyond the divide and southward beyond the waterway.

The loess of this area undergoes a modification with latitude, parallel with but less striking than that of the northern phase. In the northernmost locality, in Mitchell County, the deposit is poor in lime and in finely comminuted silica, and assumes the brownish, granular aspect common to the driftless area; in Bremer County the materials are more finely comminuted and more richly calcareous (effervescing freely under acid and containing loess kindchen), and somewhat depauperate but otherwise characteristic fossils are moderately abundant; while on the lower Wapsipinnicon and Cedar Rivers in the south the deposit approaches that of the Missouri River in texture, structure, composition, and habit of weathering.

The thickness of the sheet of loess crowning the river ridges and paha ranges from a veneer just sufficient to give character to the soil to 50 or 75 or even (about the great elbow of the Iowa River) 100

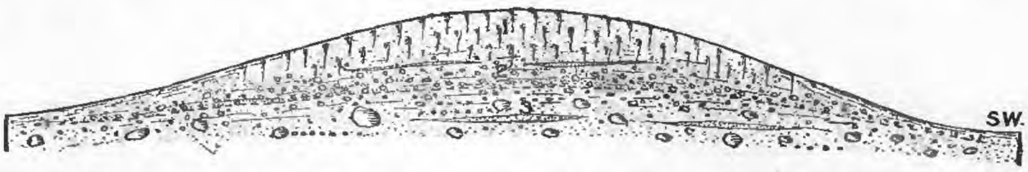

FIG. 56.—Relation of loess to drift in paha, generalized section: (1) Loess, perhaps sandy; (2) laminated sand, sometimes containing pebbles and lenses of gravel; (3) upper till.

feet. The mean thickness within its actual area is, despite the enormous local accumulation, probably less than 10 feet; for while the deposit rises in conspicuous ridges and plateaus 20 to 200 feet in height, it does not form but simply coats or only veneers most of the eminences to which it gives character. The relations are semi-ideally illustrated in Fig. 56.

The loess of the river ridges and paha is fossiliferous throughout the greater part of its extent. The northernmost locality at which fossils have been found, in the loess of this phase and of the territory as well, is the Waverly Plateau, in the SW. ¼ NW. ¼ Sec. 27, T. 91 N., R. 13 W., where it yields *Helicodiscus lineatus* and *Succinea avara*, as already noted. Abundant fossils occur also immediately above the Palisades overlooking the Cedar River south of Mount Vernon; fossils may be found in most good exposures over the Iowa-Cedar divide in northwestern Johnson and western Cedar Counties; and they are especially abundant about the elbow of the Iowa, north and northwest from Iowa City. At Stone City fragile bits of shells of *Unio* or *Anodonta* have been found. With this exception the facies of the entire fauna of the deposit is represented by that described at Iowa City by Shimek.[1]

The Iowa City fauna is as follows:

Succinea avara, quite abundant; unlike the living form.
Succinea vermeta, quite abundant; larger than the living form.
Succinea obliqua, abundant; somewhat unlike living forms.
Pupa muscorum, common; now extinct.
Pupa blandi, common; now extinct.
Pupa armifera, rare; like the modern form.
Patula striatella, quite abundant; like the recent form.
Patula strigosa, quite rare; now extinct.
Vallonia pulchella, quite abundant; larger than the recent forms.
Helicina occulta, abundant; smaller than the recent form.
Physa, sp. und.; exceedingly rare.

[1] Am. Geol., 1888, vol. 1, pp. 149 to 152.

Leptolimnœa, sp. und.; exceedingly rare.
Limnœa humilis, abundant in two forms; only one now living.
Limnœa caperata, common; smaller than living form.
Limnœa desidiosa, rare; much smaller than the living form.
Vertigo simplex, common; now extinct.
Mesodon multilineata, common; much smaller than living form.
Zonites fulvus, abundant; larger than recent forms.
Zonites limitulus, common; now extinct locally.
Zonites minuscalus, exceedingly rare; larger than recent forms.
Zonites arboreus, exceedingly rare; smaller than recent forms.
Zonites viridulus, exceedingly rare; smaller than recent forms.
Helicodiscus lineatus, exceedingly rare; like recent forms.
Ferussacia subcylindrica, rare; like recent forms.

Twenty-three of these species are terrestrial, and two (*Helicina occulta* and *Pisidium*, sp. und.) only are aquatic; most of them are now living in the vicinity, and nearly all of the others at no great distance; and the divergence of the fossil from recent forms is inconsiderable and inconsistent.

SECTION III.—THE SOUTHERN LOESS.

The second loess area in extent is that of the southern portion of the territory. This is the southern phase of the deposit. It stretches from northern Marshall County southeastward through the southern counties to the Iowa River, by which its continuity is broken. It occupies also a part of the upland between the Iowa and Cedar Rivers; and beyond the Cedar it mantles the bluffs of the Mississippi in Muscatine and Cedar Counties, commonly extending some miles inland in digitate or insulated outliers; but it attenuates and practically disappears over the uplands and divides south of the Iowa in Jasper, Poweshiek, and Iowa Counties.

The loess of this area is protean. In its upper portion the deposit indeed exhibits certain features of the northern loess and of the typical Missouri loess respectively; it is as argillaceous as the former and as calcareous as the latter; it is generally as poor in silica and as rich in clay as the former, and as finely comminuted and homogeneous as the latter; its vertical faces commonly (but not always) waste as rapidly under the weather as those of the former, and it is as abundantly charged with loess-kindchen, ramifying tubules, and characteristic fossils as the latter; and in all these and in many other respects the southern loess lies intermediate between the phases developed in the driftless area and on the Missouri River respectively, and forms a connecting link in the chain of characters, and in that of isolated deposits as well, by which these are identified. Yet, while the loess of one of these areas passes quickly into a gravelly stratum or water-laid sand bed, and that of the other runs into stratified sand or laminated silt, the southern loess of Northeastern Iowa generally grades imperceptibly into unmodified glacial drift. So the southern loess is a connecting link not only between divergent phases of the deposit, but between the deposit itself and one commonly regarded as distinct in genesis and in period of formation. It is a hybrid; there is no place for it in the accepted taxonomies; and no name commonly accepted can be applied to it that is not a misnomer with respect to certain of its parts. For convenience, it may be styled *loess-drift* or *drift-loess*, according to the local predominance of the respective characteristics of two generally distinct deposits.

The passage from loess to drift in the southern counties is commonly gradual, and the transition in the different diagnostic features of the two deposits is seldom coincident, so that the zone of intermediate character, or passage bed, may be many feet in thickness. Usually the fine comminution and homogeneity characteristic of the loess fail first, and an exceptional number of sand-grains, at first fine but of increasing coarseness, and finally pebbles (sometimes polished and striated) appear; next, the fossils diminish in number and finally fail; with the diminution of fossils the clay element becomes predominant, and at about the same horizon the obscure horizontal banding fails in turn and the characteristic promiscuity of the glacial drift ensues; then the calcareous tubules disappear, and are sometimes replaced by films of carbonate of lime coating pebbles and accumulated in cleavage planes; at length the loess-kindchen lose their characteristic nodular form and cavernous structure, and either disappear or become transformed into plates and irregular masses of carbonate of lime accumulated in pockets or about pebbles and bowlders; and finally the limy segregations fail. These successive changes supervene in such manner that the fossils sometimes extend into the horizon of striated pebbles; the obscure banding of the upper part of the deposit may reappear well within the promiscuous mass of the drift; the tubules and pebbles are frequently associated, and the horizon of loess-kindchen commonly overlaps far upon that of pebbles and bowlders—indeed, in nearly every deep roadside gully in the southwestern counties, and only less commonly in Cedar, Muscatine, and Scott Counties, loess-kindchen and pebbles (sometimes striated) may be seen intermingled if not united.

The transition from loess to drift is geographic as well as stratigraphic. The monotonous northern drift plain, with its almost imperceptible division into shallow basins connected by drainage ways and bounded by meandering ridges, gradually changes; the waterways deepen, the valleys become more clearly defined, the division into basins fails, and the gentle undulation of the divides diminishes, yet so gradually that the change is unnoticed even by the careful student within any 5 miles; then the irregular and apparently fortuitous distribution of minor tributaries depending upon the size and distribution of the shallow drift basins gradually gives place to a more definitely dendritic arrangement, the amount of relief increases, and the profiles change from flattened depressions separated by narrower elevations to flattened elevations separated by narrower depressions; next the divides expand to sensibly horizontal plains of great extent and the depressions deepen to narrow, steep-sided ravines, and the erstwhile imperceptible slopes running down to the streams rise and sharpen into bluff-browed salients and escarpments; and with the change in surface configuration the drift gradually differentiates into a homogeneous clay or loam above and a pebbly and sandy clay of promiscuous structure below; the surface bowlders fail; later the loam thickens and assumes the characteristic textural and structural features of loess in the brows of the bluffs; and finally the fully differentiated loess thickens and extends from the bluff brows over the divides into the waterways, forming a continuous mantle save where cut away by the larger rivers. These geographic changes, like those in stratigraphy, supervene in such order that the basin configuration fails and the waterways become definite while yet the surface remains undulating; the dendritic distribution of the drainage appears while yet the relief is low; the ravines contract before the uplands flatten, and the waterways exhibit typical loess profiles while yet the divides retain the characteristic configuration of the drift. The zone of transition may be many miles in width. Beaver Creek is a typical drift stream; Black Hawk Creek departs slightly from that type; Wolf Creek exhibits a dendritic division of its tributaries and its valley is feebly constricted between low-bluffed banks; Salt Creek is definitely dendritic and its bluffs are steep and loess flanked, and the divides are fairly flat; but it is only beyond the Iowa River that the typical configuration of loess areas becomes fully developed. Sometimes, however, the transition is more rapid. On the Wapsipinnicon-Cedar divide, about Clarence, the configuration is that typical of corrugated drift areas, and there is so little differentiation of the drift that bowlders sometimes lie on the surface and pebbles are frequently turned up by the plow. Within 10 miles southeastward the configuration changes by the narrowing of the plains between the ridges and the rising of the ridges into loess-capped paha sometimes expanding into considerable loess areas scored by dendritic drainage, and the differentiation of the drift becomes such that surface bowlders practically fail, and the mantle of clean clay thickens to some feet; and in western Scott County the drainage gradually becomes dendritic, the corrugated surface is gradually sculptured in autogenetic fashion, the upper portion of the drift sheet assumes the clayey or loamy character to a considerable depth, and this increases until the drift gives way to the loess of the Mississippi bluffs, and all within 8 miles.

Throughout three-quarters or more of the area of the southern phase of the deposit such transition from loess to drift is characteristic. It is a feature which the camera fails to grasp and the pencil to portray; yet the evidence is as abundant as exposures are numerous. In the classic locality in Davenport in which this Pleistocene deposit of Northeastern Iowa was first identified with the loess of the Rhine by physical characters and contained fossils,[1] the fact that it is pebbly in its lower portion was not deemed worthy of special remark by the original observers, but it was then and is to-day patent to all who visit the ground. In the section illustrating the relations of the several Pleistocene formations, in Davenport, corner Sixth and Harrison streets (Fig. 77), there is the usual transition from fossiliferous loess to pebbly drift, and the fossils extend to and just within the pebbly horizon ; near the center of section 20, 3 miles northeast of Davenport on the Princeton road, richly fossiliferous loess grades into drift of the upper sheet containing large bowlders, and the fossils and pebbles are intermingled; and in perhaps the most satisfactory exposure of the loess in Muscatine, on Green street (in the brow of the bluff overlooking Muscatine Slough and Island), the deposit grades into pebbly drift reposing upon the forest bed, and fossils, loess-kindchen, tubules, and erratic pebbles are intermingled.

Still more constant is the same relation in the southwestern part of the territory. The road-cutting in the NE. ¼ NW. ¼, Sec. 24, T. 14 N., R. 5 W., exposes 4 or 5 feet of loess with rare fossils and loess-kindchen, gradually becoming pebbly below, until at the base of the excavation it is a homogeneous sandy drift clay with abundant erratic pebbles; in the SW. ¼ SE. ¼, Sec. 12, T. 79 N., R. 7 W., a gully 30 feet deep exposes 10 feet of fossiliferous loess with numerous calcareous tubules and less numerous loess-kindchen, which gradually loses its fossils and tubules and becomes pebbly within 5 feet below the horizon of shells, at the same time taking on the other characteristics of the drift, and within 15 feet below the lowest fossils becoming a mass of typical glacial drift with abundant angular and subangular pebbles (sometimes striated and 3 or 4 inches in diameter); in the SW. ¼ SE. ¼, Sec. 11, T. 79 N., R. 7 W., another road-cutting exposes a similar succession; in the SE. ¼, Sec. 15, in the same township, a well 15 feet deep exhibits both loess and drift, the fossils and loess-kindchen of the former extending beneath the upper horizon of pebbles in the latter; the road-cutting in the NE. ¼, Sec. 26, T. 79 N., R. 7 W., exposes loess abounding in typical fossils, and containing a few loess-kindchen and tubules, passing imperceptibly into drift containing numerous subangular pebbles and a large bowlder; a similar succession is exposed in the NW. ¼ SW. ¼, Sec. 30, T. 79 N., R. 6 W., where the fossils are exceptionally numerous both in species and individuals, including *Succinea*, *Helix*, *Pupa*, etc., in hundreds; the intergradation is equally well shown in road-cuttings in the SW. ¼ NW. ¼, Sec. 18, T. 78 N., R. 7 W.; in the NW. ¼, Sec.

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[1] Proc. Dav. Acad. Sci., 1876, vol. 1, p. 96, Pl. XXXII.

19, and in the NW. ¼, Sec. 30, in the same township; in the SW. ¼ SW. ¼, Sec. 4, T. 79 N., R. 4 W., the loess is unfossiliferous but otherwise characteristic as exposed in a roadside gully, and grades downward into drift containing pebbles up to 6 inches in diameter and a 2-foot bowlder; in the NW. ¼, Sec. 26, T. 80 N., R. 6 W., an 8-inch bowlder was found in the loess; in the southeast corner of Sec. 36, T. 80 N., R. 8 W., the gradual transition from loess above to drift below is well exhibited; in the NE. ¼ NE. ¼, Sec. 33, in the same township, there is an excellent exposure of loess and the upper drift sheet into which it grades, the former abounding in tubules and loess-kindchen which extend for some feet into the latter and are associated with pebbles and even good-sized bowlders; the Chicago, Milwaukee and St. Paul Railway cutting in the NW. ¼ SW. ¼, Sec. 6, T. 80, R. 9 W. exhibits poorly fossiliferous loess with abundant loess-kindchen gradually changing from the nodular form to irregular plates and masses determined by the structure of the clay; in the SW. ¼ NW. ¼, Sec. 13, T. 80 N., R. 9 W., the transition is well exhibited in roadside gullies, the deposit about the zone of transition abounding in loess-kindchen attached to erratic pebbles; in the SE. ¼ SW. ¼, Sec. 24, T. 79 N., R. 9 W., the relations are similar; at Lytle City, near the center of Sec. 1, T. 78 N., R. 10 W., the loess passes into a thin sheet of pebbly drift, which in turn reposes upon the older drift sheet; at Parnell the loess is somewhat clayey, exceptionally dark in color, destitute of loess-kindchen and tubules, poor in fossils, but, as usual, pebbly below—the deposit here being near the southern limit of the upper drift sheet and evidently made up in large part of materials derived from the lower; in a roadside gully in the NE. ¼ NE. ¼, Sec. 28, T. 78 N., R. 11 W., fossiliferous loess grades in the usual manner into the upper drift sheet, which rests in turn upon its older homologue. These examples are but a few of the hundreds observed and the scores recorded in the area of the southern loess.

While the normal relation between the southern loess and the subjacent drift sheet is thus one of imperceptible intergradation, other relations are exhibited in certain localities; i.e., the loess may either pass into stratified sand, as in the region of the river ridges and paha, or it may repose unconformably either upon glacial drift or upon the forest bed; but the first of these abnormal types of stratigraphic relation is connected with a peculiarity in hypsographic distribution, and the second with an accident of geographic distribution.

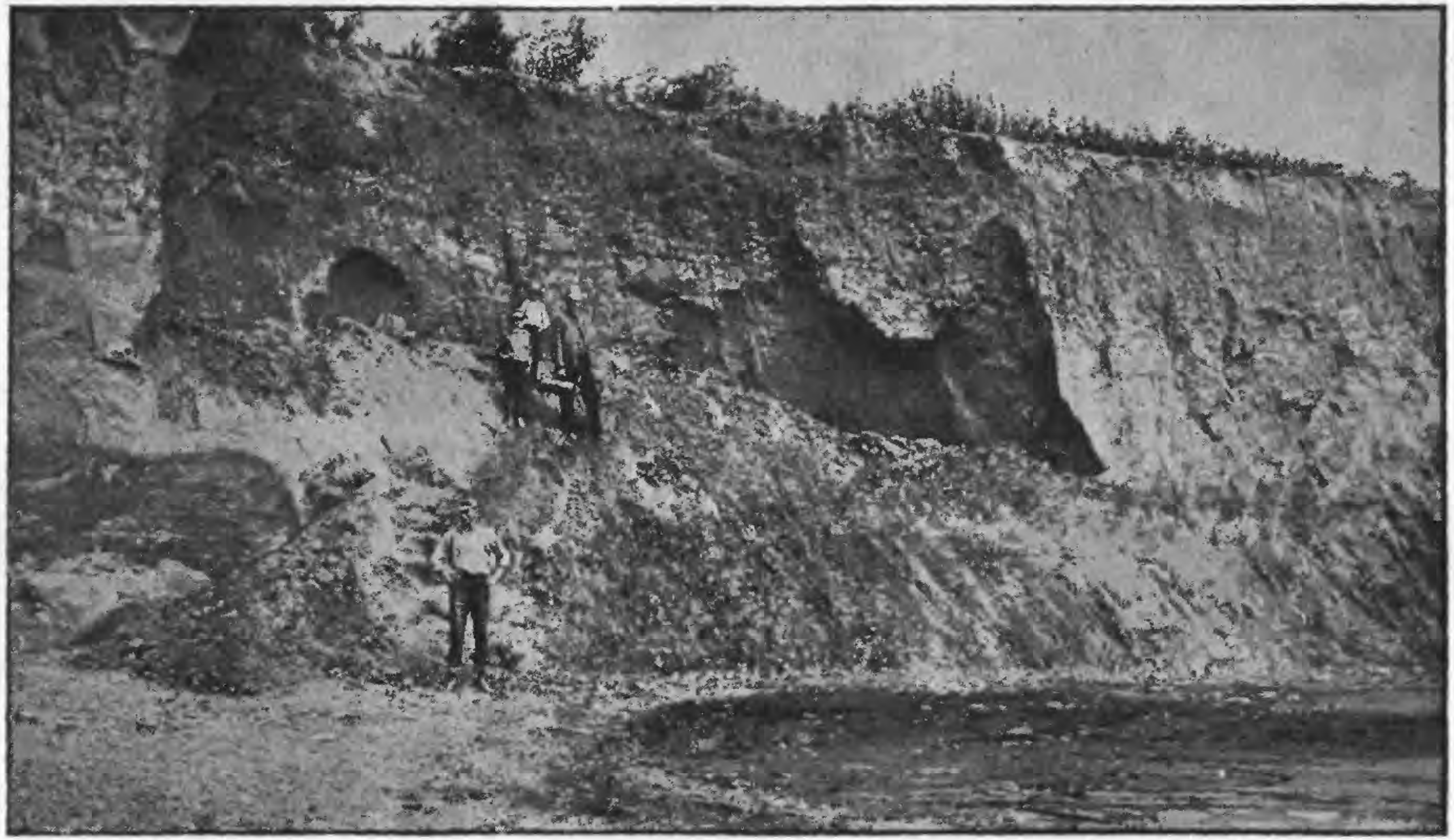
Along the northern margin of the principal continuous body of loess south of the Iowa River between Marengo and Iowa City, and along the northern margin of the lesser body south of the Wapsipinnicon in Scott County, and in general along the southern sides of east-flowing waterways in the southern area (notably Clear Creek, Old Man Creek, English River, and Duck Creek) the loess departs from its normal configuration of a sensibly horizontal plain dissected by dendritic drainage, and rises into ridges—i. e., the sensibly horizontal plains have their northern edges tilted in such manner that their margins form low, smooth scarps as seen from within, and high and steep scarps as seen from the waterway without. This feature is illustrated in the general section from the Mississippi to the Wapsipinnicon, through Scott County, forming Fig. 57. Now, in all these upturned northern edges, the loess grades downward into stratified and cross-laminated sand, sometimes of great thickness; and by the erosion of the marginal loess these basal sands are exposed, and along the Iowa and the Wapsipinnicon they are blown into dunes and drifts interspersed with ponds; and in some cases the loess fossils extend well down into the stratified sands—e. g., in the SW. ¼ NE. ¼, Sec. 29, T. 80 N., R. 5 E., in Scott County. The principal eolic deposits of the southern counties, indeed, are derived from the basal sands of the upturned and ravine-scarred northern margins of the southern loess fields.

Fig. 57.—General section through Davenport from the Mississippi to the Wapsipinnicon, showing surface planes of the loess, etc; (1) Loess; (2) upper till; (3) lower till.

There are two drift sheets in Northeastern Iowa, slightly different in composition, notably different in area, and widely different in age, yet so similar in certain characters that they may hardly be distinguished, save when well exposed in natural juxtaposition with the forest bed between. The southern margin of the upper drift sheet lies not far from the southern limits of the territory; and about its margin this drift sheet is sometimes discontinuous. So the loess may rest upon the older drift sheet, perhaps with the forest bed between. Such is the case in the classic Davenport locality, where a buried soil—an ancient land surface mantled by moss and other vegetal matter—separates the drift-like base of the loess from the older drift sheet.[1] Such is the case, too, in many other localities.

In the exposure 3 miles northwest of Muscatine, illustrated in Pl. L, the loess (which is here accumulated in the form of a paha) becomes stratified and sandy below and rests upon an ancient soil 4 or 5 feet thick, which in turn passes into the lower drift sheet. In northeastern Muscatine, in the first spur beyond Mad Creek, the following strata are exposed in the bluff face:

[1]Proc. Dav. Acad. Sci., 1876, vol. 1, Pl. XXXII.



A TYPICAL EXPOSURE OF SOUTHERN LOESS, MUSCATINE.

(1) Loess, slightly sandy, 15 or 20 feet.
(2) Sandy and pebbly loess or drift, 10 feet.
(3) Ancient soil, 2½ feet.
(4) Dense, tenacious clay, abounding in pebbles and small bowlders (locally known as "hard pan"), 20 feet.

In the section illustrated in Fig. 97, the basal portion of the loess is sandy and rests on an irregularly eroded surface of the lower drift sheet. About the margin of, and indeed generally throughout the small gumbo area in eastern Muscatine and southwestern Scott Counties, the loess is exceptionally argillaceous and dark in color, and rests upon the tenacious, blue-black clays, here unconformably upon an eroded surface, there unconformably upon an old soil, and elsewhere in apparent conformity; for the southern phase of the loess may pass into the tough black clay of the gumbo region just as does the northern phase into the more friable red residuary clays of the driftless area. At Parnell and elsewhere in southern Iowa County similar relations obtain; the loess is exceptionally dark in color and argillaceous in composition, and is evidently made up in part of materials derived from the lower drift sheet upon which it reposes, sometimes unconformably and sometimes with apparent conformity.

Even well within its southernmost limit the upper drift sheet may fail locally, leaving the loess to lie on the older deposit. A road-cutting in the SW. ¼ NW. ¼, Sec. 10, T. 78 N., R. 7 W., exhibits the following succession:

		Feet.
No. 1.	Loess, homogeneous and brownish (somewhat darker in color than the normal), perceptibly sandy, without loess-kindchen or shells	5
No. 2.	Black, peaty clay, jointed and friable	1½
No. 3.	Bluish white or ashen silten clay, containing a few small pebbles (half an inch and less in diameter)	3

The succession revealed in a roadside gully in the SE. ¼ SE. ¼, Sec. 11, T. 79 N., R. 7 W., beginning 15 or 20 feet below the general upland level, is as follows:

		Feet.
No. 1.	Loess, becoming clayey and jointed toward the base, but otherwise homogeneous; containing a few small loess-kindchen	5
No. 2.	Black or dark brown peaty silt, sometimes laminated horizontally, sometimes structureless, sometimes interlaminated with the base of the loess, about	1½
No. 3.	Glacial drift containing subangular pebbles and a few loess-kindchen	3

In the southern, as in more northerly areas, the loess varies in composition and texture both geographically and stratigraphically.

In the southwestern counties the deposit is predominantly argillaceous and calcareous; in the eastern counties it is poorer in both clay and lime, the materials are more uniformly assorted and coarser, and it includes sometimes merely fine sand frequently used by molders; and a great variety of local phases are exhibited in different localities. The nearest approach to the ideal type of the deposit displayed on the Missouri River, e. g., at Council Bluffs, is found crowning the eminence known as "The Hill" in southern Muscatine. The deposit here is practically homogeneous throughout a thickness of 30 to 50 feet; it abounds in fossils from summit to base, and not only the tiny and fragile shells of land snails, but even the minute and exceedingly fragile eggs of one of their species are preserved; the characteristic loess-kindchen occur in moderate abundance; irregularly ramifying tubules penetrate and agglutinate the mass in all parts; and the vertical faces formed in street-grading display the marks of the implements by which they were cut for months and stand intact for years.

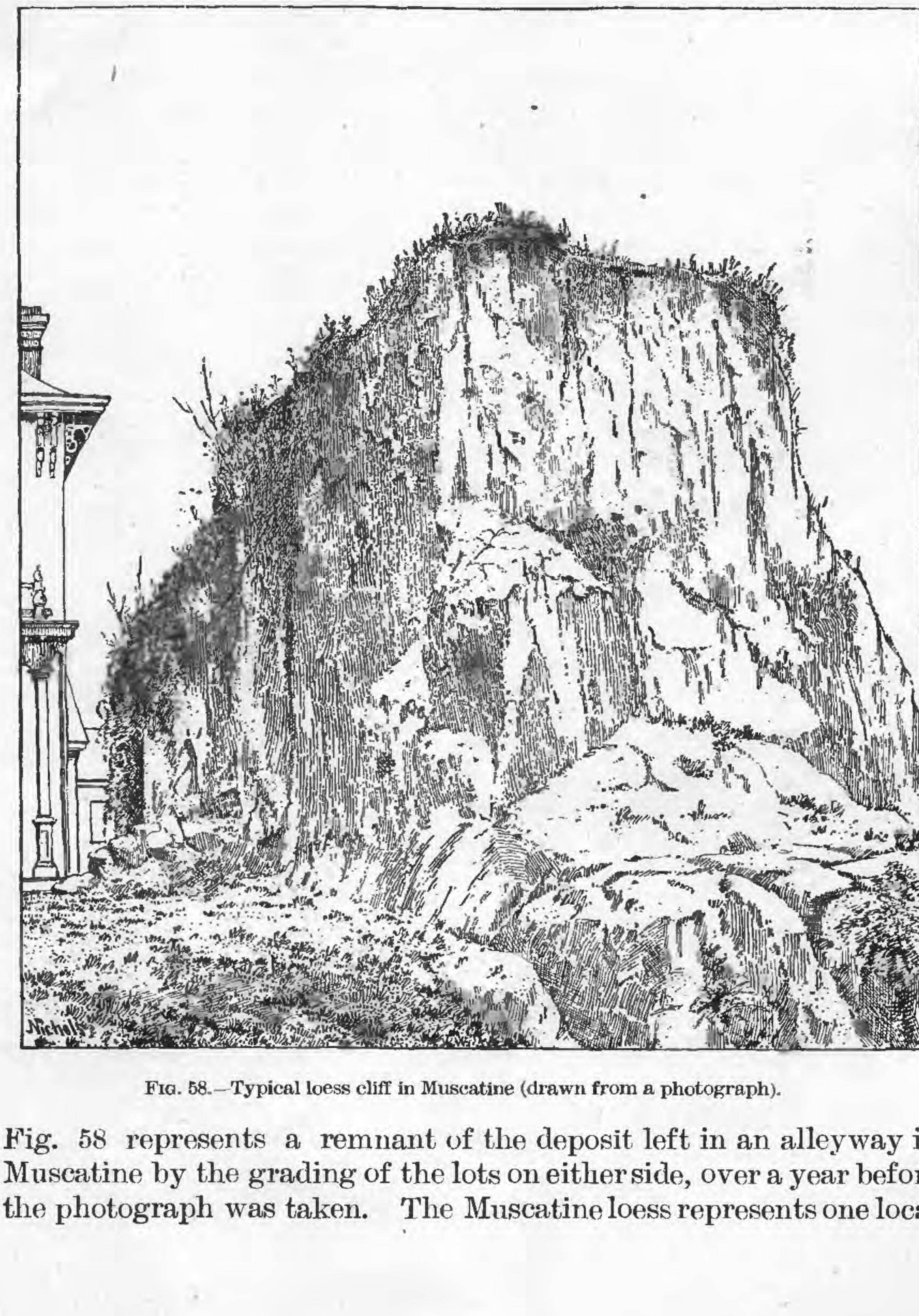
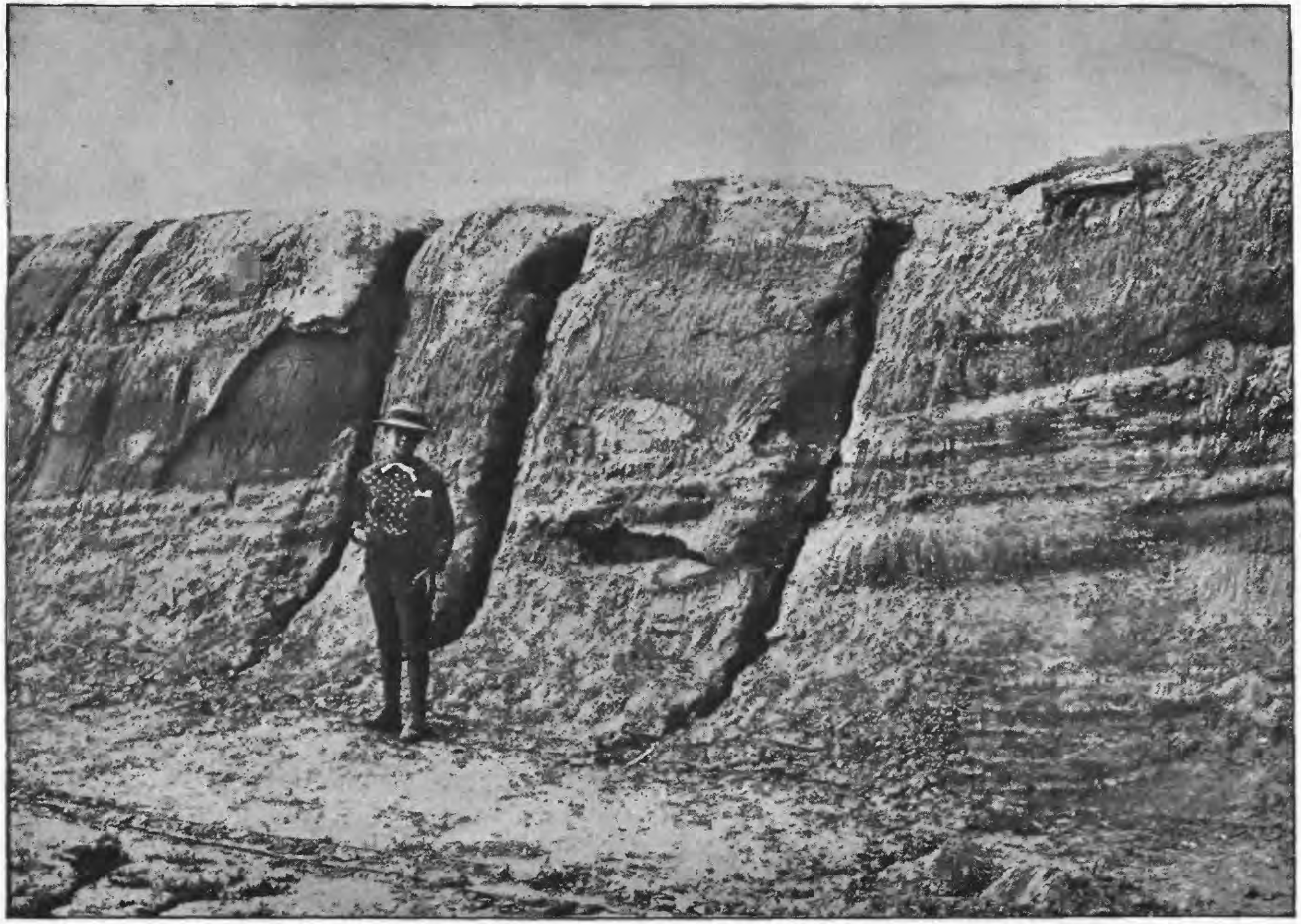


FIG. 58.—Typical loess cliff in Muscatine (drawn from a photograph).

Fig. 58 represents a remnant of the deposit left in an alleyway in Muscatine by the grading of the lots on either side, over a year before the photograph was taken. The Muscatine loess represents one local



STRUCTURE OF LOESS, MUSCATINE.

phase of the deposit; the clayey veneer concealing the drift on Deer Creek, in Tama County, represents another extreme; but all possible intermediate phases are represented in different parts of the area.

The stratigraphic variation is no less notable. Plate XLVII illustrates the transition from the homogeneous upper portion to the obscurely stratified medial portion of the deposit in Muscatine; and a parallel transition is exhibited in every considerable exposure within the southern era. The deposit is always more homogeneous above and becomes more heterogeneous below either by stratification or by the intermingling of pebbles or other coarse material.

In the southern counties as in the northern the loess is stratified or banded, perhaps by layers of unequal wetness; and this banding is most conspicuous about mid depth of the deposit between the homogeneous upper portion and the stratified or promiscuous lower portion. Plates XLVIII and XLIX, reproduced from photographs, illustrate this banding at Muscatine. As in the north the banding is horizontal or slightly inclined in the direction of the slope; and sometimes the bands are contorted. A good example of such contortion in the basal and sandy portion of the deposit, occurring in the northern part of Muscatine, is illustrated in Fig. 59. The visible

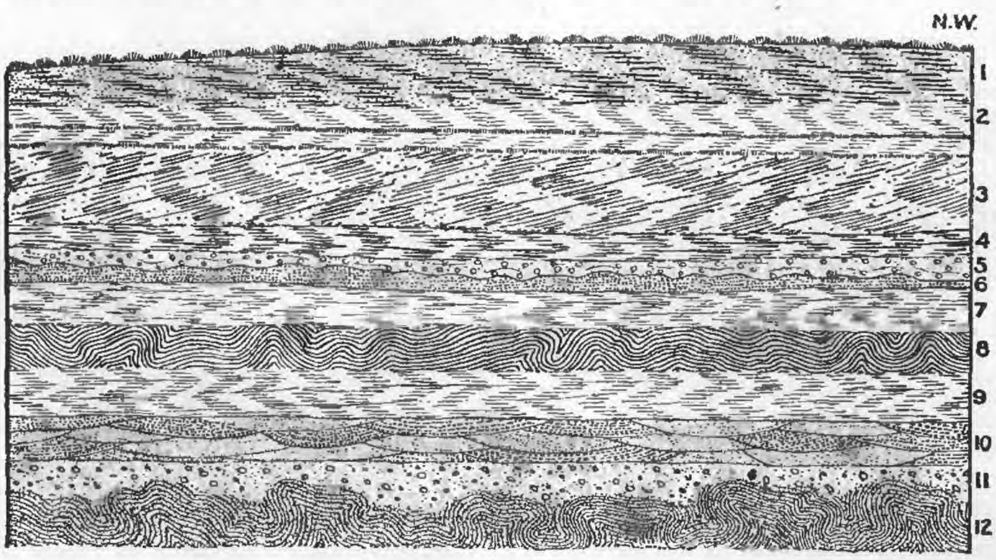


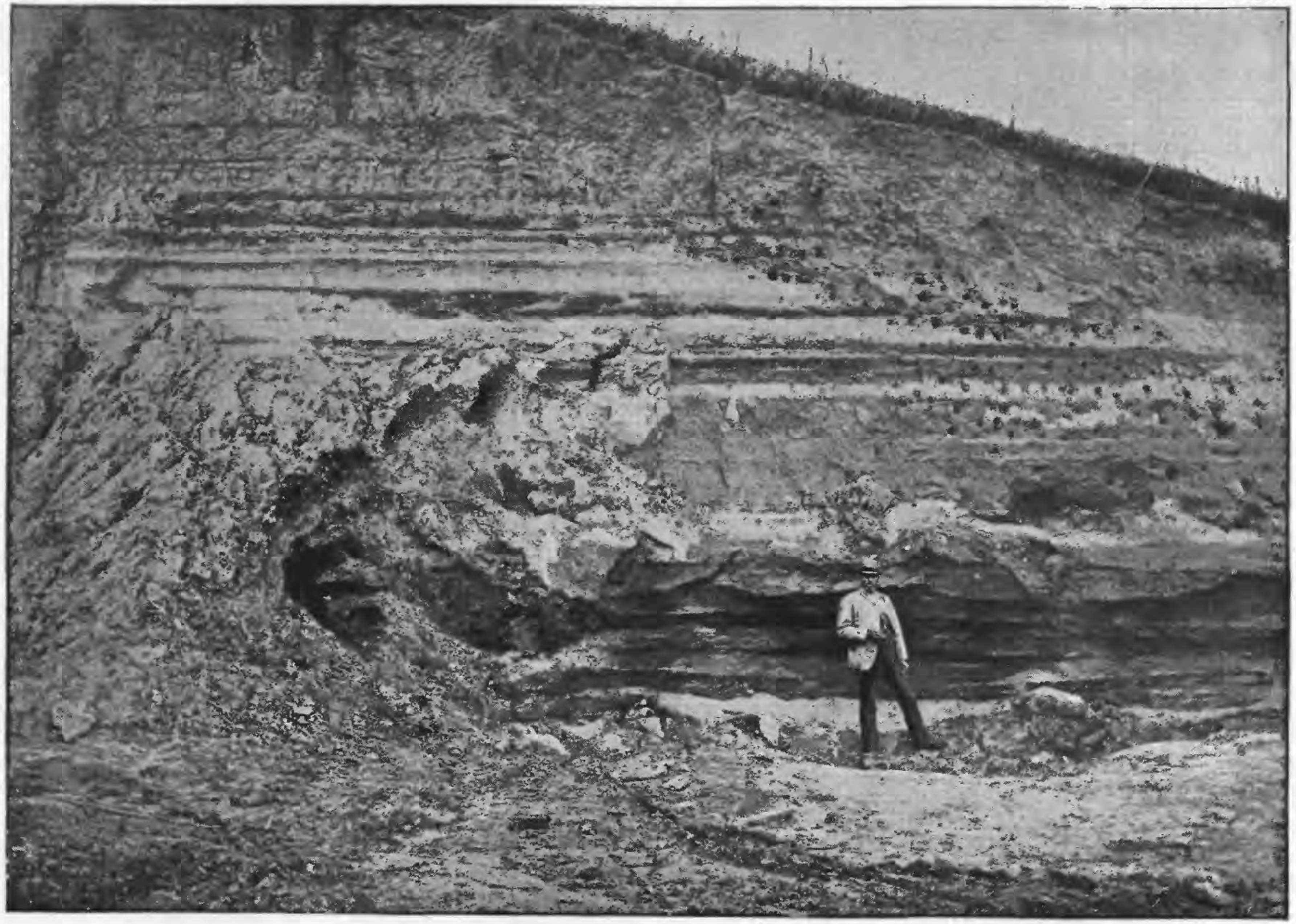
FIG. 59.—Stratification and contortion of loess base, Muscatine: (1) Surface soil and loam; (2) marly loam with a double carbonaceous line at base; (3) obliquely, laminated arenaceous silty clay; (4) fine silty clay horizontally laminated; (5) brown gravel partly cemented with iron oxide, apparently unconformable to subjacent layer; (6) brown and red horizontally laminated sand; (7) regularly laminated white silty clay; (8) laminated buff silty loam, contorted as shown; (9) regularly laminated white and light buff silty clay; (10) coarse red, brown, and buff sand, cross-stratified and laminated; (11) sand, gravel, and coarse pebbles, generally resting in and on the corrugations of the lower member; (12) laminated marly sand, contorted as shown. Total exposure, 20 feet.

deformation here is confined to certain horizontally laminated and exceptionally plastic strata, suggesting not only that the contortion was produced by inequipotential slipping of the mass, but also that the slipping was confined to the most readily yielding beds.

In hypsographic distribution the southern loess is allied to the northern phase, in that it sometimes seeks eminences and avoids depressions, and elsewhere seeks depressions and avoids eminences. Its hypsographic relations are illustrated in the section from the Mississippi to the Wapsipinnicon, forming Fig. 57. Toward the southern extremity of this section the loess crowns a notable ridge, one side of which is washed by the Mississippi and the other by Duck Creek (which flows parallel with the great river but in the opposite direction). This little loess field stands by itself; it everywhere slopes strongly to the northward, and more gently (yet more strongly than the neighboring fields) to the eastward; and the drainage leads away from the Mississippi even to the verge of the escarpment overlooking the river. North of Duck Creek there is another and broader loess field, the surface of which inclines gently southward and eastward. In the bluffs of the creek the deposit is thick, but it thins inland and finally disappears gradually as its plane surface gives way to the undulating drift plain. This loess field widens eastward and finally merges with that overlooking the Wapsipinnicon, the two uniting to form the Mississippi bluffs in the eastern part of Scott County. In the northern part of the section there is represented a third loess field rising conspicuously above the drift plain on the south, sloping southward, and upturned at its northern margin, yet drained against the slope to the northward by a multitude of ravines originating within the low-lying drift plain, deepening rapidly in the loess upland, and embouching into the Wapsipinnicon valley through deep notches. The upturning of the northern margin of this loess field, which is illustrated in the section, is imitated in every loess field (save the one at Davenport, in which the tilting is reversed) in the southern counties. The disposition to seek eminences is displayed also by the accumulation of loess on the highest land in Muscatine County, over the uplands overlooking the Cedar in southern Cedar County, and on the plateau about the headwaters of Deer Creek, in northern Marshall County; yet in the southwestern counties the deposit generally forms a mantle, continuous save along the larger waterways and over the broadest divides, thickening somewhat in depressions, thinning somewhat over the divides, and rising to a once uniform surface, now sculptured in intricate pattern by autogenetic drainage.

The thickness of the southern loess is variable. Toward its northern margin and over divides it is but a veneer, separable with difficulty from the subjacent drift; in the plateau west of Tama it is occasionally exposed to depths of 40 feet; at Muscatine it is 40 or 50 feet thick; at Davenport its thickness reaches 70 feet; and in the upturned rim of the northern Scott County field the loess with its basal sands forms the greater part of the 150 feet scarp, and probably exceeds 100 feet in thickness.

The fauna of the southern loess is for the most part of the usual simple facies, but as rich in individuals as poor in species. Nearly



STRUCTURE OF LOESS, MUSCATINE.

every satisfactory exposure yields tne common land shells, *Succinea*, *Pupa*, and *Helix;* and frequently fragmentary shells fleck the exposed faces of the deposit everywhere below the limit of weathering so closely as to turn the drab to gray. This fauna has been carefully studied by local students at Iowa City, Davenport, and Muscatine.

The fossils from the southern phase of the loess at Iowa City have been found by Shimek to agree with those of the loess of the ridges and paha farther northward.

The fossils from Davenport are, according to Pratt, as follows:[1]

Succcinea avara.
Succinea obliqua.
Helicina occulta.
Pupa fallax.
Helix striatella.
Elephas primigenus (a tusk, several molars, and some bones).

According to Witter, the Muscatine fauna is as follows:[2]

Helix striatella, abundant.
Helix fulva, common.
Helix pulchella, common.
Helix lineata, common.
Helix cuperi, common (on Illinois side of the river).
Pupa blandi, common.
Pupa quarticaria, rare.
Pupa muscorum, common.
Pupa simplex, common.
Succinea avara, abundant.
Succinea obliqua, common.
Helicinea occulta, rare.
Limnæa humilis, rare.
Unio ebenus, rare and local.
Unio ligamentinus, rare and local.
Unio rectus, rare and local.
Melantho subsolida, rare and local.
Margaretina confragosa, rare and local.
Cervus muscatinensis (teeth, bones, and antlers).

Most of the molluscan species from Davenport and Muscatine are now found living in the vicinity, and the fossils generally agree fairly with the modern forms in size and other characteristics—i. e., the species are not depauperate or otherwise notably abnormal. Here as in the north the gasteropods are mainly pulmoniferous; while the associated Unionidæ are, of course, fluviatile. The mammalian remains represent arctic or sub-arctic land animals; the cervine teeth and bones belonging to a species identical with or at least closely allied to the woodland reindeer (*Rangifer caribou*),[3] and the elephantine tusks and teeth approaching those of the "hairy mammoth" whose bodies are entombed in the ice and frozen earth of northern Siberia.

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[1] Proc. Dav. Acad. Sci., 1876, vol. 1, pp. 96–99.

[2] Proc. Iowa Acad. Sci., 1880, vol. 1, pt. 1, p. 16.

[3] Cf. Am. Jour. Sci., 3d ser., 1887, vol. 34, p. 8; and Leidy, Proc. of Acad. of Nat. Sci. Phila., vol. 31, pp. 32, 33.

CHAPTER VII.

THE DRIFT.

SECTION I.—THE UPPER TILL.

The eastern limb of that lobe of the great terminal moraine which stretches southward from central Minnesota to Des Moines lies just outside the territory of Northeastern Iowa; but there are, nevertheless, two well defined tills or sheets of glacial drift within the territory. The uppermost of these forms the prevailing surface except: (1) In the driftless area on the northeast; (2) in the great areas in the east and south and the lesser areas in other parts in which it is overlain by loess; (3) along the larger waterways, in which it is overlain or replaced by alluvium; (4) in the small gumbo area in Muscatine and Scott Counties; and (5) in the areas of exposed Paleozoic rocks and of eolic deposits, etc., which are unimportant in extent. The upper till is thus by far the most extensively developed superficial deposit of the territory.

As indicated by the monotonous simplicity of surface configuration, the upper till is moderately constant in the northern portion of its area—indeed, from exposure to exposure, from township to township, from county to county, its structure and composition remain essentially unchanged. It consists everywhere of a confused mass of sandy clay with pebbles, cobblestones, and bowlders interspersed in such abundance as somewhat to interfere with the pick and spade in the excavation and with the plow in the fields, the pebbles, cobbles, and bowlders over half an inch in diameter constituting perhaps 5 per cent of the mass. There is a certain homogeneity in the deposit which, despite the constant diversity in size of materials, quickly impresses the student. Each unit area of exposed surface exhibits about the same proportion of materials of each degree of coarseness as any other unit area, and the arrangement of the materials, coarse and fine, remains essentially the same from area to area. The characteristics are of course destroyed, either when the unit areas are so small that single pebbles constitute considerable portions of each, or when, though the area be large, huge bowlders occur in one and not in the other; but even then the finer matrix of pebble or bowlder commonly remains little changed from place to place. There is thus a certain homogeneity in the larger way, when different parts of the deposits are compared, which strikes the comparative student more forcibly than that heterogeneity in the small way which is prominent when a single exposure of small extent is studied. Let the term homogeneity for present purposes express the idea of homogeneity in this large way. Then, throughout the northern portion of the territory, the upper till is commonly homogeneous in both horizontal and vertical directions; in the horizontal direction it remains essentially the same from mile to mile, and in the vertical direction it is fairly homogeneous from yard to yard of its thickness, and from the low hilltops to the shallow valley bottoms of the gently undulating plains formed by its surface. But this homogeneity is sometimes interrupted by far traveled bowlders whose diameter may exceed the thickness of the deposit; it is also interrupted where the sheet is exceptionally thin and where the Paleozoic subterrane or the older till have, by reason of local conditions, contributed in unusual amount to its materials. Moreover, gradual change in composition may be observed in passing from the interior of the drift field toward the drift margin in the great crest overlooking the Mississippi; and a still more gradual change supervenes in traversing the territory from north to south.

The thickness of the sheet is variable. Along the margin of the driftless area it is usually denuded and, overlain as it generally is by loess, becomes inconspicuous. Along this line and north of Dubuque County it commonly rests upon the lower till or modified representatives of that deposit, though occasionally the older deposit has been removed and the newer lies in part upon ice-worn contours of the lower till and in part upon rock, as shown in Fig. 60, representing a section observed in a road cutting in NE. ¼ SE. ¼ Sec. 15, T. 90 N., R. 3 W., Delaware County.

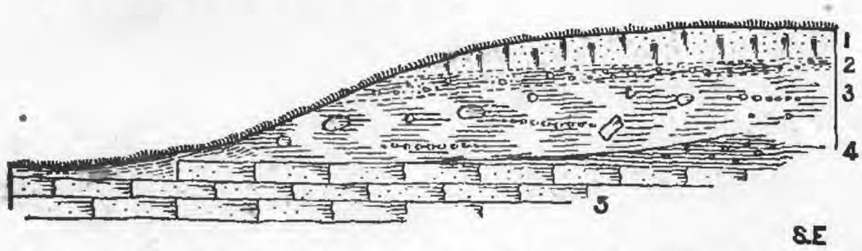

FIG. 60.—Partial removal of lower till by later ice work, Delaware County: (1) Loess; (2) yellow sandy and gravelly clay, irregularly stratified; (3) unstratified yellow clay with local and erratic bowlders and pebbles; (4) dark laminated clay with fragments of chert and small erratic pebbles; (5) Niagara limestone. Mean exposure, 10 feet.

No morainic accumulations appear along the eastern margin of the upper till save in two localities: (1) Between West Union and Fayette the marginal drift rises into an irregular series of steep, rounded knobs, sometimes loess-capped, but more frequently exposing gravel with numerous rounded pebbles and bowlders on their weathered summits. Many of these are high and conspicuous. One in particular, 3 miles southeast of West Union (locally known as Jones Hill), is a prominent landmark. Though in general form, distribution, and association with ponds and dry basins these knobs are decidedly moraine-like, they are confined to an area of only a few square miles; there is no general thickening of the drift in their vicinity, and the loess capping and elongated form of many of the isolated knobs distinguish them from true terminal moraines like that found 80 miles farther westward. (2) Again, between Rockville and Sand Spring, in eastern Delaware County, particularly 3 miles southwest of Worthington, there is a congeries of isolated knobs, sometimes loess-covered, but again built of bowlder-charged drift to their very summits, which are of decidedly morainic aspect; but they are fewer in number than those of Fayette County, and at least a part of them pass into paha.

The range in thickness of the till is increased by these anomalous deposits, yet the thickness probably nowhere exceeds, if it reaches, 100 feet; in general it is not more than 20 feet; over considerable areas it ranges from 5 to 10 feet; and toward the Niagara escarpment in northeastern Howard and northwestern Winneshiek Counties, west and south of Fort Atkinson, for some miles around Brush Creek, over the divide between Plum Creek and the North Maquoketa in eastern Delaware County, and in many more restricted areas, its thickness is less than 5 feet; and it frequently disappears completely, leaving tors of Niagara limestone wholly uncovered or only dotted with erratic pebbles and bowlders.

There is a progressive increase in thickness of the till westward from its eastern margin to the western limit of the territory, yet here and there it attenuates locally and sometimes forms but a trifling mantle over the subjacent Paleozoic strata—e. g., over the divide between Flood Creek and the Cedar in Floyd County, where an interesting relation between configuration and drift accumulation is displayed. This relation is roughly illustrated in the generalized section across Floyd County from west to east a mile south of Rockford and Charles City (Fig. 61), constructed from

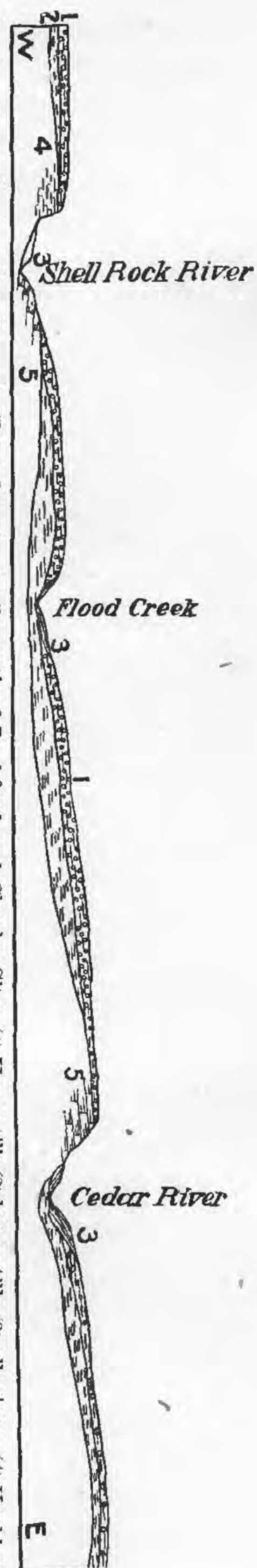

FIG. 61.—Generalized section through Floyd County, 1 mile south of Rockford and Charles City: (1) Upper till; (2) lower till; (3) alluvium; (4) Hackberry shale; (5) Cedar Valley limestone. Relief, 200 ± feet; length of section, 24 miles.

data collected by observations upon the surface and examination of natural and artificial exposures at various points. The same relation is illustrated in greater detail in the section reproduced in Fig. 62, constructed from surface observations and study of well excavations in southeastern Floyd County.[1] From these sections it will be apparent that the upper till tends to attenuate over crests and thicken in depressions (though certain exceptions to this law appear), that the lower till displays the same tendency in a much more decided way, and (from Fig. 62) that the forest bed fails in exceptionally exposed situations and is deeply buried in exceptionally protected situations—in short, it is apparent that in this part of the territory the ice sheet was both constructive and destructive in its operation, its special agency being determined by local conditions.

FIG. 62.—General section in Floyd County: (1) Upper till; (2) compact dark clays of lower till; (3) gravel and sand (water bed) of lower till; (4) Cedar Valley limestone; dark shading—forest bed. Relief, 50 feet; length of section, one-half mile.

The maximum thickness attained by the upper till in the northwestern part of the territory can be confidently estimated to probably reach and perhaps exceed 80 feet, and the mean thickness in the northern half of its extent may be roughly estimated at 20 feet.

The usual relations of the upper till to older deposits are illustrated in many of the well sections represented in Pl. LI. Its relations to older and newer Pleistocene deposits and to the Paleozoic strata about the margin of the driftless area are more clearly illustrated in Fig. 63,[2] representing general sections extending from Farley to Dubuque. The sections represent also the relation between the till and the Niagara escarpment; for it is a significant fact that for a hundred miles the glacial deposit extends with unbroken continuity over gentle slopes to the very verge of an exceedingly sinuous and deeply crenulate escarpment, to there suddenly cease entirely or suffer transformation into a bed of water-sorted sand, gravel, and bowlders. Here as elsewhere along the great Niagara escarpment the unmodified glacial deposit extends only to the verge, and its limits in the valleys thus fall far short of those reached on the hills. So about the driftless area

[1] The wells indicated are represented on a larger scale in Pl. LI, and described in section V of this chapter under the following numbers: I = 15; II = 13; III = 11; IV = 10; V = 16; VI = 12, and VII = 14.

[2] This figure represents three sections, the uppermost along the principal wagon road (the "old Delhi road"), the intermediate one along the line of the Illinois Central Railway, and the lower along the line of the Dubuque and Dakota Railway.

margin the unmodified upper till may be traced to the extremity of a salient, and no representative of the deposit may be found for miles beyond; but if the line of examination be so projected as to cross another salient, howsoever long, narrow, and curved, the till is nearly sure to reappear on its crest, as in the case a mile north of Lattner's, illustrated in Fig. 64. Viewed by itself such a section would naturally be interpreted as a record of erosion since the deposition of the till; but there is abundant evidence that the complex configuration of the Niagara escarpment has been little changed since the advent of northern ice. In some cases the upper till, or a modified representative of that deposit, may be found in completely isolated patches crowning uplands (commonly beneath a mantle of loess) completely divided from the general drift area by drift-free transverse valleys, as about Preston and Goose Lake.

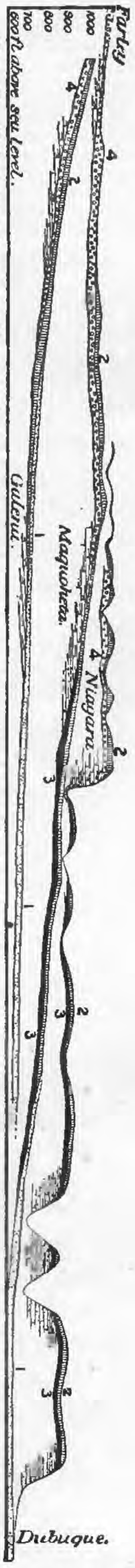

FIG. 63.—Relations of upper till toward its eastern margin; general section from Farley to Dubuque: (1) Alluvium; (2) loess; (3) geest; (4) upper drift clay.

The principal material of the upper till is a mixture of finely comminuted rock débris, exhibiting the consistency and commonly taking the name of clay. This fine material, however, can only be arbitrarily separated from sand, which in turn can be separated only in the same way from gravel, that from pebbles, and these from cobbles and bowlders; so that the dimensions of the component particles of the drift sheet here, as commonly elsewhere, represent an unbroken series from the finest to the coarsest. The finest particles, like the coarser, are found under the microscope to consist mainly of rock fragments, and beneath the reach of weathering this rock débris usually effervesces freely under acid, indicating that the particles have not been exposed to the air or to free percolation of water since the original trituration beneath the ice field.

The prevailing color of the upper till is yellow or buff, running into gray, and rarely into reds and browns; i. e., it is commonly stained by hydroferric oxide. Exceptions to this prevalent coloration frequently occur, however, particularly in ill drained sloughs, where there are considerable accumulations of iron in the form of bog ore, either in nodules or in films incrusting pebbles and bowlders, and in which the deposit frequently assumes the blue color given by the ferrous oxide which commonly characterizes the lower till.

This unusual coloration sometimes extends several feet into the newer till, but never, so far as yet seen, to the junction with its older homologue.

It is significant that other conditions leading to decomposition of organic matter than slow maceration in sloughs are equally potent. It has frequently been observed that beneath barnyards and in all similar situations the upper till assumes a blue color undistinguishable from that of the lower; and in a known instance the change was effected within a few months. The section exposed in the shallow well represented in Fig. 44, and again with associated phenomena in Fig. 65, is of interest in this connection; for although the alteration in color is mainly confined to the loess, it extends some distance into and similarly affects the upper till. The well was excavated in a barnyard which had been in use for a year or less. In this case deeper extension of the blue color may have been prevented by the more porous pebbly stratum below.

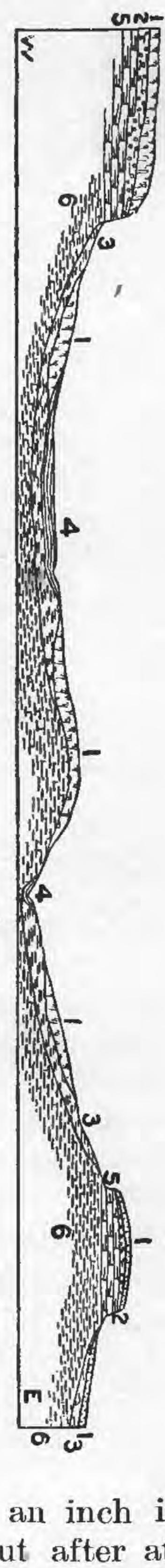

Fig. 64.—Relations of upper till toward its eastern margin; general section near Lattner's, Dubuque County: (1) Loess; (2) upper till; (3) water laid beds of local and erratic débris and residuary clays; (4) alluvium; (5) Niagara limestone; (6) Maquoketa shale. Relief, 300 feet; length of section, 3 miles.

This section is of interest, too, in that it illustrates the relation between change in coloration and the formation of ferruginous nodules, and indeed exhibits the precise mode of formation of such nodules; for nodules in all stages, from simple, indefinite staining to the complete form, were displayed. The process appears to be as follows: At a point where several minute fissures or jointage planes intersect in such manner as to form a solid angle projecting downward, but from which no openings extend in such direction as to drain the fissures at the point of intersection, a slight accumulation of the iron carried downward through the fissures takes place. At the same time the clayey material appears to undergo some condensation, so that the fissures are enlarged; and from a thin film of ferric oxide staining the surface the deposit increases until it forms a deep brown, incoherent shell, resembling ocher in composition, perhaps a tenth of an inch in thickness. Thus far the shell remains open above; but after attaining a thickness of from a tenth to a fifth of an inch (the thickness attained varying directly with the size) the process of nodulation proper commences, and the shell grows upward and inward, at first simply as a dark stain cutting off the downward projecting angle of clay; and along the rudely spherical surface so marked out, segregation proceeds, the stain is converted into a shell or crust, and a fissure is gradually formed about its periphery. Accretion from without seems to practically cease with the completion of the nodular shell; but as this becomes indurated, segregation takes place from

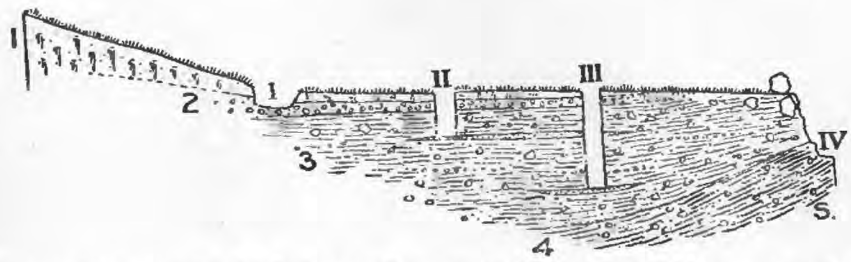

FIG. 65.—Representative section in Dubuque County: (1) Loess; (2) pebbly stratum (loess base); (3) coarse yellow pebbly clay, unstratified, but with a few irregular horizontal sand veins; (4) lower till. I is a road cutting; II is the shallow well illustrated in Fig. 44; III is a well yielding a large supply of water; the space between III and IV was in early days a quaking bog during much of the year; IV is a natural gully, with springs formerly flowing from the summit of the lower till. The bowlders near IV reach 5 feet in diameter. The striated pebbles illustrated in Fig. 68 came from the well at III. Location, near the center of Sec. 31, T. 89 N., R. 1 W.

within, and the inclosed nucleus of clay becomes bleachedand perhaps indurated. The nodules formed in this manner commonly have at first an angle projecting downward and a rounded surface above; but like other forms of limonite they are exceedingly unstable in configuration, and the original attitudes and dimensions may become greatly changed.

Next to the mass of rock débris commonly called clay, the most abundant material of the upper till is sand. A considerable proportion of this sand is quartzic and more or less sharply angular; but grains of like size of all the rock materials represented in the coarser particles, and perhaps more besides, occur also. Commonly the sand is intermixed with finer material so uniformly as to form a loam varying somewhat in composition from place to place; but in some cases there is more or less assortment of materials, and certain limited beds are made up mainly of sand, sometimes stratified and even crossbedded. Sand grains run in dimensions all the way from the finest visible or palpable particles to gravel grains; but the larger dimensions are, in general, and in nearly every local section as well, progressively rarer with increase in size.

Next to sand and the gravel into which it runs, pebbles are important as an element of the upper till; and they, like the bowlders, tell something of their own original homes and of the agencies to which they have been subjected in transportation. And pebbles and bowlders alike reveal the significant facts, (1) that by far the greater part of the coarser drift material of Northeastern Iowa is erratic, and (2) that much of it has been transported from distances of many hundred miles. In the northwestern part of the territory, hundreds of pebbles have sometimes been scanned in freshly exposed sections, or thousands in freshly storm-swept valleys, without finding a single one that might have originated either within the State or within a hundred miles north of its boundary; even so far east as the western part of Delaware County long continued search over thousands of pebbles has yielded less than 1 per cent which were not of ancient crystallines transported from beyond, and perhaps hundreds of miles beyond, the Minnesota River.

A careful enumeration was made of the pebbles above an inch in diameter exposed in an area of 2 square yards of a railway cutting in the upper till half a mile south of Maynard. No less than 75 per cent were found certainly referable to rocks occurring only north of the Minnesota River, while only 8 per cent were certainly referable to local sources and it is probable that by far the greater part of the 17 per cent of unknown origin came from far beyond the northern confines of the territory. The results of the enumeration are shown in detail in the accompanying Table 1. The enumeration was made on the ground in connection with President Chamberlin, by whom the identifications represented in the second table were made. Nearer the drift border the proportion of erratic material diminishes, but still remains surprisingly large, as indicated by the third table, representing the numbers of all pebbles from one-eighth of an inch upward (to 5 or 6 inches) on a tor in the SE. ¼ SW. ¼, Sec. 30, T. 89 N., R. 1 W., Dubuque County. All the pebbles classed as erratic are known to have come from beyond the limits of the territory, doubtless from the great crystalline areas of northern Minnesota and Canada. Those classed as local have probably been moved no more than a mile or two at most, while the greater part of the doubtful pebbles probably came from far beyond the limits of the State. It should be noted that the pebbles of both tills are represented in the third table, and those of the upper till alone in the first and second.

TABLE 1.

Rock.	Erratic.					Local.					Unknown or common.					Total.
	Angular.	Subangular.	Rounded.	Striated.	Miscellaneous.	Angular.	Subangular.	Rounded.	Striated.	Miscellaneous.	Angular.	Subangular.	Rounded.	Striated.	Miscellaneous.	
Granite		14	4		4											22
Greenstone*	1	11	2	4	2											20
Gneiss	1	5	3		1											10
Quartzite			2													2
Quartz			2													2
Limestone											6	6	1	1		14
Sandstone		1	2	3	1											7
Chert						2	1			1						4
Limonite										3						3
Aggregate	2	31	15	7	8	2	1			4	6	6	1	1		84
Per cent	2+	37−	18−	8+	10−	2+	1+			5−	7+	7+	1+	1+		99+
Aggregate by classes					63					7					14	84
Per cent by classes					75−					8+					17−	100

* Diabase, hornblende slate, hornblende schist, etc.

TABLE 2.

Formation.	Erratic.					Local.					Unknown or common.					Total.	Per cent.
	Angular.	Subangular.	Rounded.	Striated.	Miscellaneous.	Angular.	Subangular.	Rounded.	Striated.	Miscellaneous.	Angular.	Subangular.	Rounded.	Striated.	Miscellaneous.		
Pleistocene										3						3	4−
Devonian										1	2	4	1	1		9	11−
Silurian*		1	6	3		2	1				4	2				19	23−
Algonkian					1											1	1+
Huronian	1	13	2	4	2											22	26+
Laurentian	1	17	7		5											30	36−
Aggregate	2	31	15	7	8	2	1			4	6	6	1	1		84	101−

* Not exposed in Iowa in the direction whence the Pleistocene ice came.

TABLE 3.

Kind of rock.	Local.	Erratic.	Doubtful.	Total.
Chert (Niagara)	161			161
Hornblendic slate and schist		75		75
Limestone	38			38
Syenite		31		31
Hornblendic gneiss		29		29
Brown chert			27	27
Granite		24		24
Quartzite		23		23
Black, blue, and red chert			12	12
Quartz		8		8
Fossil corals	5			5
Nodular ferruginous concretions	5			5
Ocherous masses (not nodular)	5			5
Hematite		4		4
Diorite (?)		3		3
Jasper		3		3
Agate				2
Aggregate	214	202	39	455
Per cent	47+	44+	9−	100

To the tourist traveling over the surface, the bowlders form the most conspicuous element of the upper till. Everywhere within an area of several thousand square miles in the northwestern portion, they are so numerous that a dozen or a score are always in sight,

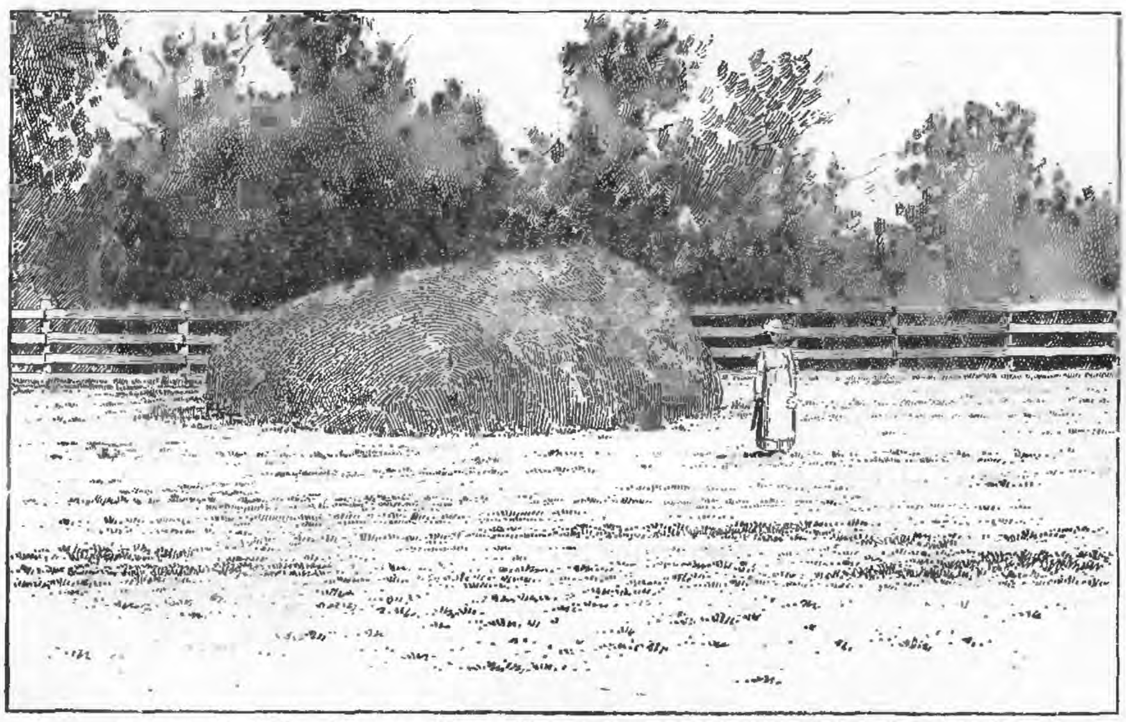

FIG. 66.—Drift bowlder, 1½ miles northwest of Maynard, 18 by 23 feet, 7 feet high.

and so large that they rise above the drift surface as high as houses or haystacks, and give character to every landscape. They culminate in abundance and size in Butler, Bremer, Black Hawk, and Buchanan

Counties, and they are quite as large, though barely so abundant in Mitchell, Floyd, Chickasaw, and western Howard Counties. The largest measured lies 2½ miles north of Sumner. At the time of measurement its diameters at the surface were 25 by 40 feet and its height above the surface 11 feet; but enough of it had been quarried to form foundations for two or three houses, and the larger portion appeared to be buried in the drift. Scores of others rise higher than this, reaching 15 to 18 feet above the surface, and hundreds of others measure more than 20 feet in mean diameter at the drift surface. Most of them are incorporated in the drift sheet and only peep out from its mass; but many others lie mainly or wholly upon the surface.

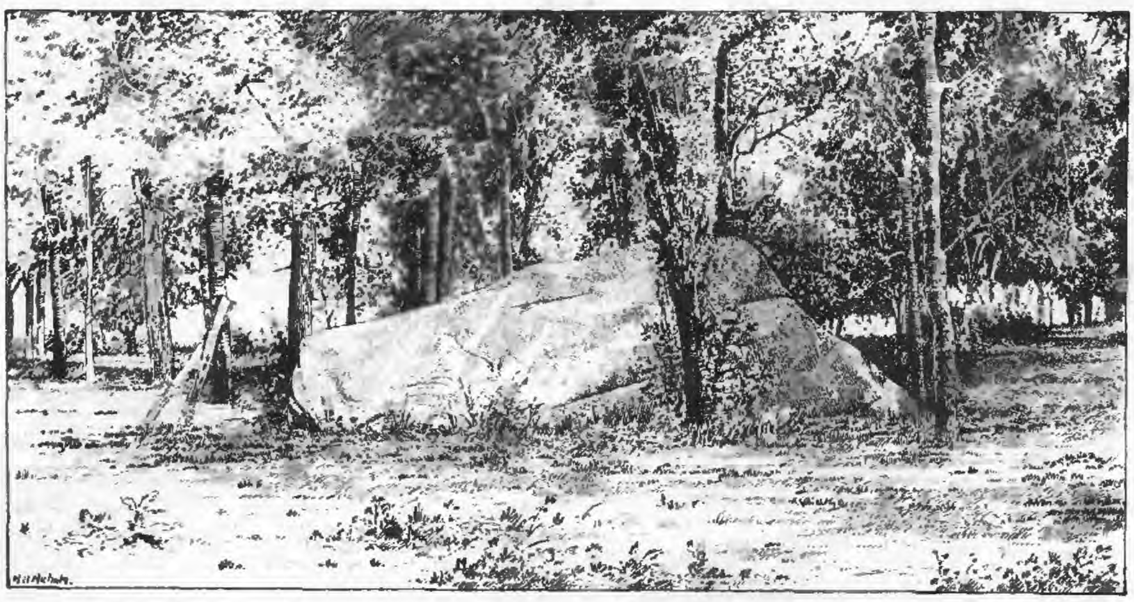

FIG. 67.—Drift bowlder in Buchanan County (NE. ¼ NE. ¼, Sec. 18, T. 89 N., R. 7 W.), 25 by 32 feet, 9 feet high.

In the southern part of the territory the surface bowlders are smaller and rarer. The southernmost observed bowlder of large dimensions lies in Duck Creek, in the southwestern part of Sec. 21, T. 78 N., R. 4 E. Its mean diameter is about 12 feet. Another notable bowlder, 16 by 21 feet measured at the ground, and rising 11 feet above the surface yet mostly buried, occurs 2 miles northeast of Massillon, in the NE. ¼ SE. ¼ Sec. 1, T. 82 N., R. 1 W. Another, of beautifully variegated syenite, was nearly buried beneath the drift of the SE. ¼ SW. ¼, Sec. 4, T. 81 N., R. 9 W., in Iowa County. Its least dimension was 11 feet, and on breaking up it yielded material for the walls of a house, the foundations of a barn and other outbuildings, and the lining for a well.

The greater part of the larger bowlders are of coarse feldspathic granite of firm texture. A coarse-textured syenite in which large crystals of feldspar predominate and in which hornblende is conspicuous is also common. None of the larger bowlders have been observed to be striated; but those commonly seen have been long exposed to weathering, and their angles are more or less rounded by exfoliation.

Although so conspicuous, the great bowlders of a thousand cubic feet or more are far less numerous than those of smaller sizes, ranging down (in increasing numbers) to cobblestones. These sometimes dot the surface and charge the drift beneath in vast numbers; those lying so near the surface as to interfere with the plow are either more deeply buried by the agriculturist or dragged away, a score or possibly a hundred from an acre, until the lanes are lined with rod-wide ranks of bowlders sometimes piled two or three deep; and now and then they are so abundant in certain lots of land as to discourage agriculture and the lot is given over to grazing. But this abundance of bowlders is local, and apparently confined to spots subjected to exceptional wash during the melting of the ice sheet.

Many of the smaller bowlders are striated; and still larger numbers of the cobbles and pebbles are similarly marked—the dimensions most frequently exhibiting striæ probably lying between one-fifth and three-fifths of an inch. The striæ on small pebbles are not, however, so regular as those upon large. Their character is illustrated in Fig. 68, representing three such pebbles, of the natural size.

FIG. 68.—Striated pebbles; natural size.

The striæ and other markings exhibited by the bowlders and pebbles of Northeastern Iowa are in no way specially distinctive, but closely similar to those displayed by ice-fashioned bowlders throughout the drift-covered portion of North America, and in the moraines at the termini of the Alpine and other living glaciers as well—they simply represent one of the most interesting and instructive features of the trail of the ice monster. Indeed the proportion of striated bowlders, particularly of the larger sizes, is considerably less than that commonly observed east of the Mississippi. One of the best illustrations of bowlder striation observed in the territory is that afforded by the limestone bowlder represented (one-half natural size) in Pl. XLVI; and a curious illustration of the effect of ice wear upon a previously water worn pebble is shown in Figs. 69–71. It was taken from unmodified upper till in a well in NW. ¼ SE. ¼ Sec. 1, T. 88 N., R. 1 W., Dubuque County.

There are several less important but significant elements locally found in the upper till. One of these is Cretaceous fossils (chiefly fish teeth) occasionally found in the northern part of the territory.

Another comprises pebbles and bowlders, sometimes well worn but again little affected by the agencies of transportation, of ferruginous pudding-stone evidently representing the meagerly developed Cretaceous formation of the territory—the Rockville conglomerate.

FIG. 69—Ice-worn pebble; natural size.

Still another element of the upper till is wood, commonly in the form of battered and broken logs, sticks, and smaller fragments of coniferous wood similar to that found in the forest bed. This material was notably abundant in the railway cuttings between Fayette and Brush Creek, and between Maynard and Oelwein, in Fayette County. The same railway cuttings expose to view many examples of another highly interesting element of the upper till, i. e., ferruginous nodules such as frequently abound in the lower till associated with the forest bed. These nodules are sometimes intact, but again battered and broken, and occasionally striated and polished like the erratic pebbles with which they are commingled. Similar striated concretions, evidently derived from the lower till, have been found, also, in the lower part of the upper till in the cutting of the Chicago, Milwaukee and St. Paul Railroad, 3 miles east of Lawler. These nodules evidently represent the period of ferrugination and soil formation represented more decisively by the forest bed; and it is evident that they were completely formed and indurated as firmly as to-day before the advent of the later ice sheet by which they were dislodged and incorporated in the newer deposit and impressed with the unmistakable seal of the Ice King.

FIG. 70—Ice-worn pebble; natural size.

FIG. 71—Ice-worn pebble; natural size.

Of related interest and significance are the bowlders of clay and sand sometimes incorporated in the upper till. These may represent either the red residuary clays of the drift margin or the pebbly deposits of the lower till; and the included masses may be either true bowlders, rounded or subangular, or flattened, elongated, or otherwise modified masses. In the case illustrated in Fig. 72 (ob-

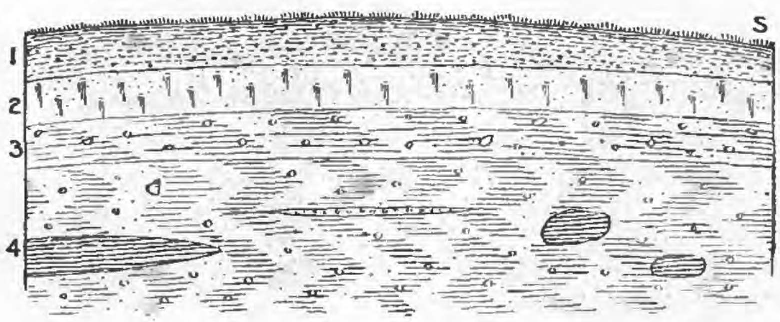

FIG. 72.—Bowlders of lower till incorporated in upper till, Linn County: (1) alluvium, 3 feet; (2) loess, perhaps rearranged, 2 feet; (3) yellow pebbly and sandy clay, obscurely stratified, 2 feet; (4) unstratified yellow clay with local and erratic pebbles, with a 5-foot bowlder near by, containing lumps and an elongated band of blue clay, 8 feet.

served in a railway cutting between Paralta and Springville, Linn County) the two smaller masses are simply rounded bowlders, while the largest body was apparently washed and compressed in such manner as to simulate an intercalated stratum. A remarkable example observed in a natural exposure on Mad Creek, 1½ miles north of Muscatine, is represented in Fig. 73. Here

FIG. 73.—Clay bowlder embedded in sand bowlder, near Muscatine: (1) Soil and débris; (2) loess, fossiliferous above, sandy below, passing into stratified sand; (3) stratified sand, fine above, coarse and somewhat gravelly below; (4) fine stratified sand containing a mass of structureless sand in which is embedded a rounded bowlder of pebbly clay, the stratification of the bed being horizontal save in the neighborhood of the sand bowlder, to which the stratification is adjusted; (5) somewhat sandy yellow clay containing erratic pebbles, grading into the sand beds between which it lies; (6) stratified sand containing lines of gravel, resting on an irregular surface of distinct material, somewhat ferruginated at base; (7) tenacious blue clay with disseminated erratic pebbles and with carbonaceous spots and streaks above. Exposure, 30 feet.

a rounded bowlder of tenacious pebbly clay, undistinguishable from that of the lower till in the base of the same section, is embedded in a mass of structureless sand, which is itself incorporated in a bed of coarser and distinctly stratified sand—the two merging to some extent laterally, though the sides of the bowlder are clearly defined above and sharply distinct below. This is near the margin of the upper till.

Yet another locally developed element appears, but thus far only in the southern portion of the territory, in the form of calcareous concretions, or loess-kindchen. When the upper till is overlain by and grades into loess, the transition from the one to the other may be marked either by an intermediate stratum of bedded sand or by imperceptible transition without intermediate deposits. In the latter case, the loess fossils gradually disappear downward and drift pebbles take their places; then the loess-kindchen commonly diminish in numbers and assume more irregular forms, and frequently entangle the associated pebbles; and sometimes at still lower depths, where pebbles are abundant and bowlders occasionally found, the loess-kindchen remain either as rounded or botryoidal nodules or as films and sheets of lime carbonate incrusting pebbles and coating jointage planes. This succession is illustrated in scores of sections—notably in one exposed in a road cutting in the NE. ¼ NE. ¼, Sec. 13, T. 80 N., R. 13 W., Poweshiek County.

An element of the glacial drift generally throughout the entire basin, which is almost insignificant in volume but sometimes important in value, is triturated gold. This element occurs in Iowa, as elsewhere, commonly in exceedingly small quantity; but there is a considerable area in which the local conditions of deposition of the upper till have led to such concentration that it may prove of economic value. It has already been noted that the headwaters of the Volga rise in an elongated basin, trending in the general direction of stream-flow and drained through waterways at first flowing in opposite directions, but later uniting in the lowest part of the basin a few miles west of Fayette, and thence finding their way through a narrow gorge in the northeastern rim of the basin and so beyond the Niagara escarpment into the Turkey. Now, this basin is a magnified similitude of the miner's pan, or rather the prospector's horn; and when the débris from the slightly auriferous crystalline rocks of the northwest was partly pushed and partly washed into and through the basin, the heavier gold was caught in its lower portion, and there remains to lure if not to reward the prospector. About Brush Creek gold has been frequently found in such quantity that mining fevers have frequently broken out. In one case an experienced miner is reliably reported to have realized a dollar per day for some months in extracting the shining dust with a small rocker and with inadequate water supply. About Fayette, at Maynard, and everywhere in the northeastern part of the basin, indeed, more or less gold has been found, and even in the gap cut by the Volga in the basin rim, at Wadena, gold has been obtained in nearly paying quantities.

SECTION II.—THE FOREST BED.

As indicated by the detailed description of the well sections illustrated in Pl. LI, vegetal accumulations—logs, sticks, branches and twigs, cones and leaves, stems and roots of grasses, and indigenous plants, together with peaty soils—are sometimes found at all horizons both in the upper till and in the lower till. In the majority of cases, however, the vegetal accumulations are found in the largest volume and least broken condition at the junction of the two drift sheets; and in some cases the plane of junction of the sheets is definitely marked by a peaty soil, containing stumps and rootlets evidently in place, grading first into a subsoil and then into characteristic lower till, with abundant woody fragments on the soil surface.

The relative abundance of such vegetal accumulations is fairly indicated by the sections illustrated in Pl. LI, for these have been selected at random and may be considered representative of the succession of deposits encountered in excavating wells throughout the territory. More than 80, or something over 40 per cent of these, encountered vegetal accumulations; and in 20 or 25 per cent of the wells a definite forest bed marked the junction of the tills.

Neither the clearly defined forest bed nor the vegetal accumulations in general are uniformly distributed; but the distribution of both, and particularly of the former, is evidently related to that of the upper till. Thus, in the western third of the territory, and notably in the northwest, where the upper till may be fairly considered to be the product of energetic glaciation, the forest bed proper is seldom found, and vegetal accumulations are not frequent; toward the eastern margin of the upper till in the northern half of the territory the ancient soil is rather infrequently found in undisturbed condition, but battered wood, displaced stumps, and scattered remnants of soil occur in 50 per cent or 60 per cent of the excavations penetrating the drift. Toward the eastern margin of the southern half of the territory the forest bed is more and the débris from the forest bed less abundant—perhaps 33 per cent of the excavations penetrating a little disturbed soil at the junction of the tills, and 20 per cent or 25 per cent yielding broken and displaced remnants of the soil and its products; while in the southern portion of the territory, along the southeastern margin of the upper till, fully 50 per cent of the excavations reveal the forest bed in situ, and a much smaller proportion contain the battered logs and sticks characteristic of the northern exposures. In short, the frequency of the occurrence of the undisturbed forest bed is inversely proportional to the intensity of glaciation indicated by other phenomena; while the frequency of occurrence of erratic remnants of the soil and its products is related to the intensity of glaciation in more complex fashion, culminating 20 to 50 miles from the margin of the glaciated tract, and diminishing toward both the interior and the periphery.

The deposit in itself as well as in its relations varies from place to place. The section illustrated in Fig. 74, revealed in a railway cutting 2 miles southeast of Fayette (SW. ¼ NE. ¼, Sec. 3, T. 92 N., R. 8 W.) is exposed in the margin of a paha veneered with loess though chiefly

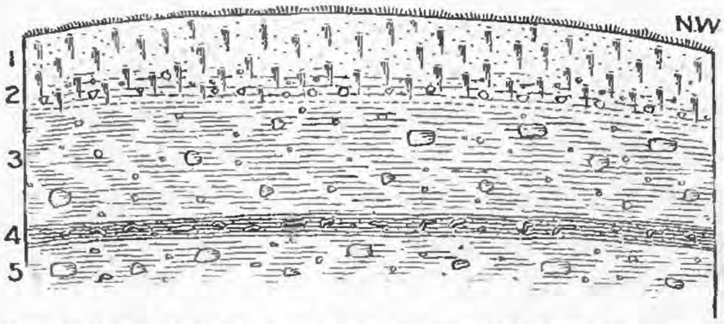

FIG. 74.—Intercalation of forest bed below s mmit of lower till, near Fayette. (1) Loess; (2) sandy, gravelly, and pebbly yellow clay passing into the loess; (3) plastic clay, yellow above, blue below, with a few pebbles and small greenstone bowlders, as well as crushed fragments of wood; (4) dark blue and black friable loamy earth and clay, with rootlets, fragments of wood and ferruginous nodules passing into the subjacent clay; (5) compact unstratified blue clay with striated pebbles. Total exposure, 22 feet.

formed of upper till. Here the soil and its arborescent products are broken up and intermingled with débris apparently derived largely from the lower till but redeposited by the later ice sheet. This rearranged portion of the lower till contains crushed fragments of coniferous wood at various levels, and is less compact than the undisturbed deposit below. Rootlets and much decayed fragments of wood are found in the dark soil represented in the section, the rootlets apparently in part in situ. A large quantity of wood (estimated at 50 to 75 cubic feet) was thrown out from this cutting. Most of it was apparently cedar, several specimens resembled pine, a few pieces appeared to be elm, and some fragments were not identified. Several striated ferruginous nodules were found associated

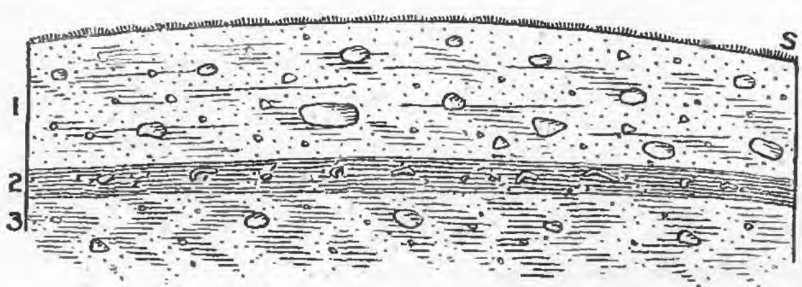

FIG. 75.—Normal position of forest bed, Fayette County: (1) Unstratified yellow clay with sand and gravel irregularly disseminated, with local and erratic (mainly the latter) pebbles and bowlders, in part striated, and with two or three rudely spherical bowlders of lower till, 8 feet; (2) dark friable and crumbling earth with crushed and twisted fragments of wood, rootlets apparently in situ passing into the subjacent member, ferruginous nodules (one striated), etc., 1 foot; (3) compact blue clay, jointed above, with striated pebbles chiefly of greenstone, and a few small bowlders, 3 feet.

with the wood. A similar section in which the forest bed materials were even more profoundly disturbed and nearer to the surface is exposed on the same railway (the Chicago, Milwaukee and St. Paul) half a mile nearer Fayette.

In the sections illustrated in Figs. 75 and 76 the forest bed was observed at what appears to be its normal horizon. The former is exposed in a cutting on the Burlington, Cedar Rapids and Northern Railway, a mile south of Maynard, Fayette County, on the divide between the Turkey and Wapsipinnicon basins. The upper till here contains numerous and large superficial bowlders, one within a few yards of the section reaching a diameter of 18 feet. The section is noteworthy by reason of the occurrence within the upper till of rounded masses of pebbly clay evidently derived from the older glacial deposit. There was also found in this section, intimately associated with the wood of the forest bed (identified as cedar and ash, the former greatly predominating), three sections of a partly silicified tree trunk 7 inches in diameter, two of which bore marks of glacial action. An analogous exposure is displayed on the same railway a mile north of Oelwein. The section illustrated in Fig. 76 was exposed in a well in the SW. ¼ SE. ¼, Sec. 15, T. 89 N., R. 9 W., Buchanan County, under the most favorable conditions, i. e., just as the excavation was completed. It is in the region of huge superficial bowlders, and a dozen or more measuring from 15 to 25 feet in diameter lie within rifle shot. The unstratified mass of the upper till is here overlain by a stratum of irregular sandy material, which extends from this point to the Wapsipinnicon River and represents the puzzling series of deposits connecting the Pleistocene drift sheet with the modern alluvium all over the northwestern part of the territory; and the drift mass is divided by a fissure, filled with similar sand, trending southeasterly and northwesterly and cutting entirely through the newer glacial deposit. The forest soil was apparently but slightly disturbed, though only a single fragment of wood was found.

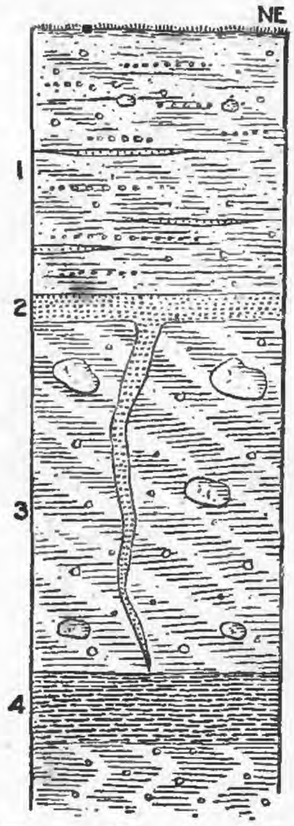

FIG. 76.—Normal position of forest bed, Buchanan County: (1) Sandy and pebbly yellow clay, partially stratified, 4 feet; (2) coarse stratified sand, 6 inches; (3) unstratified yellow clay with striated pebbles and bowlders up to 18 inches in diameter, 6 feet; (4) crumbling loamy black earth with a marshy odor, yielding an inky fluid on compression, with fragments of wood, rootlets, etc., passing into compact blue clay with small striated pebbles, 2 feet.

In Johnson and Muscatine Counties the forest bed is so commonly encountered in well digging as to be well known to residents. Sometimes in whole townships the well water is generally affected by the deposits, perhaps utterly ruined, but again revealing the presence of vegetal matter in the subterranean strata only by characteristic odor or flavor; and the well-diggers aim to so select locations with respect to the topography that the well will lie altogether within the lower till or within the upper till and the loess. The following section (observed in the NW. ¼ SE. ¼, Sec. 24, T. 79 N., R. 6 W.) is representative of the broad lowland east of the Iowa River in southern Johnson County:

		Feet.
1.	Silty loess containing the usual fossils	15
2.	Fine sand	2
3.	Sandy clay containing a few pebbles	2
4.	Peaty soil charged with sticks, leaves, twigs and roots, with a strong swampy odor	3
5.	Blue sandy clay with a few small pebbles	27

Another section in the same lowland, constructed from the materials brought up from a 2-inch bore put down for the purpose, is similar. It was located near the center of SE. ¼, Sec. 30, T. 79 N., R. 5 W., Johnson County:

		Feet.
1.	Soil	2
2.	Loess, becoming silty below	15
3.	Silty loess, containing fossil shells	2
4.	Same, without shells	1
5.	Sandy stratum	0.1
6.	Black, silty, loamy loess	2.5
7.	Peaty soil	2
8.	Brownish peaty matter, largely made up of decayed wood	1
9.	Decayed wood	0.5
10.	Fine black compact vegetal mold	1
11.	Gumbo	2
12.	Homogeneous silty clay, dark blue above, becoming greenish below	6

Over the uplands the upper till is commonly well developed, though sometimes absent. Thus, the succession observed in the SE. ¼ SW. ¼, Sec. 11, T. 79 N., R. 7 W. (a few miles west of Iowa City), is as follows:

		Feet.
1.	Loess, rather clayey and jointed toward the base, but otherwise homogeneous, unfossiliferous, and containing a few small loess-kindchen	5
2.	Dark brown or black clay, peaty and silty, sometimes laminated horizontally and interlaminated with the base of the loess, but sometimes massive	0.5
3.	Homogeneous drift clay, containing disseminated sand and sub-angular pebbles up to a quarter of an inch in diameter, with a few small calcareous nodules	3

Quite similar is the section displayed in a road cutting in the SW. ¼ NW. ¼, Sec 10, T. 78 N., R. 7 W. It is as follows:

		Feet.
1.	Loess, homogeneous, brownish (somewhat darker than typical loess in color), perceptibly sandy, without loess-kindchen or shells	5
2.	Black, peaty clay, jointed and friable	1.5
3.	Bluish white or ashen silty drift clay, containing a few small pebbles (up to half an inch in diameter)	3

A like relation is displayed in the well known section yielding elephantine remains in Davenport, described by Pratt in the Proceedings of the Davenport Academy, vol. 1, p. 96, Pl. XXXII, and by White in the Geology of Iowa, 1870, vol. 1, p. 119; for it should be observed that the "loess" of these descriptions includes toward its base layers of sand and erratic pebbles.

Elsewhere in Davenport, however, the upper till is better developed, e. g., in the section on the northwest corner of Sixth and Harrison streets, represented by the drawing from a photograph forming Fig. 77. The present surface at this point does not represent the

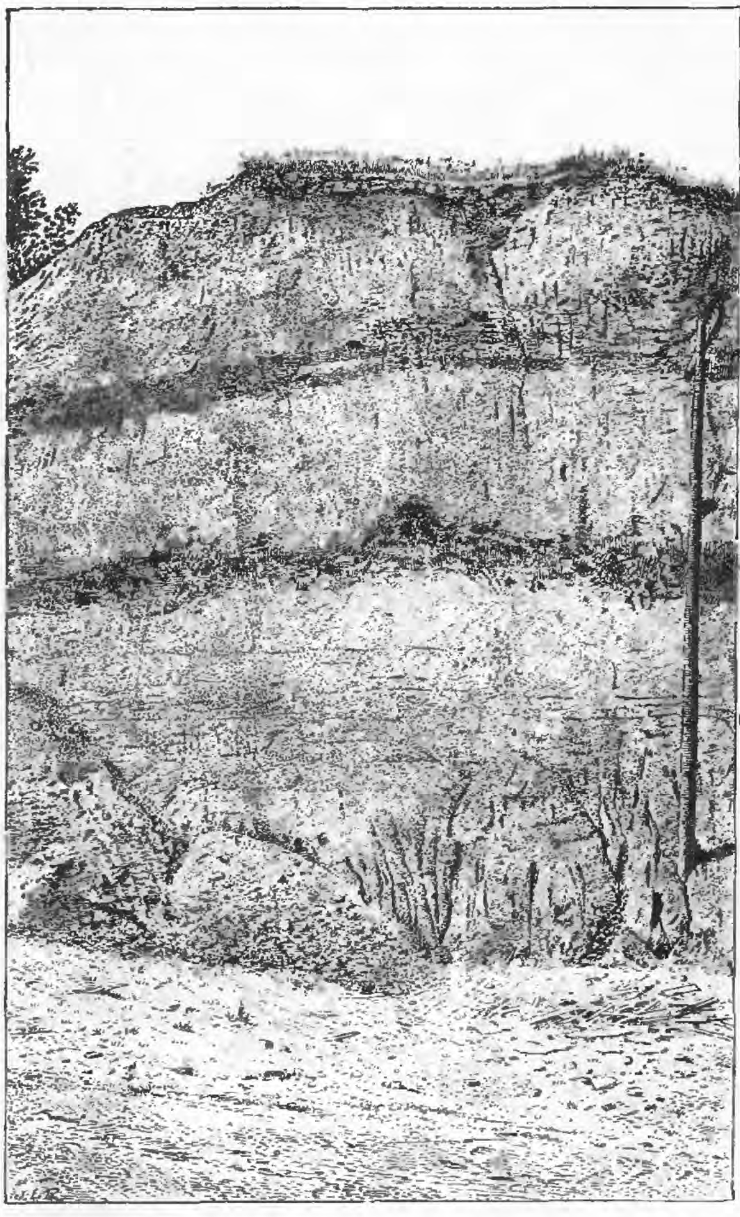

FIG. 77.—Section in Davenport showing relations of forest bed: (1) Loess; (2) pebbly clay (upper till); (3) brown sand, etc.; (4) blue pebbly clay (rearranged lower till); (5) soil, etc. (forest bed); (6) compact pebbly blue clay (undisturbed lower till). Total exposure, about 75 feet.

original loess surface, a considerable thickness of that deposit having been eroded. Thus the loess (which is massive and homogeneous, and abounds locally in loess-kindchen and tubules, contains a few small specimens of *Succinea*, and elsewhere yields a calcareous efflorescence similar to that sometimes observed on the Columbia loam on the upper Chesapeake and Delaware bays) is only 5 or 6 feet thick. It grades downward into homogeneous drift clay containing small pebbles, occasionally striated, commonly less than half an inch in diameter; and the loess-kindchen extend into the pebbly clay. In its lower portion this drift becomes more heterogeneous, the pebbles are larger though less frequently striated, and several bowlders occur—one subangular in form, 3 by 2½ by 1½ feet in dimensions, of hornblende schist, and another subangular, with one side polished, 1½ by 1 by ¾ feet in size, of reddish gray granite, being observed in place, and others of even greater dimensions appearing in the talus. In the lower part, too, this drift sheet is sometimes obscurely stratified and contains intercalated lines of laminated sand and of pebbles, together with some pebble pockets. It ranges from 10 to 15 feet in thickness and rests upon or grades into irregularly stratified brown sand. At one point a considerable bed of soil occurs at its base. This soil is jet black, weathering brownish, light, friable, of peaty appearance, with a maximum thickness of 2 feet. Below lies compact blue drift clay with disseminated sand and pebbles, 20 or 30 feet in thickness. It is noteworthy that the upper part of this deposit, 5 to 15 feet in thickness, is evidently rearranged. The lower part is so dense that blasting was required to remove it, while the upper portion is much more friable and intermixed with irregular seams, beds and pockets of sand, silt and old soil, and elsewhere is divided by planes of fracture exhibiting slickensided surfaces.

In an exposure on the southern slope of "The Hill" in Muscatine (on Green street), the loess, which is in all respects characteristic at higher levels, grades into pebbly clay in the usual fashion; and it is noteworthy that here the shells as well as the loess-kindchen descend into the zone of striated pebbles. This attenuated representative of the upper till is 10 or 12 feet thick, and rests upon a bed of black, peaty, and carbonaceous earth, which grades downward into massive blue or brown clay containing disseminated gravel and small pebbles. To the northwest of Muscatine the relations of the forest bed to a paha are well displayed. One of these loess-covered eminences rises from the moderately uniform drift plain in the western part of Sec. 10, T. 77 N., R. 2 W., and extends east-southeasterly in increasing magnitude to the southwest corner of the adjoining section 11. Here it is laid open by a gulley leading down to Mad Creek, and the following section exposed:

	Feet.
1. Loess, with a few tubules but no shells or loess-kindchen	4
2. Striated sand into which the loess grádes, containing in the lower part a few small pebbles and in its more loess-like and finer layers a few loess-kindchen	12–18
3. Brown and black peaty soil with a marshy odor, weathering white in some portions	2–5
4. Pebbly and somewhat sandy blue clay containing abundant bowlders in its lower portion	8

FOREST BED, NEAR MUSCATINE.

This is the only case in Northeastern Iowa in which the condition of the exposure and the circumstances of observation rendered it at all practicable to photograph the section. It is represented in the photo-mechanical reproduction forming Pl. L.

A specimen of the soil was submitted to the well known paleodendrologist, Knowlton, who reports upon it as follows:

DEPARTMENT OF THE INTERIOR, U. S. GEOLOGICAL SURVEY,
Washington, D. C., February 15, 1890.

DEAR SIR: I have the honor to submit the following brief report upon the interglacial earth from Iowa, which you sent me a few days ago for examination.

At the first glance the material appears to be very largely of vegetable origin, and no one, even the most inexperienced, would hesitate to ascribe its origin at once to this source. It is black in color and contains many fragments of wood of larger or smaller size, and in fact is quite like the humus that may be found in almost any forest at the present day. When a small quantity of this fine black material is viewed under the microscope it is found to be largely composed of more or less completely disintegrated woody tissue, mixed with numerous irregular grains of silica. This woody material is so badly disintegrated that it is quite impossible to determine its exact nature; but from the abundance of fragments of coniferous wood mixed with it, it is more than probable that it is also coniferous.

The best preserved woody material is in the form of small twigs or bits of branches. It is very well preserved, and when suitably prepared for the microscope its internal structure may be almost as well made out as from the living tree. Numerous specimens have been examined and they are *all* coniferous. The wood cells have been but little distorted by the processes of decay and the fine lines and characteristic bordered pits can be clearly made out upon them. In transverse section the annual rings are rather indistinct, yet they can in almost all cases be detected. The wood cells, as seen in this section, are characteristic of young twigs or branches.

As nearly as can be ascertained from the limited study made, this material belongs either to the genus *Juniperus* or *Thuya*, either of which might have occurred in that region during glacial times.

Very respectfully,

F. H. KNOWLTON.

Mr. W J McGEE,
U. S. Geological Survey.

A section related to those of Davenport and Muscatine, in the attenuation of the upper till and in other respects, was observed beyond the limits of the territory in a railway cutting a mile and a

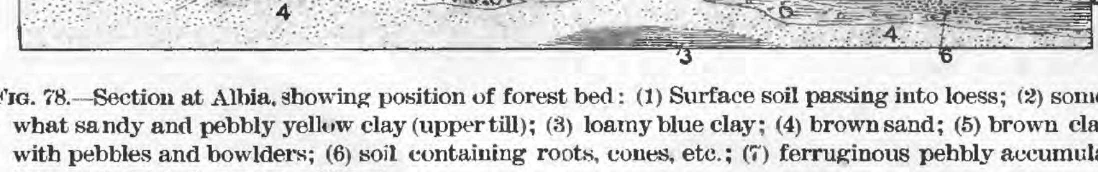

FIG. 78.—Section at Albia, showing position of forest bed: (1) Surface soil passing into loess; (2) somewhat sandy and pebbly yellow clay (upper till); (3) loamy blue clay; (4) brown sand; (5) brown clay with pebbles and bowlders; (6) soil containing roots, cones, etc.; (7) ferruginous pebbly accumulations. Height of exposure 30 feet.

half south of Albia, Monroe County, Iowa. It is illustrated in Fig. 78. Well preserved grasses, endogenous stems, cones, etc., with many rootlets evidently in place, were found in the old soil of this section. But generally in the interior of the drift-covered area the old soil is disrupted, completely removed, or buried beneath deposits evidently derived from the lower till, as in the section observed in the railway excavation at Blue Cut and illustrated in Fig. 79.

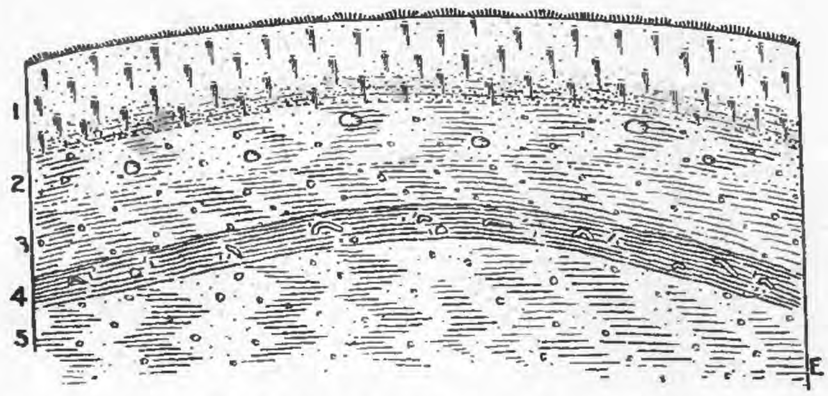

FIG. 79.—Intercalation of forest bed within lower till, Jones County: (1) Loess, sandy and obscurely stratified at base, 8 feet; (2) sandy and gravelly yellow unstratified clay, with local and erratic pebbles, mainly the latter, 4 feet; (3) plastic blue clay, with a few small pebbles and traces of lamination, 3 feet; (4) dark blue and black friable clay, turning brown on exposure, with many ferruginous nodules and a few fragments of much decomposed wood, 18 inches; (5) dense and compact blue clay, with striated pebbles and small bowlders, 8 feet.

A section observed beyond the limits of the territory, and specially notable only in that it was susceptible of reproduction by photography, is illustrated in Pl. LII (p. 517). It is revealed in the "stripping" of Whalen's quarry, a mile north of Durham, Marion County, Iowa. Here the deposit superimposed on the old soil is mainly loess, though it contains toward the base a considerable element of coarse sand with a few pebbles and other materials allying it to the upper till. The photograph, which was obtained through the courtesy of Mr. Charles R. Keyes, of Baltimore, and Mr. F. M. Kinne, of Knoxville, Iowa, is reproduced photomechanically.

In brief, as indicated by the foregoing descriptions and by those relating to the well sections represented in Pl. LI, the forest bed is simply a horizon of ancient soil, normally occurring at the base of the lower till and unconformably overlain by the upper till, though frequently disturbed or profoundly broken up; and in many cases it has apparently been completely removed. Generalizing the various occurrences, it would seem that the soil differs from that of the present, notably in greater thickness and more abundant humus, somewhat less notably in the greater abundance of arboreal vegetation, and still less notably but yet decidedly in the peaty character. There are certain other differences, which may be ascribed to the greater age of the buried soil. Thus, the forest bed soil frequently abounds in ferruginous nodules such as those locally observed now in process of formation in the upper till. In some cases, too, nodules of pyrite, reaching in one instance a diameter of 2½ inches, have been found associated with woody and peaty matter in the ancient soil (well section 100, Pl. LI). The ancient wood is sometimes partially or wholly lignitized and rarely silicified, though commonly little altered. The odor and taste of the soil itself or of water flowing from it also is commonly much more decided in the forest bed than in the modern soil. In some cases, too, marsh gas is given off in considerable quantities when the upper till is penetrated. Thus, in well section 42 of Pl. LI inflammable gas was emitted, and inflammable oleaginous matter accumulated on the surface of water flowing from the ancient soil stratum.

Little is known of the specific character of the flora of the forest bed epoch, for in general the leaves and the remains of grasses and small plants are so badly preserved as to prevent identification. The wood is nearly all coniferous, by far the larger portion being cedar (*Juniperus virginiana*), which now grows sparingly in several localities throughout the territory. Pine, oak, elm, sumac, walnut, willow, ash, hickory, and tamarack also have been recognized. Pine is rare in the modern forests, tamarack absent, and the other woods abundant. A tooth of *Equus complicatus* is the only trace of animal life thus far brought to light in Northeastern Iowa.

Beyond the limits of the territory a few additional fossils of interest have been found at the same horizon. In his description of a deep boring at Washington, Iowa, Calvin mentions the occurrence in a definite forest bed of cones of black spruce (*Abies nigra*).[1]

Mr. Frank Leverett has found in the forest bed of Des Moines County a few well preserved bones, identified by Dr. F. W. True as (1) a portion of the pelvis and the upper part of the femur of the wood rabbit (*Lepus sylvaticus*), and (2) the scapula of the common skunk (*Mephiticus mephitica*); and from the same horizon, in a well at Bloomington, Illinois, Dr. J. B. Moody obtained a considerable quantity of material pronounced by the late Prof. T. P. James to be a new species of *Dichelyma*, a characteristic peat mass.

The forest bed of Northeastern Iowa derives interest from its wide extent and, indeed, practical continuity over an immense area. As already stated, it has been found in more than 40 per cent of a series of well sections selected at random throughout the territory, some of which were not carried down to its horizon; so it seems safe to say that over nearly half of the territory the old soil may be found either in original condition or disturbed more or less by the later ice action. Certainly there are whole countrysides in which nearly every excavation of sufficient depth penetrates the old soil and brings to light remains of its old forest covering; this old soil is thicker than that of to-day; and it seems not extravagant to infer that nearly or quite as much soil stuff lies at the long-buried surface of the lower till as now mantles the subaerial surface of the upper till.

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[1] Am. Geol., 1888, vol. 1, p. 28.

The forest bed is of interest, too, by reason of the immense quantity of wood found at the horizon. In well after well logs and stumps are brought to light by the well-digger, the road-maker, the railway contractor, and in whole townships the waters of wells and streams, of springs and of streamlets are contaminated by the decaying wood; yet by far the greater part of the present surface of the territory is prairie land. In view of the frequent occurrence and immense quantity of forest-bed wood and of the sparseness of arborescent vegetation to-day, it would seem not an exaggeration but only a moderate illustration to say that more wood is preserved in the Pleistocene forest bed of Northeastern Iowa than to-day exists upon the surface of the same territory.

SECTION III.—THE LOWER TILL.

In only a limited area in the extreme southeastern part of the territory does the lower till generally approach the surface; but its distribution is indicated by exposures, most commonly and satisfactorily in wells, less frequently in railway or roadway excavations, and more rarely in natural stream-ways. Its general distribution is indicated upon the map of Pleistocene deposits forming Pl. XLIV, from which it may be seen to form a fairly continuous deposit overlying the indurated rocks beneath the upper till except in that part of the driftless area extending into Iowa. Its continuity is interrupted along certain waterways which have cut their channels through the Pleistocene deposits and into the indurated rocks, as shown upon the map, and it is more frequently but less widely interrupted over tors and knobs upon which it was perhaps never deposited in considerable thickness. It fails also over eminences and northwesterly slopes well within the area of the upper till, from which it was probably removed by the subsequent glaciation.

By reason of the difficulties in the way of observation upon the deeply buried deposit, it is impossible precisely to represent the distribution of the formation in detail. But generalizing the two hundred well sections represented in Pl. LI and the various other sections displaying the deposit, it would appear that in at least 90 per cent of the exposures of sufficient depth the lower till occurs. Judging from the closeness of the margin of the older deposit to that of the newer over tors, knobs, and ridges in various parts of the territory where observation is possible, it would appear that the lower till is nearly conterminous with, but usually somewhat less nearly continuous than, the upper till; and comparing the distribution thus inferred with the easily observed distribution of the later glacial deposit, it would appear that the lower till occupies at least 85 per cent of the portion of the territory lying south and west of the northeasterly margin represented upon the map.

The materials of the deposit are substantially identical with those of the later glacial formation. It is a mass, homogeneous in the large way, of finely comminuted rock débris, sand, gravel, and rather sparse and small pebbles, all together constituting what is commonly called a pebbly clay, interspersed with subangular or rounded bowlders; and bowlders, pebbles, and gravel grains are occasionally striated or polished. The pebbles are rarely arranged in beds or lines; thin intercalated sheets or lenticular masses of sand or gravel appear now and then, and in a few instances obscure bedding has been observed; but in general the deposit is more uniform and homogeneous than its newer homologue.

Comparing the common phase of the deposit as displayed throughout the greater part of the territory with the upper till, certain differences appear. Most conspicuous is the difference in color; the older deposit is commonly blue (colored by the protoxide of iron), perhaps weathering ashen or dark brown, while the upper till is commonly yellow, buff, or drab. Next in order of prominence is the greater ferrugination and oxidation of the older deposit; the colors are deeper and stronger; ferruginous nodules and concretions are more common; sand grains, pebbles, and bowlders are more frequently and deeply stained and incrusted with iron; usually the materials are so lixiviated as no longer to effervesce under acid; and the general facies of the deposit—that appearance readily caught by the eye of the experienced geologist though impossible clearly to describe—is ancient. Third in order of prominence is the greater compactness and density of the deposit. This difference is one recognized not only by the geologist but still more fully by the well-digger, the road-maker and the railway contractor; for the cost of excavation of lower till is often twice and sometimes thrice that of the newer deposit. Another difference is found in the relative size, volume, and abundance of pebbles and bowlders; for the pebbles of the older deposit are more numerous but smaller and more worn and rounded than those of the upper drift sheet. Finally there is a difference in petrographic character of the bowlders and pebbles, sometimes so decided as to attract the notice of the layman; the prevailing pebbles and bowlders of the older deposit are greenstones, and the prevailing erratics of the newer deposit are granites. These differences are general; but both deposits vary from place to place, and thus it sometimes happens that the bowlders displayed in a given section are not sufficiently distinctive to permit assignment of the mass of glacial débris to either drift sheet; and now and then excavations display undoubted upper till in one part of the section, undoubted lower till in another part, and yet no distinctive demarkation can be drawn between them; indeed, in many, perhaps a majority, of cases the deposits can not be certainly discriminated unless the forest bed intervenes.

Comparing the lower till of Northeastern Iowa with the prevailing glacial deposits of northeastern United States, certain features become conspicuous. Perhaps most noteworthy is the relative paucity of the pebbles and bowlders; for it would appear, without careful and probably bootless counting, that each average cubic yard in Iowa contains not more than a half, a quarter, or an eighth as many pebbles as are found in corresponding volumes of drift in Wisconsin and Michigan, northern Indiana and Ohio, New York and New England. Almost equally noticeable is the relatively small proportion of local pebbles; for although local pebbles are somewhat more abundant in the lower till than in the upper in Northeastern Iowa, 80, 90, or 95 per cent and even more of the fragments of such size as is to be traced to their sources represent terranes beyond the limits of the territory and probably many hundreds of miles distant.

Although more uniform in its typical aspect than the upper till, the older glacial deposit varies materially in different parts of the territory. Frequently along the eastern border, and commonly in the south, there is a differentiation of the upper and lower portions; the lower portion maintaining the characteristic aspect, save perhaps that bowlders become relatively more abundant, while in the upper the bowlders and pebbles diminish in size and number, and the materials become fine, plastic, perhaps stratified and even laminated, passing into the distinctive deposit found in southern Iowa, northern Missouri, and parts of southern Illinois, and locally known as "gumbo," or "hard pan." In Northeastern Iowa this aspect is best displayed in a limited tract overlooking the Mississippi River in southwestern Scott and contiguous parts of Muscatine Counties.

Another type of differentiation is common throughout the area of the upper till. While the mass of the deposit maintains the uniform homogeneous condition, the lower part may be exceptionally pebbly and even become a bed of gravel, coarse sand, and bowlders, well known to residents in different parts of the territory as the "water bed."

By reason of the relatively small number and probably non-representative character of the measurements (for the deposit is seldom penetrated where it attains great thickness), as well as by reason of its known variability, it is impossible to determine accurately the thickness of the lower till. It is known to range from 0 to over 200 feet, with every reason to believe that its greatest thicknesses have not yet been measured. Generalizing the relative thicknesses of the two drift sheets exposed in wells penetrating both, and so placed as to indicate that both are fairly represented, it would appear that the older deposit is considerably the heavier. So it is probable that, despite its somewhat more limited area, the mean thickness of the lower till exceeds that of its newer homologue. It may be roughly estimated at 50 feet. The thickness varies both locally and in a more systematic way. Local variations in thickness are noteworthy in the northwestern part of the territory, where the deposit culminates in thickness in valleys and on the lee (southeasterly) sides of eminences in the indurated rocks, as illustrated in Figs. 61 and 62 (pp. 474, 475); also in the southern-central part of the territory, where there is reason to believe that some of the deep wells of Pl. LI mark lines of preglacial erosion. In its systematic variation the deposit ranges from noteworthy tenuity in the northwestern part of the territory, where the action of the later ice sheet was most energetic, and from feather edges along the margin of the driftless area in Winneshiek, Clayton, Dubuque, and Jackson Counties to a maximum thickness a few dozen miles within the eastern margin of the deposit and the southern line of the territory—the thickness culminating in the tier of counties running from Marshall to Cedar. The law of systematic variation is a compound one: the deposit originally attenuated in a simple way from a central tract toward its periphery; but it was afterward ground down by the later glacier, more deeply toward the central tract than toward the periphery.

It is worthy of specific mention that nowhere does the lower till display a moraine-like peripheral thickening, even to the extent observed in the upper till. Everywhere toward its margin it either attenuates gradually and disappears in a feather edge or suffers horizontal differentiation, the upper part becoming fine, stratified, or laminated and evidently waterlaid, the lower portion retaining the characteristic glacial structure with a concentration of coarse materials, and both the lower and the upper members gradually attenuating and feathering out.

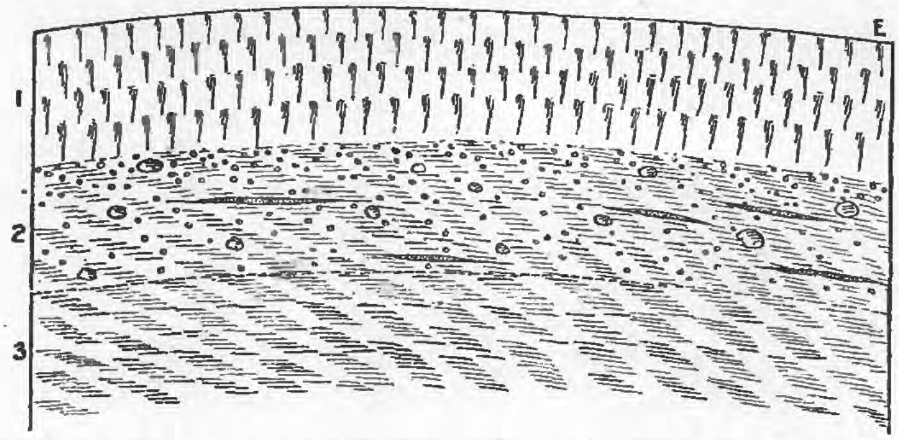

FIG. 80.—Relation of tills near easternmost margin, Dubuque County: (1) Loess, 15 feet: (2) brownish yellow clay with a few erratic pebbles and considerable quantities of chert, especially near summit, 15 feet; (3) clean and plastic blue clay containing a few ferruginous nodules, with some traces of lamination, 12 feet.

In the section illustrated in Fig. 80, the two tills are quite distinct, even to the precise line of junction; for here the older deposit exhibits the clean and plastic peripheral stage. The section is exposed in a railway cutting in the NE. ¼ NW. ¼, Sec. 10, T. 88 N., R. 1. E., Dubuque County, within a mile of the eastern limit of the upper till. Quite similar is the section represented in Fig. 81 (exposed in

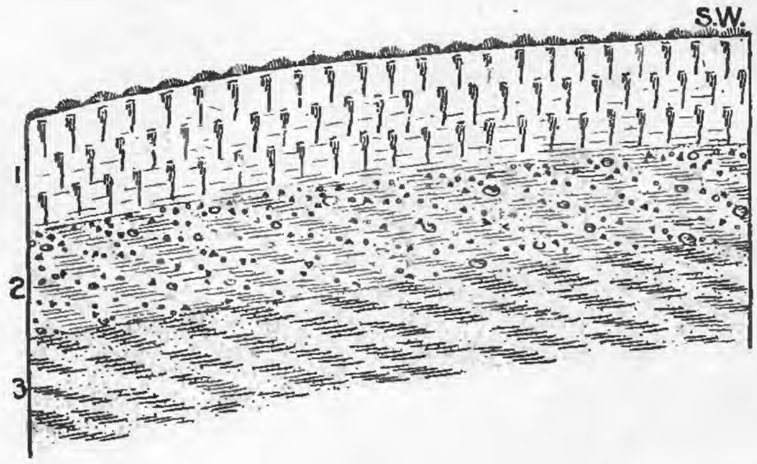

FIG. 81.—Relation of sillt toward easternmost margin, Clayton County: (1) Loess, slightly heterogeneous and obscurely laminated, especially at base, 5 feet; (2) coarse gravel of limestone and chert embedded in yellowish brown calcareous clay and sand, 4 feet; (3) homogeneous blue clay, with fine and uniformly disseminated sand, and with a few small ferruginous nodules, 3 feet.

a wagon-road cutting in the SW. ¼ SE. ¼, Sec. 25, T. 92 N., R. 5 W., Clayton County), save that the superior peripheral phase of the lower till is coarser textured and sandy. This section practically marks the margin of the upper till, and contains a preponderance of local material.

The next section (Fig. 82) is of interest since it represents in normal condition, though attenuated thickness, the various Pleisto-

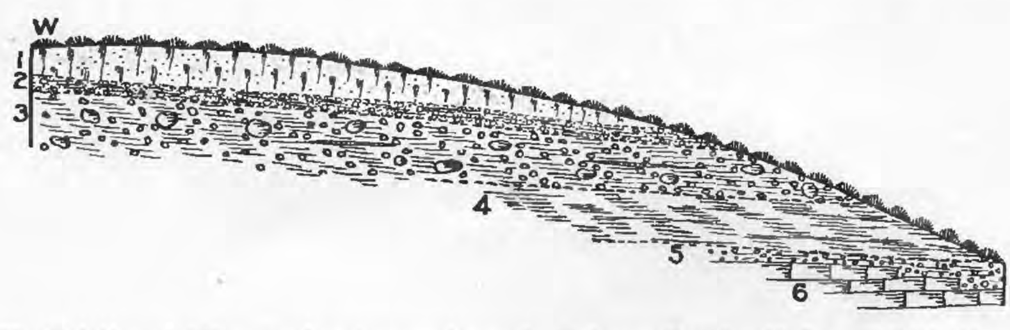

FIG. 82.—Relation of tills toward easternmost margin, Dubuque County: (1) Loess, 5 feet; (2) gravel, sand, and yellowish brown clay, 2 feet; (3) coarse yellow clay, with chert and erratics, 5 feet; (4) clean laminated blue clay, 4 feet; (5) coarse brown gravelly clay with greenstone pebbles, 2 feet; (6) Niagara limestone.

cene deposits found about the margin of the driftless area. It was observed in a wagon-road cutting in the SW. ¼ SE. ¼, Sec. 19, T. 87 N., R. 1 E., Dubuque County.

Although study of the distribution of the two tills and associated deposits indicates that the earlier glacial deposit was frequently removed by erosion before the later was laid down, the effect is seldom indicated by a single section. That illustrated in Fig. 83, however, gives such indication. The lower till is altogether absent from a part of the section and the subjacent limestone is much crushed and broken, and has granite pebbles such as characterize the newer till firmly embedded in its crevices and cavities. The section was ob-

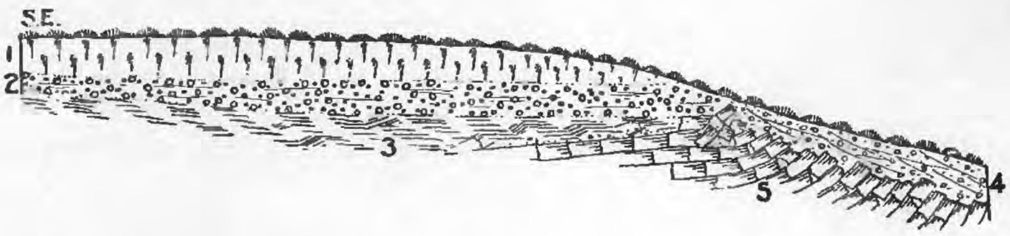

FIG. 83.—Deformation of earlier drift sheet and subjacent rock by later ice invasion, Dubuque County: (1) Loess, 4 feet; (2) gravelly and pebbly yellow unstratified clay, 3 feet; (3) plastic blue clay, clean except at immediate base, 4 feet; (4) talus; (5) Niagara limestone.

served in a roadside gully in the NW. ¼ NW. ¼, Sec. 16, T. 90 N., R. 2 W., Dubuque County. It is possible that the partial absence of the lower till at this point is to be ascribed to the later ice work; but in other examples it is evident that this can not be the case, since the forest bed is preserved in place.

The greater thickness of the lower till, even well toward the margin of the driftless area, is illustrated by the section shown in Fig. 84, constructed from a roadside exposure, a natural gully, and a

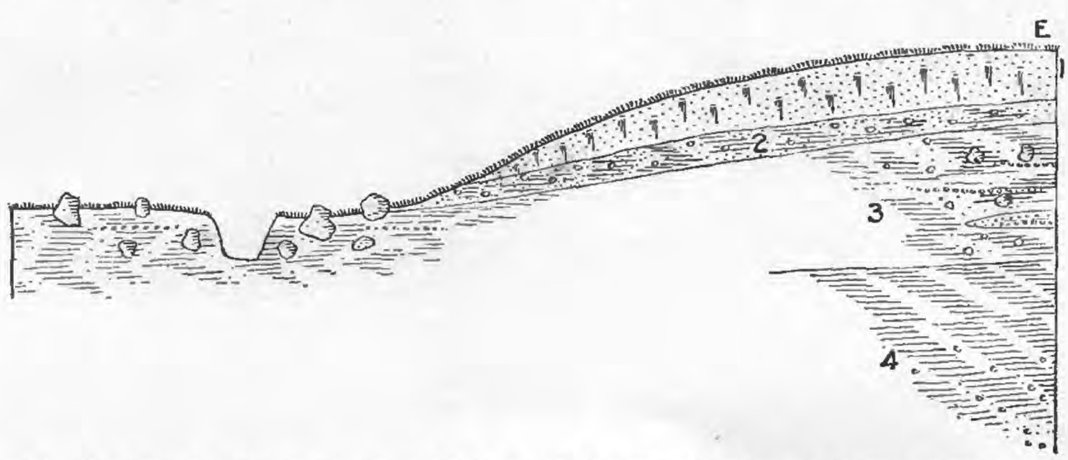

FIG. 84.—Relations of upper and lower drift sheets, Dubuque County: (1) Loess; (2) sand, gravel, rounded pebbles, and brown clay; (3) coarse yellow clay with good sized bowlders and some fragments of chert and limestone; (4) compact blue clay, with traces of lamination.

neighboring well 65 feet deep, in the NE. ¼ NE. ¼, Sec. 21, T. 90 N., R. 2 W., Dubuque County. The upper till here contains abundant rounded bowlders predominantly of granite up to 3 feet in diameter, while the lower till is destitute of erratics in its upper portion, and below contains a few well rounded greenstone pebbles. The lower till was not penetrated.

Sometimes the great compactness and tenacity of the lower till in comparison with the upper is indicated by the configuration of gullies. This is the case illustrated in the section (Fig. 85) exposed in a roadside gully near the northwest corner of Sec. 15, T. 89 N., R. 1 W., Dubuque County. This section displays in miniature the condition displayed on grander scale by the stream-ways of the vicinity.

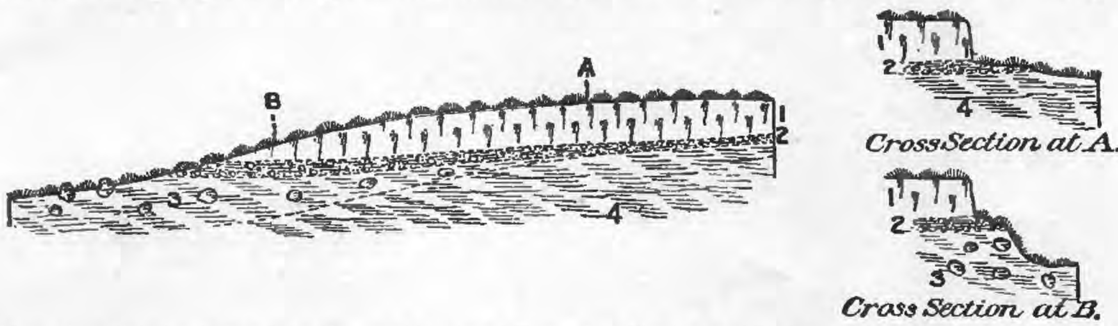

FIG. 85.—Section illustrating the obduracy of lower till. Dubuque County: (1) Loess; (2) sand, gravel, pebbly, and brown clay; (3) coarse yellow clay with large bowlders; (4) clean and plastic blue clay, obscurely laminated. Mean exposure, 8 feet.

The portion of the gully, and of the valley as well, carved in the upper till is deep, large, and irregular; while the parts of gully and valley excavated in lower till are shallow, small, and flat-bottomed.

Despite the general uniformity of the lower till, intercalations of sand and pockets of pebbles are occasional features. A notable example is that illustrated in Fig. 86, representing a section dis-

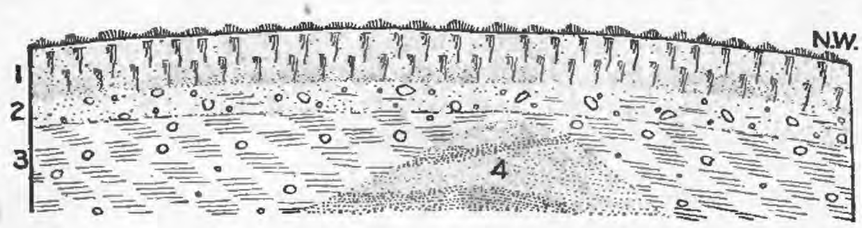

FIG. 86.—Sand pocket in lower drift sheet, Dubuque County: (1) Loess, slightly arenaceous, especially at base, 4 feet; (2) unstratified yellow clay, with worn granite bowlders up to 2½ feet in diameter, 3 feet; (3) compact blue clay with bowlders mainly of greenstone up to 1 foot in diameter in small part striated, 5 feet; (4) coarse and fine cross stratified sand.

played in a railway cutting in the NE. ¼ SE. ¼, Sec. 35, T. 87 N., R. 1 E., Dubuque County. Here the lower till is bowlder-charged throughout, and is intersected by a compact body of stratified and cross laminated brown and yellow sand. This sand bank extends obliquely across the cutting in a direction a little south of east, or nearly that of ice motion.

Within certain limits the color of the lower till may vary with its texture. Thus, the massive, fine-textured portions commonly called clay are usually blue; while intercalated pebble and sand beds and the fairly well defined water bed at the base of the deposit are commonly brown. Moreover, when the whole mass is exceptionally sandy the brown color is sometimes assumed throughout. This is exemplified in two sections exposed in wagon-road cuttings in Clayton County, the first in the NW. ¼ NW. ¼, Sec. 21, T. 94 N., R. 5 W., and the second in the SW. ¼ NE. ¼, Sec. 14, T. 92 N., R. 5 W., which are alike, save that in one the materials of the lower till are fine and clayey, while in the other there is a considerable element of sand, and that the usual blue color is displayed in the first while the other is brown. With the marginal differentiation of the deposit the lower portion sometimes becomes a mass of gravel or bowlders, when the brown color is commonly displayed. This condition is illustrated in a section displayed in the SE. ¼ SW. ¼, Sec. 32, T. 95 N., R. 6. W., in Clayton County, on the Elkader and Clermont road. Here the deposit is represented by a reddish brown sandy gravel and loam largely cross stratified and sometimes imperfectly cemented by infiltration of iron.

It has already been noted that the upper till extends to and terminates at the great Niagara escarpment by which the driftless area is overlooked from the southwest; and the same thing is true in even greater degree of the earlier glacial deposit. Throughout southern Clayton and northern Dubuque Counties the lower till margin is sinuous, creeping out along the salients and retreating along the reentrants of the crenulate escarpment, marking its line almost as closely as would the surface contours of a map. The manner in which the drift runs out to the very verge of the Niagara upland and overlooks the lower driftless area to the northeast is imperfectly illustrated in the general section through Dubuque County, forming Fig. 63. In the northern part of the territory, where the Niagara escarpment is less inconspicuous yet fairly followed by the later drift deposits, the earlier sheet pushed far beyond and well toward the locally more conspicuous escarpment given by the Trenton limestone. It is, indeed, one of the most significant among the glacial phenomena of the territory that the ice sheet advanced to but was unable to push beyond the great crest by which the territory is divided.

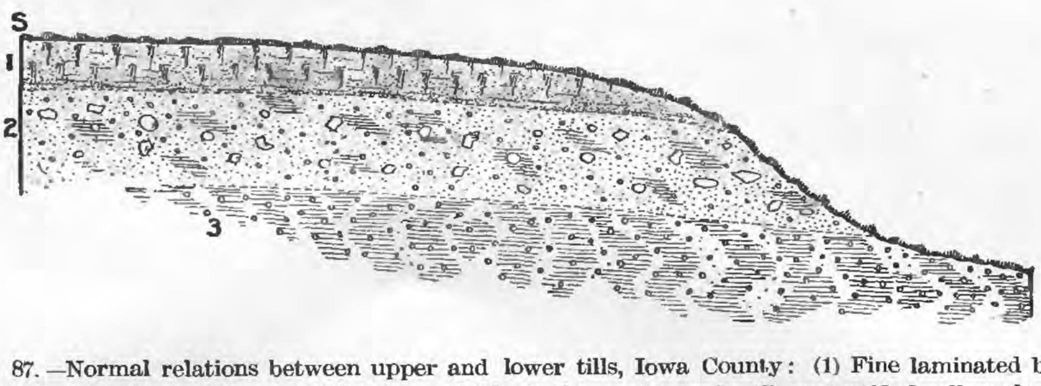

FIG. 87.—Normal relations between upper and lower tills, Iowa County: (1) Fine laminated buff sand forming base of loess, which is seen a little farther southward: (2) unstratified yellow clay intermixed with fine and coarse sand and gravel, and containing a few local and angular, and more erratic and subangular pebbles; (3) compact blue clay with many rounded pebbles, say one-fourth striated, and numerous nodular concretions. Total exposure, about 30 feet.

Although it is usually difficult if not impossible to discriminate the tills unless the forest bed intervenes, they are in some cases fairly distinct. Thus, in the section illustrated in Fig. 87 (displayed in a cutting on the Homestead and Amana wagon road in the SW.

¼, Sec. 25, T. 81 N., R. 9 W., Iowa County), the older formation exhibits several distinctive features: (*a*) Its pebbles are by far the more numerous, smaller in size and better rounded; (*b*) its proportion of striated pebbles is much the greater; (*c*) its proportion of local pebbles is the less—a feature which is locally characteristic, though not characteristic of the territory as a whole; (*d*) the proportion of greenstone among the erratic pebbles is considerably the larger; (*e*) the blue color prevails throughout; and (*f*) there is a vastly larger number of ferruginous nodules. Moreover, here as generally elsewhere the upper till presents a decidedly fresher aspect, due in part to the absence of incipient cementation and ferrugination. The lower till is rectangularly jointed, particularly in its upper portion, and its numerous ferruginous nodules take approximately cubical forms coinciding with the jointing and are of exceptionally large size, often reaching 3 or 4 inches in diameter. Two such nodules at the extreme summit of the formation were found to be distinctly striated on their upper surfaces.

In the section illustrated in Fig. 88, observed in a railway cutting in the eastern part of Brush Creek, in Fayette County, the two glacial deposits may not be discriminated; for, while the upper part of the section displays buff and yellow bowlder clay, with subangular granite bowlders, and the lower part displays much more compact

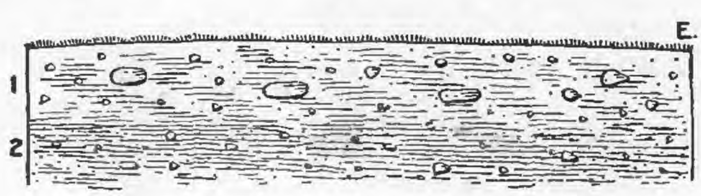

FIG. 88.—Apparent intergradation of drift sheets, Fayette County: (1) Compact and unstratified yellow clay, with erratic bowlders up to 3½ feet in diameter, and with 2½-inch pebbles quite numerous; (2) compact and unstratified blue clay, with bowlders up to 3 feet in diameter, and with numerous pebbles 2 inches in diameter below but not above. Total exposure, say, 13 feet.

blue pebbly clay, with greenstone predominating among its erratics, no line can be drawn between the phases, which appear to intergrade through a stratum of 5 to 8 feet in thickness, in which battered bits of coniferous wood occasionally occur. It is noteworthy that both tills here are auriferous and in very nearly the same degree.

As already noted, there are local variations in thickness of the lower till, some of which are, while others are not, due to erosion by ice or water since deposition. When studied in detail this inequality is found to indicate that in general the drift thickens in depressions and thins over eminences, and the same is indeed true of the upper till. Thus, within certain limits, the tills singly and in combination mantle the surface after the fashion of sediments, softening the ante-Pleistocene contours and bringing the surface approximately to the condition of a plain of construction. One of the sections illustrating this characteristic of the tills is that depicted in Fig. 89. It is based on two wells a thousand feet apart, and several intermediate exposures in the NW. ¼ SE. ¼, Sec. 13, T. 88 N., R. 4 W., Delaware County.

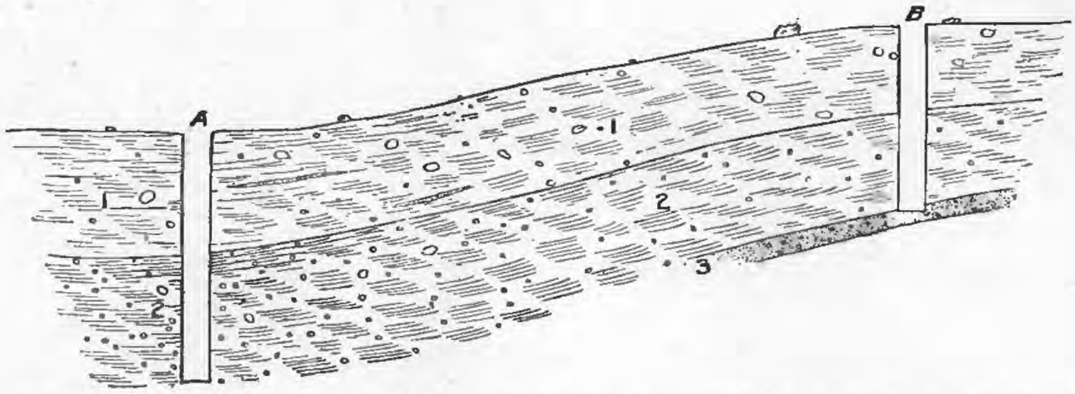

FIG. 89.—Relation of drift sheets to topography, Delaware County: (A1) Yellow clay, with pebbles and bowlders and a trace of stratification, 10 feet; (A2) compact blue clay, with small pebbles, laminated at top, 14 feet. (B1) Unstratified yellow clay, with pebbles and bowlders, 8 feet. (B2) plastic blue clay, with very few pebbles and without lamination, 8 feet; (B3) brown sand and gravel, with water.

In the northwestern part of the territory this mantling is modified, (1) by the rupture and removal of the later sheet over eminences, and (2) by the tenuity and occasional absence of the newer sheet over the higher eminences, as illustrated in Figs. 61 and 62, representing generalized sections in Floyd County. A related case is exhibited in the section illustrated in Fig. 65 (p. 478), found near the margin of the glacial deposits. The upper part of the lower till takes on its usual peripheral aspect of blue (locally tinged greenish), clean,

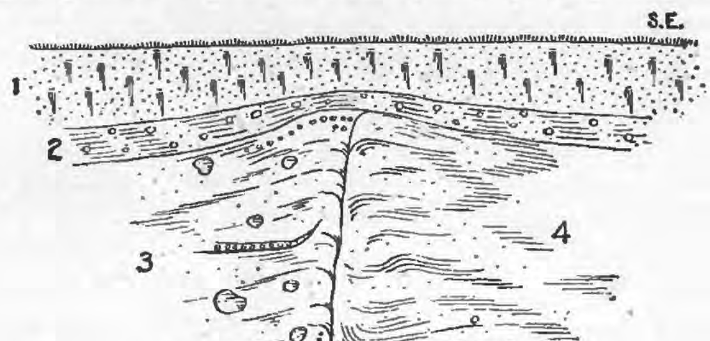

FIG. 90.—Contortion of lower till by later ice invasion, Dubuque County: (1) Loess; (2) sandy, gravelly, and pebbly clay; (3) unstratified yellow clay with rounded and angular erratic bowlders; (4) plastic blue clay, obscurely laminated, and with laminæ contorted; (5) sandy and pebbly brownish yellow clay; (6) Niagara limestone. Total exposure, 23 feet.

plastic, laminated clay, abounding in small ferruginous concretions similar to the "buckshot" of certain Pleistocene deposits of the Lower Mississippi.

Not infrequently the lower till displays crumpling and contortion evidently due to later ice work. An example is illustrated in Fig.

90, observed in a well in the NW. ¼ SW. ¼, Sec. 24, T. 89 N., R. 2 W., Dubuque County. Here the older deposit seems to have been completely removed by the later ice sheet and thrown and compressed into a scarp against which the newer drift sheet abuts. In the section illustrated in Fig. 91 (exposed in a wagon road cutting in the NW.

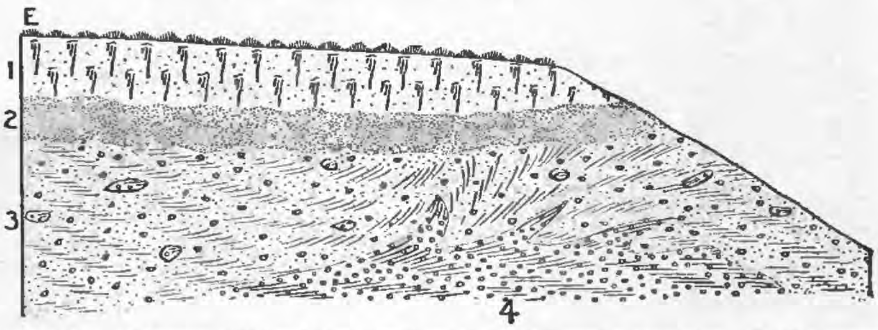

FIG. 91.—Contortion of lower till by later ice invasion, Delaware County: (1) Re-arranged loess; (2) homogeneous fine sand, unconformable to both loess and drift; (3) reddish yellow sandy clay, with northern pebbles and much local chert; (4) dark compact clay with small pebbles. Total exposure 18 feet.

¼ SE. ¼, Sec. 24, T. 88 N., R. 3 W., Delaware County) the lower till was not removed but was so squeezed and compressed as to send tongue-like protuberances into the newer deposit; and the newer deposit contains several completely isolated masses, or clay bowlders, identical in composition and appearance with the lower till. A related and even more striking example of displacement is that illustrated in Fig. 92, which was observed in the bank of the North Maquoketa, in

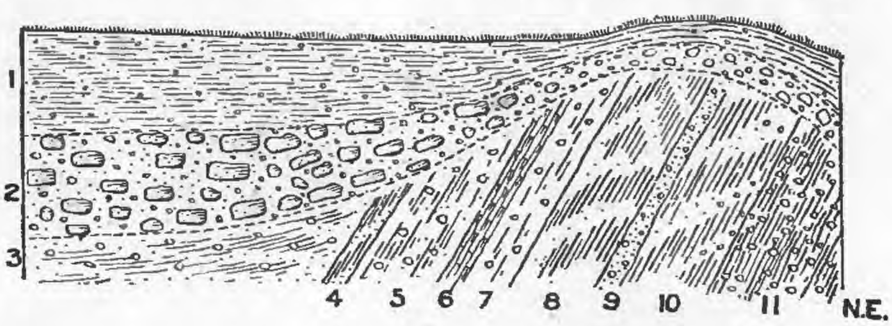

FIG. 92.—Deformation of earlier glacial deposits by later ice work, Dyersville: (1) Yellow and brown sandy and pebbly alluvium; (2) pebbly alluvium of lighter color, containing great numbers of worn bowlders, nearly all local; (3) pebbly yellow clay; (4) sandy blue clay; (5) pebbly red clay; (6) ocherous band, firmly incrusted at both sides; (7) pebbly red clay; (8) plastic blue clay with ferruginous nodules; (9) sandy and pebbly red clay; (10) rather compact blue clay with small pebbles and ferruginous nodules; (11) brown granular clay with white specks, containing worn quartz pebbles. Mean height, about 13 feet.

the northern part of Dyersville. Still more interesting, because of the complete sequence of deposits displayed, is the section illustrated in Fig. 93, observed (in company with President T. C. Chamberlin and Prof. W. H. Norton) in a quarry in the eastern part of Mount Vernon. The uppermost member represents the loess, which thickens in the neighborhood to form the Mount Vernon paha; the second member represents the usual sandy base of this deposit; the third member is the upper till; the fourth and fifth together constitute the lower till, the upper part of which here takes on the peripheral aspect; while the sixth member is largely a residuum formed by decomposition of the subjacent limestone, although as usual in such sections it is somewhat rearranged and intermixed with glacial

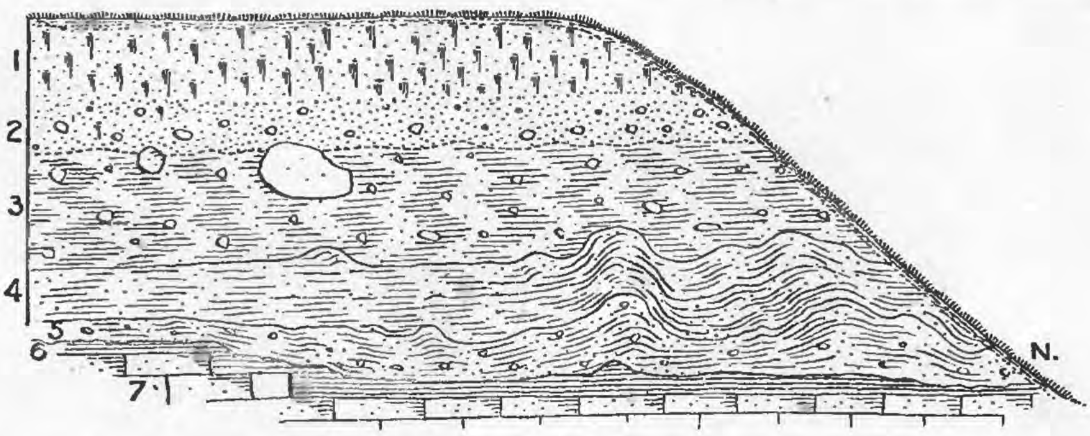

FIG. 93.—Contortion of earlier glacial deposits by the later ice sheet, Mount Vernon: (1) Loess, or loess-like loam, massive, calcareous, firm textured, containing toward base a very few granitic grains up to an eighth of an inch in diameter, 4 feet; (2) stratified sand, containing erratic pebbles, not clearly separable from the loess, 2 feet; (3) massive or obscurely laminated pebbly clay, containing sand pebbles and bowlders up to 8 inches, with one bowlder of 512 cubic feet, well striated and polished on two sides, 5 feet; (4) massive and much more compact clay indistinctly stratified in layers marked by ferruginous staining, without bowlders or large pebbles, 3 feet; (5) massive or obscurely laminated pebbly clay containing small pebbles (predominantly greenstone) frequently striated, 2 feet; (6) black or dark brown plastic clay (geest), 1 foot; (7) Niagara limestone.

débris. Members 4 and 5 are contorted and crumpled in the manner indicated.

An equally interesting example of contortion produced in decomposed limestone by glacial action is illustrated in Fig. 114 (p. 556),

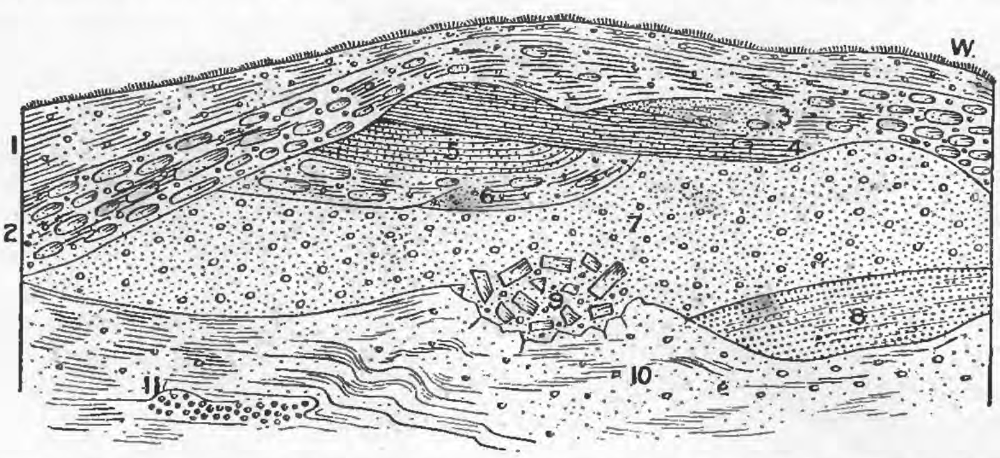

FIG. 94.—Section in St. Paul, exhibiting contortion of lower part of drift by ice action: (1) Gravelly surface soil; (2) ash-colored sand, gravel, and loam, with small erratic pebbles and local subangular bowlders (of Trenton limestone) varying in abundance in different portions as shown, but without other arrangement; (3) a portion of the same becoming extremely sandy; (4) a portion of the same passing into fine laminated loam; (5) coarser loam with sand partings obliquely laminated; (6) the same as 2; (7) coarse sand and gravel, ash-colored and bluish, with a few pebbles up to 5 or 6 inches in diameter, altogether without arrangement, but containing angular fragments of 10, as shown; (8) the same, coarsely laminated; (9) an ular fragments of 10 embedded in 7; (10) fine reddish brown or chocolate loam, containing a few pebbles (in part striated) finely laminated in some portions and these portions sometimes contorted; containing also a pocket of gravel. Maximum exposure, 30 feet.

representing a section observed near Delaware; and examples of contortion observed beyond the limits of the territory are illustrated in

Figs. 94 and 95, representing sections observed in St. Paul, Minnesota, in 1880—the former near the southeast corner of Rosabel and Fifth

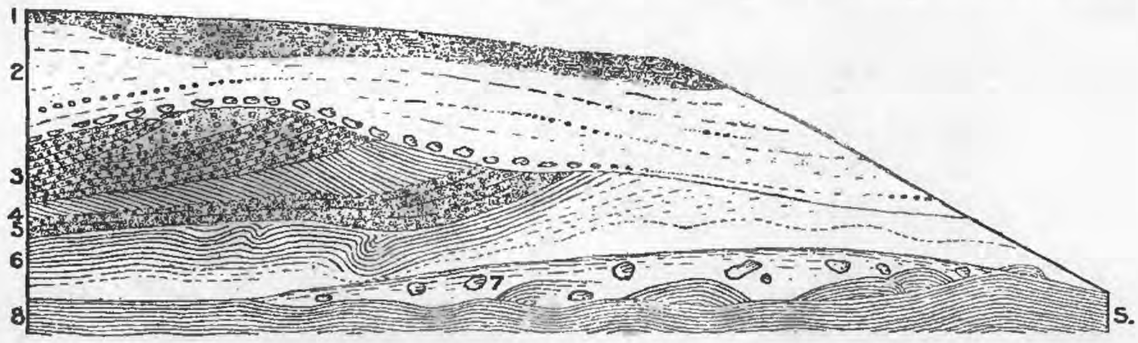

FIG. 95.—Section in St. Paul, Minnesota, exhibiting contortion of lower part of drift by ice action: (1) Reddish sandy and gravelly loam; (2) somewhat sandy and gravelly calcareous loam with a few small erratic pebbles and blocks of sub-angular limestone and with a few obscure lines of stratification, reddish at top then grayish, ash-colored, and finally bluish below; (3) sandy and gravelly reddish brown clay, in part laminated; (4) the same, without gravel; (5) the same, very gravelly; (6) nearly clean, purplish red, loamy clay, partially laminated and with a few erratics as shown; (7) plane of dislocation in same; (8) the same as 6, but distinctly laminated and contorted as shown. Total exposure (from top of embankment to bottom of cellar), 45 feet.

streets, the latter near the southeast corner of Wacouta and Fourth streets.

Only rarely does the lower till form the present surface. In the gumbo area the deposit takes on its usual peripheral differentiation, and it is the plastic clay of its upper member that approaches the surface; and even here the deposit is commonly concealed by a veneer either of loess or of loam of like age and related genesis. Toward the southern limits of the territory generally this attenuation and differentiation of the newer deposits occur. In the southwest the veneer is commonly loess, perhaps passing into pebbly clay as in the section illustrated in Fig. 96 (observed just outside the territory in

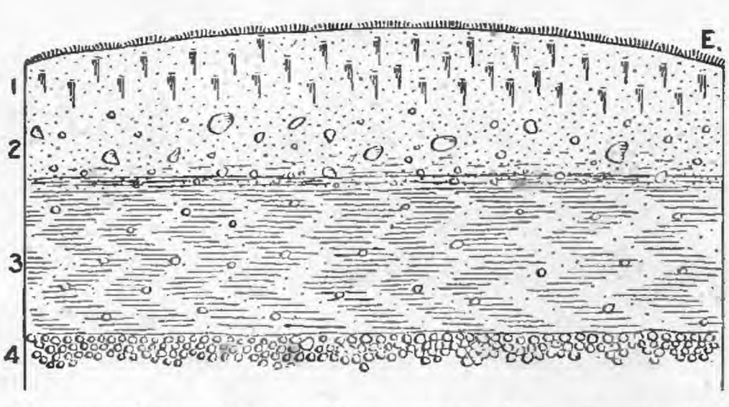

FIG. 96.—Relations of lower till toward its southern margin, Jasper County: (1) Loess, becoming sandy and pebbly at base and passing without distinct line of separation into drift, say 5 feet; (2) upper Till, containing small pebbles medially, and stratified sand and gravel below, say 9 feet; (3) compact blue clay, with many small pebbles and a few bowlders, 13 feet; (4) dark brown and yellow gravel of quartz and greenstone pebbles, partially cemented by iron.

a railway cutting in the NW. ¼, Sec. 33, T. 80 N., R. 17 W., Jasper County); while in the southeast it is either of similar character, as at Davenport (Fig. 77), or—particularly at low levels—a sheet of semi-alluvial sand, perhaps resting on an eroded surface of lower till, as in a section exposed at the eastern margin of the broad late Pleistocene flood plain of the Cedar in the NW. ¼ SW. ¼, Sec. 15, T. 77 N., R. 1 W., Muscatine County (Fig. 97). In some localities, how-

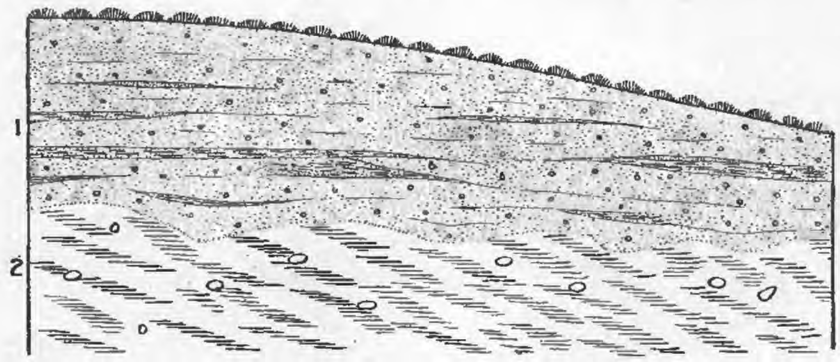

FIG. 97.—Relations of lower till in the southeast, Muscatine County: (1) Stratified brown and yellow sand, both fine and coarse, with a little gravel and several bands of sandy clay; (2) light blue plastic clay with a few small erratics, one striated. Exposure, 28 feet.

ever, the later deposits have either been wholly removed or were never deposited in considerable thickness, and in these, accordingly, the lower till lecomes a superficial deposit. Thus, in the eastern part of Scott County, between Davenport and Princeton, notably about Porter's Corners, the upper till is thin or absent and the loess mantle of limited thickness, and the steep-sided stream-ways and storm runnels radiating toward the Mississippi have generally removed the more friable newer deposits over considerable zones, leaving flat-bottomed intervals of the more obdurate deposit. In the western part of Muscatine County, and in the southeastern townships of Johnson County, too, the altered Pleistocene deposits are thin, and sometimes the lower till (either as a bowlder clay or in its gumbo phase) is denuded over areas reaching some square miles in extent. In southwestern Johnson and southeastern Iowa Counties, also, the lower till, there commonly undifferentiated, frequently approaches the surface and merges into a veneer either of upper till or of loess, and the color and texture of the veneer in a measure reflect the characteristics of the older deposit. Even well within the limits of the upper till that deposit locally fails—e. g., about Martelle, in central Jones County, the tenacious blue clays of the lower till are frequently exposed in shallow roadway excavations, in roadside gullies, in post holes, and are even turned up by the plow. In all of these localities the habit of weathering is alike: Where the clays are exceptionally sandy or gravelly, they weather brown and form a more or less friable and fruitful soil; but where the clay is plastic and sand-free and of the usual blue color, as in the superior peripheral portion generally, it commonly weathers whitish or ashen to a limited depth and forms a tenacious, intractable soil, drowning when wet and baking when dry. This phase is colloquially known as "gumbo," sometimes as "hard pan," and locally as "white clay," or (from its behavior before the plow) "push land." Commonly, when the blue clay weathers white the contained iron segregates in nodules—sometimes the firm, concretionary shells with earthy nuclei such as usually characterize the deposit in the vicinity of the forest bed, again cylindrical concretions accumulated about rootlets, and elsewhere rounded or botryoidal masses ranging from one-eighth to one-half an inch in diameter, colloquially called "buckshot." In a railway cutting 3 miles east of Lone Tree, Muscatine County, concretions of the character last mentioned are found in such abundance as to form nearly one-third of the mass.

SECTION IV.—THE GLACIAL TALUS.

As shown on other pages, the transition from ice-fashioned to water-carved topography along the margin of the driftless area is commonly gradual; and, moreover, the ice forms extend farthest into the driftless area, not in valleys, as in montanic regions, but along ridges and over divides.

There is a coincident distribution of deposits. Glacial drift, more or less closely resembling that of the central part of the area, is pushed out not only to the extremities of the salients in the Niagara escarpment, but on most of the lower divides in Winneshiek and northern Clayton Counties, where the Niagara escarpment is faint,

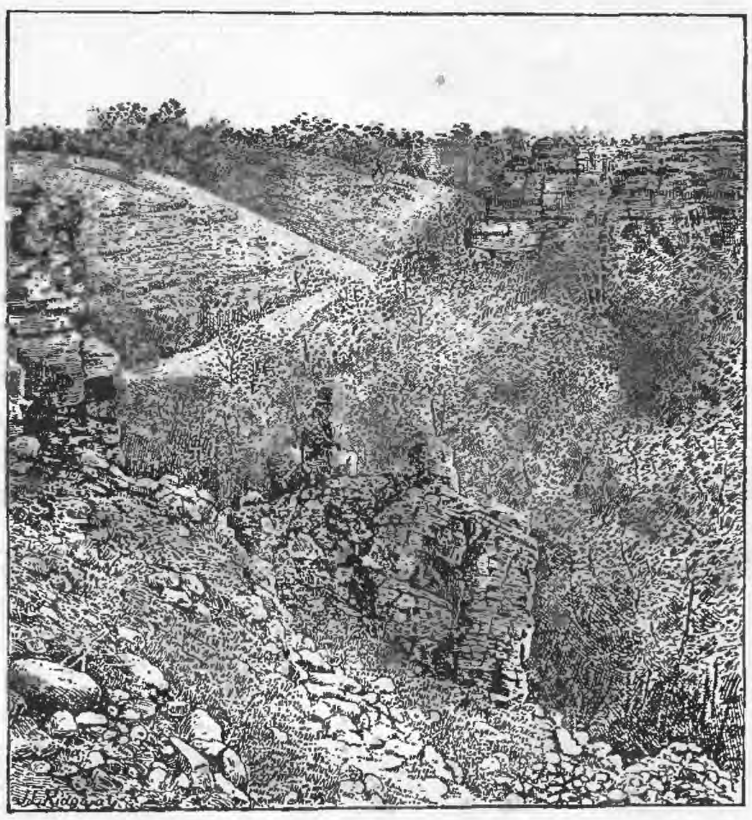

FIG. 98.—Combined water sculpture and ice molding, the former in foreground at lower levels, the latter confined to summits. Near Preston.

and in southern Dubuque and Jackson Counties wherever the ice failed to reach its verge; and moreover, in some cases, sheets of bowlder clay containing beds of erratic pebbles and bowlders have apparently been pushed across transverse valleys and now crown eminences completely isolated from the body of drift. This is well illustrated in northeastern Clinton County, in the neighborhood of Goose Lake, and in contiguous parts of Jackson County; for the abandoned channel of the Mississippi here cutting off the tip of "Cromwell's Nose" was apparently bridged by the ice, and glacial débris

FIG. 99.—Combined water sculpture and ice molding, the former in foreground at lower levels, the latter on summits in distance. Near Preston.

mantles the summits on its eastern side, while its mid-walls display the characteristic features of water carving and are nearly or quite destitute of erratic deposits. But now and then in this transverse valley and in others of like character about the margin of the glacial deposits, as well as sometimes far within the glaciated area, there is a distinctive accumulation more or less closely approaching glacial drift in structure, though made up wholly of local materials. Such a deposit is illustrated in Fig. 100, representing an exposure in the valley of the Wapsipinnicon, 3 miles northwest of Anamosa. The coarse member here is made up of angular blocks and fragments of Niagara limestone, identical with that quarried in the immediate vicinity, embedded in a matrix of worn pebbles, gravel, sand, and finer débris of like material. Fig. 53 represents a neighboring exposure at Stone City, with a coarse member of like character; and Fig. 101 illustrates a section, also exposed in the Wapsipinnicon valley, but at a point several miles below (in a railway cutting in the NE.

¼, Sec. 7, T. 83 N., R. 2 W., Jones County). It is noteworthy that the upper till is unusually thin in this part of the territory (as has already been mentioned, the lower till forms or closely approaches the surface about Martelle, a few miles south of Anamosa). At Stone

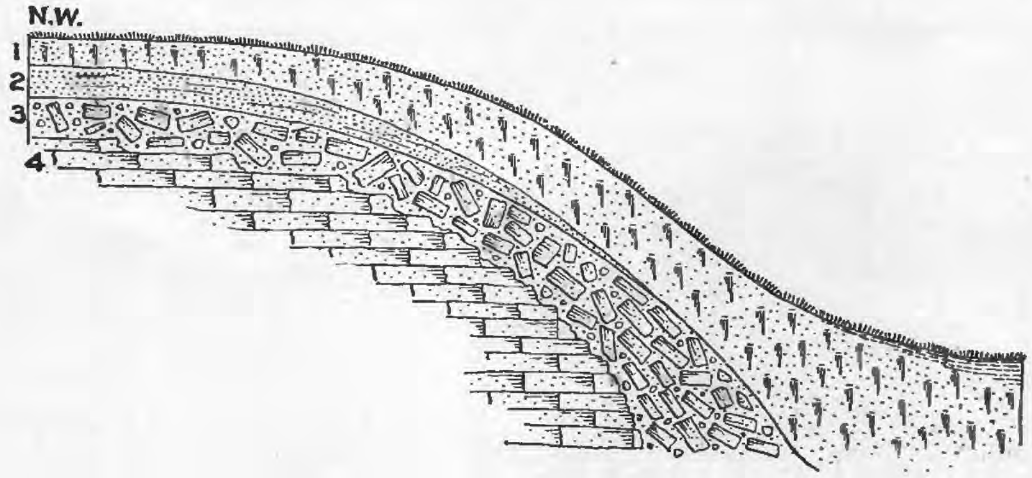

FIG. 100.—Glacial deposit of local materials, near Anamosa: (1) Loess; (2) obscurely laminated sand, generally merging with the loess; (3) light buff calcareous loam containing sand, pebbles, and angular blocks of Niagara limestone; (4) Niagara limestone. Height, 60 feet.

City the loess rests upon the Niagara limestone either directly, as shown in Fig. 54 (reproduced from a photograph), or with a bed of sand intervening, as illustrated in Fig. 53; and it is quite possible

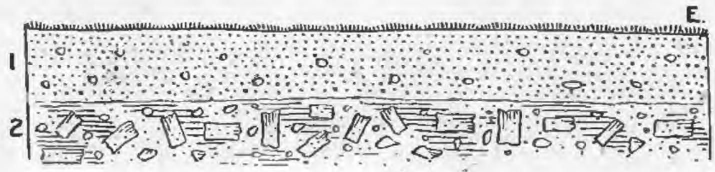

FIG. 101.—Glacial deposit of local materials, Jones County: (1) Fine, clean, obscurely stratified sand with some gravel, largely erratic; (2) reddish yellow clay with gravel and angular blocks of limestone, and a few erratic pebbles. Exposure, 10 feet.

that the later glacial deposits fail completely beneath the loess over a larger area than is represented upon the map of Pleistocene deposits (Pl. XLIII).

The section represented in Fig. 102 was observed in a little valley

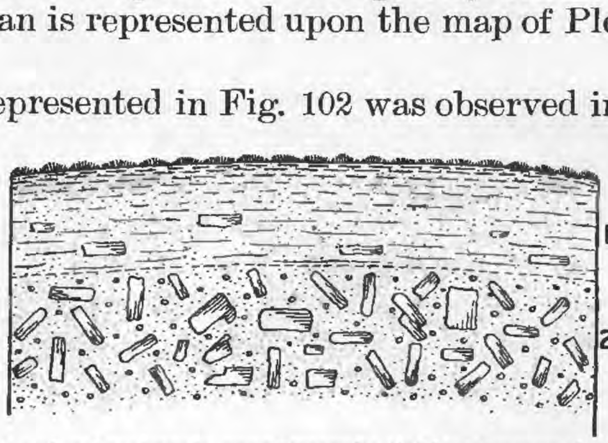

FIG. 102.—Glacial deposit of local materials, near Decorah: (1) Black humus-charged loam with rounded blocks and small fragments of Trenton limesto e; (2) light buff calcareous gravel, sand, and impalpable powder, enclosing great numbers of angular and slightly rounded blocks and fragments of Trenton limestone. Exposure, 7 feet.

opening into the Oneota, near Decorah (SE. ¼ SE. ¼, Sec. 5, T. 98 N., R. 8 W.), just beyond the limits of well characterized ice marking.

The coarse deposit here consists of angular fragments of Trenton limestone, similar to that forming neighboring cliffs, embedded in a matrix of partially oxidized and lixiviated limestone débris. Analogous sections appear near Plymouth Rock in Winneshiek County, near Kidder in Dubuque County, and at several points in western Jackson County, as well as in the vicinity of Goose Lake, Clinton County.

The common situation of such accumulations is in deep, steep-sided, and tortuous valleys, transverse or oblique to the direction of ice flow and about the drift margin; and there are few such valleys so placed that are not at least partially lined with deposits of this character.

These accumulations of angular débris connect themselves definitely with two distinct and well characterized deposits. In some cases the materials sometimes become progressively smaller and better rounded downstream or in the direction of the driftless area, sometimes taking on the character illustrated in Fig. 103 (represent-

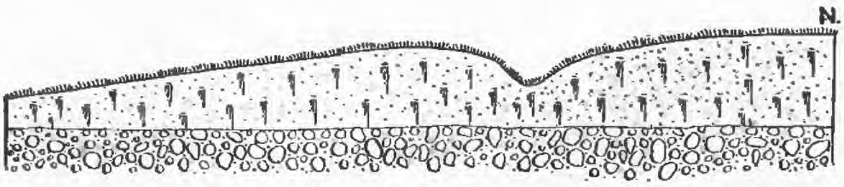

FIG. 103.—Local bowlder deposit beneath loess, Dubuque: (1) Loess; (2) rounded masses of Galena limestone from 8 or 10 inches in diameter downward to fine powder, piled together without arrangement; including also two or three small rounded erratics. Total exposure, 10 feet. The loess is separated from the subjacent bed by a ferruginous band with stains running down to the uppermost bowlders.

ing a section observed in a street cutting immediately west of Linwood Cemetery, Dubuque), and gradually passing into the pebble bed generally found at the base of the loess in the driftless area. In other cases the deposit passes stratigraphically (upward) and geographically (westward) in the same and contiguous exposures into an accumulation of like massive structure containing progressively larger proportions of rounded rock fragments of local origin and pebbles and bowlders from far to the northward, thus grading into the unmistakable glacial drift of one sheet or the other. Indeed, it is a conspicuous fact that the marginal portions of both tills contain exceptionally large proportions of local débris and that this proportion increases quite to the verge of either sheet, so that the last outcrop of either till on any meridian frequently contains more local than erratic rock fragments. So, too, the proportion of erratic rock fragments in either till, particularly toward the margin, decreases toward the base of the deposit, and the last yard in depth of the drift may thus contain more local than foreign rock fragments, though in the upper part of the same exposure the latter may greatly predominate. Similarly the proportion of striated rock fragments in either till sheet progressively diminishes toward the periphery, and in the marginal ice deposits striated pebbles may completely fail, while for many miles within the drift margin the proportion of striated bowlders is surprisingly small.[1]

In short the deposit is unlike the modern taluses or torrential accumulations in structure and in the condition of its material; for the structure is of that peculiar homogeneity in the large way and heterogeneity in the small way characteristic of glacial deposits; and the materials are commonly little if at all worn and rarely striated, though sometimes crushed and battered, as if by ice action, and only partially oxidized and lixiviated. At the same time it is like the Pleistocene glacial deposits in structure and condition of materials, though not in the materials themselves; but in this respect it grades imperceptibly into the glacial deposits. It may therefore be classed as a glacial deposit of unusual character and aspect, and may be ascribed to that peculiar marginal ice action which finds topographic expression in the molding of hill-tops without modification of the intervening valleys.

The land configuration alone indicates that the marginal lobes and tongues of the ice sheet bridged the valleys and bore hard on the hilltops; the characteristic ice deposit alone indicates in like manner that the marginal ice lobes spanned the transverse valleys and formed ground moraines on either side; the hybrid deposit alone suggests that the marginal ice crept into the valleys and there moved so sluggishly as to slightly grind the cliffs and crags without carrying into them the far-traveled erratic débris; while the land forms and the two deposits together seem to indicate that as the marginal lobes of the ice pushed forward they first filled the transverse valleys to the brim and then pushed on over gelid valley-filling and rock-built hilltop alike, the principal plane of slip bridging the valley rather than following its contour. And this, with many other phenomena, suggests that the marginal ice was thin.

SECTION V.—REPRESENTATIVE WELL SECTION.

The actual sections derived from observations in wells, represented on Pl. LI, are so arranged on the sheet as to indicate the elevation of each above sea level; the altitudes having been determined when practicable from railway surveys, and elsewhere from estimates made on the ground. No high degree of accuracy can be claimed for these estimates. Care has, however, been taken to avoid giving undue prominence to differences in altitude based on questionable estimates; and where two or more wells occur in proximity the relative elevation has been deemed more important than absolute altitude. Several of

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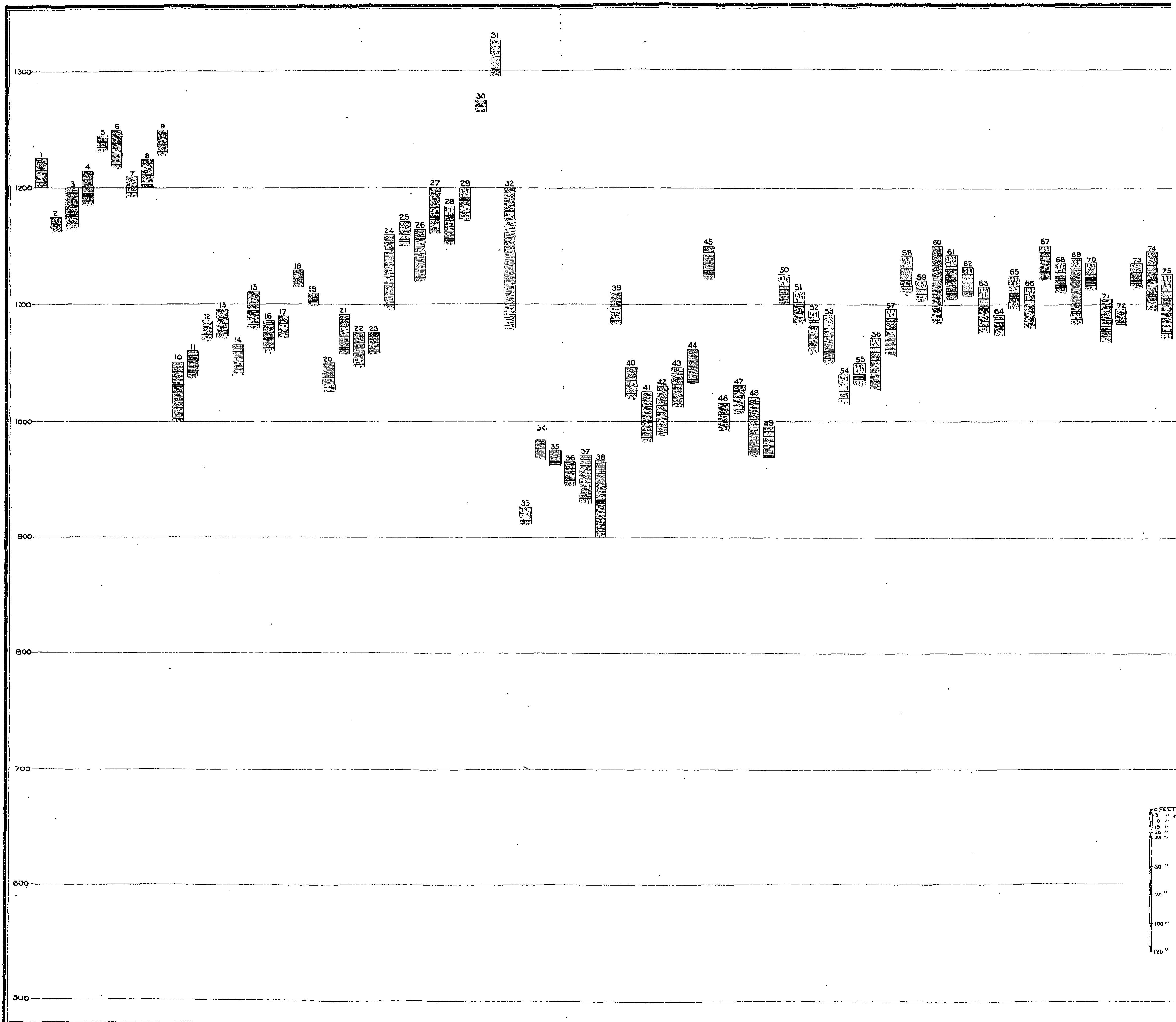
[1] Vide Proc. Am. Assoc. Adv. Sci., 1878, vol. 27, p. 203.

U.S.GEOLOGICAL SURVEY.



the sections are based on information derived from other observers; but in no case in which the testimony was doubtful or conflicting, or inconsistent with the character of the surface, has the record been introduced. A number of wells were reached immediately after completion or while walling-up was in progress, and while yet the materials thrown out were fresh and unaltered; and in such cases the statements of intelligent owners or excavators as to thickness of members, etc., were usually accepted unless the phenomena reported differed in kind or essentially in degree from those personally observed.

It should be remarked that, unless the fact is distinctly specified, these sections do not reach the rock. It is generally impossible to certainly determine whether a stratum of water-bearing gravel, reached after excavating some feet into lower till clays, is altogether below or is intercalated within these clays; but if no evidence to the contrary was observed, such strata have in all cases been assigned to the water bed, or basal portion of the lower till. Furthermore, the excavations often terminated only slightly within the lower till, either on account of the difficulty of removing it or for other reasons. Too limited thickness for this formation, and too low relative position for the forest bed, will therefore be indicated by a casual glance at the plate.

A few of these well sections have already been described;[1] but in order to exhibit the sequence of deposits over so much of the region examined as possible, it has been deemed expedient to repeat the descriptions.

The sections are drawn to a uniform scale. In each county in Iowa except Dubuque the wells are grouped in the order in which they occur in passing from west to east across the county; and in Dubuque County the arrangement is the same for each township represented. A few Illinois sections, partly observed and partly compiled, are introduced for comparison. These sections are shown in their order of occurrence on the Illinois Central Railway from Foreston to Vandalia, i. e., from north to south.

MITCHELL COUNTY.

1. *Sec.* 30, *T.* 100 *N.*, *R.* 18 *W.*—Coarse yellow clay, somewhat gravelly, with rounded and subangular bowlders and lenticular bands of pebbles, 10 feet. Clean and compact laminated blue clay, with rolled fragments of wood, 10 feet. Red granular clay, with roundish masses of partially decomposed limestone, resting on rock, 5 feet.

2. *NW.* ¼, *Sec.* 9, *T.* 99 *N.*, *R.* 18 *W.*—Coarse, yellow pebbly clay,

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[1] Am. Jour. Sci., 3d. ser., xv, 1878, p. 339; Proc. Am. Assoc. Adv. Sci., 1878, vol. 27, p. 189; Geol. Mag., decade 2, vol. 6, 1879, pp. 353, 412.

with superficial bowlders in vicinity, 5 feet. Clean blue clay, extremely compact, 3 feet. Brown sand, obscurely laminated.

3. *One-half mile west of Lyle, Minnesota.*—Dark earthy alluvium, 4 feet. Compact gravelly yellow clay, with granite bowlders, 12 feet. The same, with horizontal bands and rounded lumps of blue clay, 6 feet. Black peaty earth, with many fragments of much decayed wood, 2 feet. Compact blue clay, with pebbles, 6 feet. Sand and gravel, with water rising 20 feet.

4. *Lyle, Minnesota.*—Unstratified yellow pebbly clay, 15 feet. Laminated blue clay, with a few small pebbles and rolled fragments of wood, 7 feet. Black loamy clay, with a marshy odor, containing fragments of coniferous wood and ferruginous concretions, passing into the next bed, say 2 feet. Unstratified blue clay, with striated bowlders, say 2 feet. Sand and gravel, resting on rock.

Both of these wells are just across the line from Mitchell County. So much foul gas was emitted from the peaty stratum in No. 3 as to prevent laborers from remaining in the well for more than 20 minutes at a time, and farther excavation was deemed impracticable. A small test bore was, however, put down with a hand drill, which was forced out by hydrostatic pressure on reaching the water bed. The bore was with difficulty plugged until the well was walled with limestone. The water soon became so impregnated with products of organic decomposition as to be unfit for use. A superficial film of oleaginous appearance and a ferruginous precipitate formed on standing in open vessels. In No. 4 the ancient soil is broken up.

5. *Mean of several wells in Mitchell.*—Yellow or brownish yellow unstratified clay, with striated bowlders and a little coarse sand disseminated, 3 to 6 feet. Compact blue clay, with small pebbles, 0 to 5 feet. Sand or gravel, resting on rock.

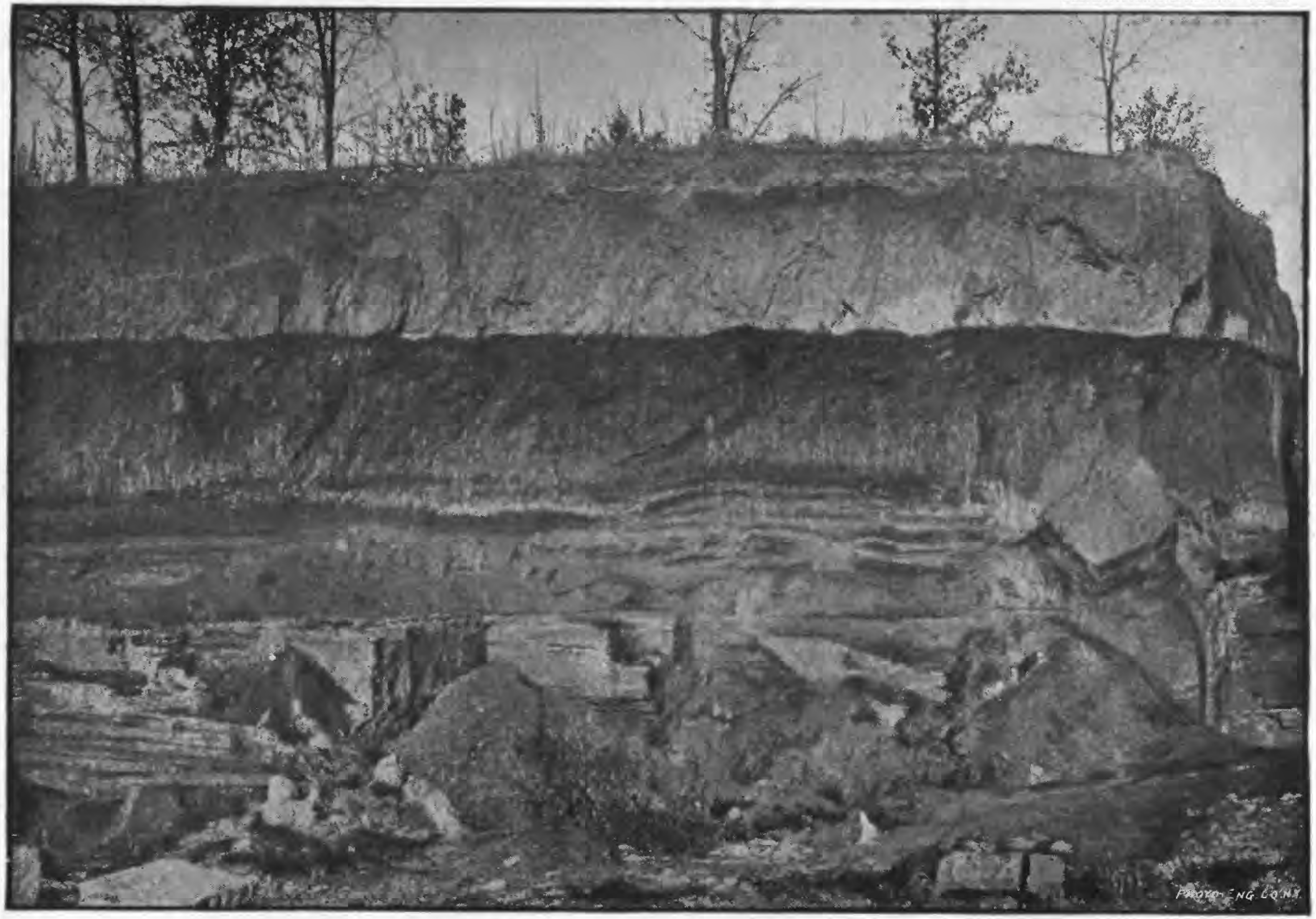
6. *NE. ¼, SW. ¼, Sec.* 4, *T.* 98 *N., R.* 17 *W.*—Unstratified yellow clay with several scattered pebbles and a little gravel, 10 feet. Compact blue clay, laminated and containing a few crushed fragments of wood in its upper portion, unstratified and with striated pebbles below, 18 feet. Stratified sand, gravel, and red clay.

7. *Eastern part of Osage.*—Pebbly yellow clay, altogether unstratified, 5 feet. Coarse stratified brown and yellow sand, 3 feet. Coarse yellow sandy clay with bands and lumps of blue clay, 5 feet. Partly decayed limestone, thinly covered with red clay and sand.

8. *Near Stacyville.*—Pebbly yellow clay, 14 feet. Compact blue clay, clean and laminated, 8 feet. Black peaty soil with a layer of bog ore at its base.

This well was not personally examined, but samples of the bog ore were seen.

9. *Five miles east of Osage.*—Sandy yellow clay with one or two lines of brown sand, with a 10-foot superficial bowlder near by, 12 feet. Compact blue clay with a few small pebbles, 6 feet. Gravel resting on rock.



FOREST BED AT DURHAM, MARION COUNTY.

FLOYD COUNTY.

10. *NW.* ¼, *NE.* ¼, *Sec.* 26, *T.* 94 *N.*, *R.* 17 *W.*—Black alluvial soil, 4 feet. Ferruginous "hard pan" of cemented soil and gravel, 6 inches. Yellow gravelly clay with striated bowlders, 3 feet. Clean laminated blue clay, 11 feet. The same, darker and friable, with fragments of cedar and sumac, 1 foot. Compact clay, pebbly throughout, 28 feet. Partially cemented gravel with water, 2 feet.

11. *SE.* ¼ *SW.* ¼, *Sec.* 24, *T.* 94 *N.*, *R.* 17 *W.*—Black alluvial soil, 3½ feet. Cemented gravel, 6 inches. Coarse yellow clay with small bowlders, 3 feet. Perfectly clean laminated blue clay, 10 feet. Black peaty loam with several well bucketsful of wood, usually much decomposed, part mineralized, 2 feet. Brown gravel and sand with water.

12. *Sec.* 19, *T.* 94 *N.*, *R.* 16 *W.*—Unstratified yellow clay with bowlders up to 3 feet, 10 feet. Stratified yellow sandy clay with water, 2 feet.

13. *Sec.* 19, *T.* 94 *N.*, *R.* 16 *W.*—Unstratified yellow clay with bowlders, 13 feet. The same interstratified with and containing lumps of blue clay, 7 feet. Brown gravel resting on rock.

14. *Sec.* 19, *T.* 94 *N.*, *R.* 16 *W.*—Alluvial soil, 5 feet. Laminated blue clay with small pebbles below, 20 feet.

15. *NE.* ¼ *NW.* ¼, *Sec.* 30, *T.* 94 *N.*, *R.* 16 *W.*—Very pebbly yellow clay with a little sand in horizontal lines, 16 feet. Dark, jointed clay with fragments of wood, 1½ feet. Compact blue clay with striated pebbles and bowlders, 10 feet. Brown sand and gravel.

16. *NE.* ¼, *Sec.* 19, *T.* 94 *N.*, *R.* 16 *W.*—Dark alluvial soil with a layer of cemented gravel at base, 3 feet. Yellow clay with bowlders and pebbles, 6 feet. Clean laminated blue clay, 4 feet. Bog ore and peaty soil with leaves, twigs, and crushed fragments of wood, 1½ feet. Pebbly blue clay, 6 feet. Brown gravel.

CHICKASAW COUNTY.

17. *Northeastern part of Bradford.*—Rather compact gravelly yellow clay intermixed with fine sand, 6 feet. Clean and compact laminated blue clay with occasional intercalations of sand, 12 feet.

18. *NE.* ¼ *NE.* ¼, *Sec.* 16, *T.* 94 *N.*, *R.* 13 *W.*—Gravelly yellow clay with large superficial bowlders, 8 feet. Plastic blue clay with rolled and crushed fragments of wood, 7 feet.

19. *Sec.* 25, *T.* 94 *N.*, *R.* 12 *W.*—Partially stratified sandy clay, 6 feet. Dark silty soil with fragments of wood and of endogenous plants passing into compact blue clay, 4 feet. Water comes in from old soil, and is so foul that strange horses will not drink it.

FAYETTE COUNTY.

20. *NW.* ¼ *NW* ¼, *Sec.* 20, *T.* 93 *N.*, *R.* 10 *W.*—Unstratified yellow clay with striated pebbles and bowlders up to 3 feet, 12 feet. Compact blue clay with smaller striated pebbles and bowlders, 13 feet.

21. *SE.* ¼ *SW.* ¼, *Sec.* 15, *T.* 93 *N.*, *R.* 9 *W.*—Coarse yellow clay, with sand and gravel disseminated throughout, 10 feet. Laminated blue clay, with rolled fragments of wood and small pebbles, 18 feet. Crumbling black earth, with many fragments of wood, roots, bark, leaves, twigs, etc., and lines of brown oxide of iron, 1½ feet. Pebbly blue clay.

22. *Randalia.*—Sandy and gravelly reddish yellow clay with some traces of stratification, and a bed of reddish brown washed soil at its base 9 feet. Clean, finely laminated blue clay, 4 feet. Compact unstratified blue clay, with nodular concretions above and striated pebbles throughout, 14 feet. Reddish and brown sand and gravel.

23. *Maynard.*—Somewhat sandy and gravelly yellow and brownish yellow clay with a few lines of pebbles and large superficial bowlders, 6 feet. Compact blue clay with striated pebbles and ferruginous nodules, 9 feet. Brown sand and gravel.

24. *NW.* ¼ *NW.* ¼, *Sec.* 36, *T.* 92. *N.*, *R.* 8 *W.*—Sandy and gravelly brownish yellow clay, 6 feet. Compact blue clay, with striated bowlders and pebbles below, 54 feet. Fine yellowish brown sand with a running stream of water, which may be seen and heard from the surface.

25. *SW.* ¼ *SW.* ¼, *Sec.* 29, *T.* 92 *N.*, *R.* 7 *W.*—Somewhat sandy and gravelly yellow clay, 11 feet. Blue clay interstratified with sand and gravel, 4 feet. Black, crumbling clay, with wood, etc., 2 feet. Compact pebbly blue clay.

A cedar log 8 inches in diameter extending across the well, fragments of bark (perhaps walnut) 2 inches thick, undetermined roots, branches, and obscure leaf impressions were found in the forest bed.

26. *Pacific House, Brush Creek.*—Very pebbly yellow clay, 9 feet. Pebbly blue clay, 33 feet. Gravel, with water rising 20 feet.

27. *Eastern part of Brush Creek.*—Coarse yellow clay with many local and erratic pebbles and a few bowlders, 17 feet. Laminated blue clay, with many crushed fragments of wood, 9 feet. Compact, unstratified blue clay with striated and polished erratics, 11 feet. Sand and gravel, with an abundant supply of water.

In several wells in and around Brush Creek the water from the water bed rises to the surface, and in a few cases flows permanently. The water is usually good; though in the last described well it became foul shortly after completion, and remained so until pumped dry at a fire; since which it has been good.

28. *Sec.* 11, *T.* 92 *N.*, *R.* 7 *W.*—Loess, 8 feet. Sandy and pebbly brownish-yellow clay, with erratics up to 1 foot, 4 feet. Clean blue clay, with rolled fragments of wood, 16 feet. Black friable earth, with unbroken but much decomposed fragments of wood (cedar alone recognized), bark, roots, twigs, and impressions of leaves and cones, 1½ feet. Compact blue clay.

29. *SE.* ¼ *SE.* ¼, *Sec.* 23, *T*, 95 *N.*, *R.* 7 *W.*—Loess, sandy and laminated below, 15 feet. Dark soil, with fragments of wood and rootlets in place, passing into laminated clean blue clay, 6 feet. Compact pebbly blue clay, with erratics (rarely striated) of greenstone, etc., up to 15 inches, 20 feet. Shale and clay, 8 feet.

WINNESHIEK COUNTY.

30. *SE.* ¼ *Sec.* 7, *T.* 99 *N.*, *R.* 10 *W.*—Rather compact pebbly yellow clay, with bowlders up to 20 inches, 6 feet. Extremely compact laminated blue clay, with a few striated pebbles resting on rock, 4 feet.

31. *SE.* ¼, *Sec.* 16, *T.* 100 *N.*, *R.* 9 *W.*—Loess, 14 feet. Fine laminated sand, growing coarser below, 10 feet. Very gravelly and sandy brown clay, with two bowlders each 3 feet in diameter, resting on rock, 6 feet.

CLAYTON COUNTY.

32. *Enfield.*—Rather sandy and pebbly yellow clay, 20 feet. Compact blue clay, 100 feet.

33. *2 miles Southwest of Wadena.*—Loess, 10 feet. Coarse brown sand and erratic gravel resting on disintegrated shale, 2 feet.

BUCHANAN COUNTY.

34. *Iowa Insane Asylum, Independence.*—Coarse unstratified yellow clay, with many bowlders and pebbles, in part striated, 14 feet. Compact blue clay, containing a few small pebbles in part striated and several crushed fragments of cedar, 6 feet. Not completed when examined.

35. *NE.* ¼ *NE.* ¼, *Sec.* 22, *T.* 89, *N.*, *R.* 9 *W.*—Coarse sandy and pebbly yellow clay, imperfectly stratified, 4½ feet. Unstratified brownish yellow clay, with a few pebbles and bowlders, 6 feet. Black peaty soil passing into blue clay.

36. *NW.* ¼ *SW.* ¼, *Sec.* 28, *T.* 87 *N.*, *R.* 8 *W.*—Coarse unstratified yellow clay, with bowlders, 8 feet. Clean and compact blue clay, with rolled fragments of wood and ferruginous nodules, 8 feet. Brown gravel.

37. 1½ *miles east of Quasqueton.*—Dark soil passing into brownish-yellow alluvium, 8 feet. Blue clay, with now and then a pebble up to 6 inches, 30 feet. Red water-bearing sand.

38. 2½ *miles southeast of Quasqueton.*—Soil and yellow alluvial sand, 11 feet. Dark blue clay, with a few pebbles and pieces of wood 35 feet from the surface, 50 feet. Water-bearing gravel.

The last two sections were furnished by Mr. F. M. Hedger, of Quasqueton.

39. *NW.* ¼ *NW.* ¼, *Sec.* 3, *T.* 88 *N.*, *R.* 7 *W.*—Soil, including loess washed down from the adjacent paha, 3 feet. Stiff yellow pebbly

clay, with a 15-foot bowlder near by, 9 feet. Soft, clean, and plastic blue clay, 12 feet. Brown sand and gravel, partially cemented.

DELAWARE COUNTY.

40. *Southern part of Masonville.*—Unstratified yellow clay, with many erratic and a few local pebbles, in part striated, 10 feet. Rather compact pebbly blue clay, with a 4-inch erratic, finely ground and polished on parallel surfaces, 12 feet. Yellowish-brown sand and gravel.

41. *SW.* ¼ *SW.* ¼, *Sec.* 28, *T.* 89 *N.*, *R.* 6 *W.*—Slightly arenaceous yellow clay, with bowlders up to 25 inches, 12 feet. Plastic blue clay, with a few pebbles, 25 feet,

42. *NE.* ¼ *NE.* ¼, *Sec.* 16, *T.* 88 *N.*, *R.* 6 *W.*—Unstratified yellow clay, with coarse sand and pebbles disseminated throughout, 15 feet. Dark and compact blue clay, clean, laminated above, with rolled fragments of wood and carbonaceous lines medially, without arrangement, and containing finely striated pebbles below, 27 feet.

Excavation was still in progress at the time of examination. Though the forest bed was not clearly defined, a decided odor of marsh gas was emitted, an inky fluid sceped from the clay near the carbonaceous lines, and the water collecting over night was reported to be oleaginous. Water from the well exposed in an open vessel for some hours was observed to deposit a ferruginous precipitate and to become covered with an iridescent film.

43. *SW.* ¼ *SW.* ¼, *Sec.* 10, *T.* 88, *N.*, *R.* 6 *W.*—Unstratified gravelly yellow clay, 14 feet. Compact blue clay with striated pebbles and crushed fragments of wood, 18 feet.

Water supply scanty and disagreeable in both taste and odor.

44. *SW.* ¼ *NW.* ¼, *Sec.* 35, *T.* 88 *N.*, *R.* 6 *W.*—Unstratified yellow clay, with pebbles and bowlders, 8 feet. Compact blue clay, with small pebbles and bowlders of greenstone, 17 feet. Brownish and black earth, like surface soil, with sticks, twigs, branches, and other fragments of cedar, 2 feet.

Water was obtained in forest bed, and is periodically foul. Reported by the owner, Mr. J. S. Barry.

45. *Greeley House, Greeley.*—Pebbly yellow clay, 4 feet. Clean laminated blue clay, 17 feet. Black loam, with partially decomposed logs, sticks, bark, and twigs of coniferous wood, 2 feet. Dense blue clay, with a few pebbles and a water-bearing sand vein.

46. *NE.* ¼ *SE.* ¼, *Sec.* 14, *T.* 88 *N.*, *R.* 4 *W.*—Unstratified pebbly yellow clay, 10 feet. Blue clay, with a few thin sheets of gravel and sand, 14 feet.

47. *NW.* ¼ *SW.* ¼, *Sec.* 13, *T.* 88 *N.*, *R.* 4 *W.*—Pebbly yellow clay, 8 feet. Clean and plastic blue clay, 8 feet. Brown sand and gravel.

48. *NE.* ¼ *SW.* ¼, *Sec.* 24, *T.* 89 *N.*, *R.* 3 *W.*—Gravelly yellow clay, with a few bowlders, 25 feet. Clean and plastic blue clay, with fer-

ruginous nodules, 25 feet. Brown clay, thinly interstratified with sand and gravel, 3 feet.

49. *Sec.* 12, *T.* 87 *N., R.* 3 *W.*—Loess, 10 feet. Fine stratified sand, 2 feet. Coarse pebbly yellow clay, 4 feet, Clean, laminated blue clay, extremely compact and shaly in part, with crushed fragments of wood throughout, 8 feet. Coarse, erratic gravel, mainly of greenstone, resting on rock.

50. *SE.* ¼ *NW* ¼, *Sec.* 24, *T.* 90 *N., R.* 3 *W.*—Loess, 10 feet. Fine stratified sand, 2 feet. Coarse pebbly yellow clay, 4 feet. Clean, laminated blue clay, extremely compact, almost shaly, with crushed fragments of wood throughout, 8 feet. Coarse, erratic gravel, mainly of greenstone, resting on rock.

51. *SE.* ¼ *NW.* ¼, *Sec.* 24, *T.* 90 *N., R.* 3 *W.*—Loess, 9 feet. Laminated sand of medium fineness, 2 feet. Pebbly yellow clay, 3 feet. Compact laminated blue clay, with crushed fragments of wood above and pebbles below, 10 feet. Greenstone gravel.

52. *SE.* ¼ *NW.* ¼, *Sec.* 24, *T.* 90 *N., R.* 3 *W.*—Loess, 8 feet. Washed sand and fine gravel, 1½ feet. Plastic blue clay, with a few obscure plant remains above and greenstone pebbles near base, 20 feet. Water-bearing sand and gravel.

The three wells last described are contiguous.

DUBUQUE COUNTY.

T. 90 *N., R.* 2 *W.*

53. *SE.* ¼ *NW.* ¼, *Sec.* 19.—Loess, 8 feet. Stratified sandy and pebbly clay, 2 feet. Slightly pebbly blue clay, laminated above, with dark earth and much wood, including a tamarack (?) log 10 inches in diameter, extending across the well at 30 feet from the surface, 27 feet. Brown sand and gravel.

54. *SE.* ¼ *NW.* ¼, *Sec.* 31.—Loess, passing into sand and gravel at base, 15 feet. Compact blue clay, with rolled fragments of pine and cedar near top, 5 feet. Brown sand, 4 feet.

55. *SE.* ¼ *NE.* ¼, *Sec.* 31.—Loess, sandy and gravelly below, 10 feet. Partially stratified dark friable blue clay, with a pine log 5 inches in diameter, as well as smaller fragments of wood, 4 feet. Water-bearing brown sand.

54 and 55 are about 50 yards apart.

56. *NW.* ¼ *SE.* ¼, *Sec.* 30.—Loess, 6 feet. Pebbly yellow clay, stratified above, 9 feet. Plastic blue clay, laminated except near base, with rolled fragments of wood and ferruginous concretions above, pebbly below, 25 feet.

57. *NW.* ¼ *SE.* ¼, *Sec.* 30.—Loess, 8 feet. Pebbly yellow clay, assorted and stratified above, 9 feet. Compact blue clay with a few small pebbles and woody fragments, 19 feet.

56 and 57 are perhaps 40 yards apart.

58. *NE.* ¼ *NE.* ¼, *Sec.* 19.—Loess, 10 feet. Pebbly and gravelly yellow clay occasionally interstratified with lines of sand, 15 feet. Dense, semi-indurated blue clay with one or two gravelly lines, 5 feet.

59. *NE.* ¼ *NE.* ¼, *Sec.* 19.—Partially stratified sandy and gravelly yellow clay, 4 feet.

58 and 59 are contiguous. The surface here is broken by ravines which cut down to the drift as shown in figures 84 and 85.

60. *NE.* ¼ *NE.* ¼, *Sec.* 21.—Loess, growing sandy at base, 3 feet. Rather sandy and pebbly yellow clay, stratified above, 22 feet. Clean plastic clay, laminated for 5 or 6 feet, homogeneous below, 4 feet.

61. *SW.* ¼ *SW.* ¼, *Sec.* 15.—Loess, 8 feet. Stratified sand and gravel, 2 feet. Yellow clay occasionally interstratified with sand or gravel, 20 feet. Laminated dark and friable clay with an 8-inch cedar log, cut off at both sides of the well, and smaller sticks of the same wood, passing into clean blue clay, 4 feet.

60 and 61 are less than 100 yards apart. 62 is also near.

62. *SW.* ¼ *NW.* ¼, *Sec.* 22.—Loess, passing into sand and gravel, 6 feet. Yellow pebbly and gravelly clay, cross-stratified occasionally, 14 feet. Compact blue clay.

63. *SW.* ¼ *NW.* ¼, *Sec.* 35.—Yellow clay, clean above, sandy medially, and pebbly below, 30 feet. Laminated blue clay with scattered fragments of wood above, 16 feet. Brown clay interstratified with sand and gravel, 5 feet.

64. *SE.* ¼ *NW.* ¼, *Sec.* 24.—Alluvium, 6 feet. Rather compact clean blue clay, 5 feet. Yellowish brown sand and gravel, 4 feet.

65. *SE.* ¼ *NE.* ¼, *Sec.* 36.—Loess, sandy and stratified below, 20 feet. Plastic blue clay with woody fragments, 5 feet. Pebbly blue clay, 7 feet. Brownish-yellow sand with pebbles and bowlders, 2 feet.

66. *NE.* ¼ *SE.* ¼, *Sec.* 24.—Loess, 12 feet. Yellow clay with pebbles, stratified above, 8 feet. Clean and plastic blue clay, mainly laminated, 14 feet.

T. 89 *N.*, *R.* 1 *W.*

67. *SW.* ¼ *NW.* ¼, *Sec.* 31.—Loess, 6 feet. Coarse yellow clay slightly assorted above, 4 feet. Soft and tenacious blue clay, 12 feet. Dark soil containing woody fragments and ferruginous nodules, with a marshy odor, 2 feet. Finer tenacious blue clay with a few small pebbles, 8 feet. Water flowed in from the forest bed, and was so foul that the well was abandoned.

68. *NE.* ¼ *SE.* ¼, *Sec.* 18.—Loess, 8 feet. Sandy and gravelly yellow clay, cross-stratified above, 5 feet. Dark blue tenacious clay with an upright tree-trunk 4 inches in diameter, broken off near the summit of the blue clay, 6 feet. Yellowish brown sandy clay with gravel and greenstone pebbles resting on rock, 4 feet.

69. *SW.* ¼ *NW.* ¼, *Sec.* 20.—Loess, 8 feet. Slightly pebbly yellow

clay, stratified above, 12 feet. Laminated blue clay, compact and shaly in part, 27 feet. Dark friable clay with carbonized wood, 2 feet. Compact blue clay, 4 feet. Brown sand and gravel resting on rock, 3 feet.

70. *SW.* ¼ *NW.* ¼, *Sec.* 20.—Loess, 9 feet. Laminated sands, 2 feet. Partially stratified yellow clay, containing twigs and branches near its base, 9 feet.

71. *NE.* ¼ *SW.* ¼, *Sec.* 20.—Pebbly yellow clay with a few small bowlders and lines of gravel, 20 feet. Blue clay, with fragments of cedar and sumac above and with small pebbles below, 6 feet. Brown clay, sand, and gravel, on rock, 4 feet.

72. *NE.* ¼ *SW.* ¼, *Sec.* 20.—Pebbly yellow clay, rearranged above, 10 feet. Tenacious clean blue clay, with woody fragments, including a stick 4 inches in diameter, 2 feet.

73. *NE.* ¼ *SW* ¼, *Sec.* 17.—Loess, 10 feet. Somewhat pebbly yellow clay, stratified above, 5 feet. Jointed blue clay with ferruginous nodules and a piece of wood 2 feet in length, 2 feet. Brown gravel and sand.

74. *SW.* ¼ *SE.* ¼, *Sec.* 17.—Loess, 12 feet. Somewhat pebbly clay, stratified and assorted above, 13 feet. Plastic blue clay with traces of decayed wood, 20 feet. Sand and gravel, 3 feet.

75. *NE.* ¼ *NE.* ¼, *Sec.* 21.—Loess, 15 feet. Sandy and pebbly yellow clay, unstratified below, 10 feet. Plastic blue clay, laminated throughout, with many fragments of wood, rootlets, and ferruginous nodules toward the base, 25 feet. Brown sand and gravel.

T. 89 *N.*, *R.* 2 *W.*

76. *NE.* ¼ *NE.* ¼, *Sec.* 5.—Pebbly yellow clay, assorted above, 15 feet. Partially laminated blue clay with crushed fragments of wood, 7 feet.

77. *NW.* ¼ *NE.* ¼, *Sec.* 33.—Unstratified yellow clay with pebbles and bowlders, 30 feet. Plastic blue clay with lines of sand above and a stump (elm?) in situ of such size that it could not be removed and led to the abandonment of the well, 4 feet.

78. *NW.* ¼ *NE.* ¼, *Sec.* 3.—Loess, 20 feet. Laminated sand and fine gravel, 4 feet. Unstratified yellow clay with subangular bowlders, 16 feet. Brown stratified sandy and gravelly clay with a dark line at summit, 19 feet.

79. *NW.* ¼ *NE.* ¼, *Sec.* 3.—Loess, 14 feet. Pebbly yellow clay, stratified above, 12 feet. Dark blue jointed clay with a log 5 inches in diameter.

78 and 79 are contiguous.

80. *SE.* ¼ *NE.* ¼, *Sec.* 22.—Unstratified pebbly yellow clay, 20 feet. Laminated blue clay, 3 feet. Dark loamy earth with a marshy odor, containing twigs and a partially carbonized log.

81. *SW.* ¼ *SW.* ¼, *Sec.* 14.—Loess, 5 feet. Washed sand and gravel, 3 feet. Pebbly yellow clay, 16 feet. Laminated blue clay, with lines of brown gravel and ferruginous nodules, containing near its base an 8-inch coniferous log, cut off at both sides of the well, together with smaller fragments of wood, 11 feet. Sand and gravel, with an abundance of water, 2 feet.

82. *SW.* ¼ *SW.* ¼, *Sec.* 14.—Loess, 5 feet. Stratified sand, 2 feet. Pebbly yellow unstratified clay, 17 feet. Extremely compact blue clay, 4 feet. Brown sand and greenstone pebbles with an abundance of water.

The last two wells are 60 yards apart; and 83 is only a few rods distant.

83. *NE.* ¼ *NW.* ¼, *Sec.* 23.—Loess, 3 feet. Fine laminated sand, 2 feet. Coarse pebbly yellow clay, 5 feet. Plastic blue clay, with many fragments of wood and bark at base, 7 feet.

84. *SE.* ¼ *NW.* ¼, *Sec.* 23.—Pebbly yellow clay with rounded bowlders up to 18 inches in diameter, 6 feet. Soft tenacious clean blue clay, 14 feet.

85. *NE.* ¼ *SW.* ¼, *Sec.* 23.—Pebbly yellow clay, with bowlders 3 feet in diameter within a few yards, 16 feet. Brown sand and gravel, with a line of clean blue clay above, 4 feet.

84 and 85 are contiguous.

86. *NE.* ¼ *SE.* ¼, *Sec.* 11.—Loess, 25 feet. Laminated sand, 6 feet. Coarse, unstratified yellow clay, with bowlders, 9 feet. Plastic blue clay, with a few thin sheets of sand, 4 feet. Dark peaty soil, with fragments of wood, bark, twigs, leaf impressions, etc., with a marshy odor, used successfully as a fertilizer, 2 feet. Compact blue clay, with a few greenstone pebbles, 6 feet. Sand and gravel.

87. *NW.* ¼ *SW.* ¼, *Sec.* 24.—Loess, 5 feet. Pebbly and sandy stratified clay, 2 feet. The same, unstratified, 7 feet. Contorted blue clay, 8 feet. Brown gravelly and sandy clay, resting on rock, 6 feet.

88. *NW.* ¼ *SW.* ¼, *Sec.* 24.—Loess, 5 feet. Obscurely stratified sandy and pebbly yellow clay, 3 feet. The same, unstratified, 8 feet. Compact blue clay, with a few small greenstone pebbles, 6 feet. Brown clay, interstratified with sand and gravel or rock, 8 feet.

87 and 88 are contiguous.

89. *NW.* ¼ *NE.* ¼, *Sec.* 1.—Loess, 6 feet. Pebbly yellow clay, with rounded erratics up to 20 inches, assorted at summit and sandy at base, 30 feet. Peaty black soil, with fragments of wood and ferruginous nodules, 3 feet.

90. *SW.* ¼ *SE.* ¼, *Sec.* 12.—Loess, 5 feet. Stratified sand and gravel, including pebbles up to 6 inches, 4 feet. Unstratified yellow clay, with pebbles and bowlders, 8 feet. Tenacious blue clay, laminated, and occasionly interstratified with lines of brown gravel, 13 feet. Black crumbling earth, with fragments of wood, some partly carbonized, others well preserved, 2 feet. Compact blue clay, 5 feet. Brown sand, resting on rock.

91. *SW.* ¼ *SE.* ¼, *Sec.* 12.—Loess, 15 feet. Laminated pebbly and sandy clay, 3 feet. Unstratified yellow bowlder clay, 12 feet. Compact blue clay, laminated in part, with rolled fragments of wood, 20 feet. Brown sand and gravel, resting on rock.

The last two wells are contiguous.

92. *NW.* ¼ *SE.* ¼, *Sec.* 24.—Loess, 15 feet. Yellow gravelly and pebbly clay, assorted above, 7 feet. Laminated blue clay, with a much decayed log 1 foot in diameter almost in contact with the rock, 2 feet.

93. *NW.* ¼ *NE.* ¼, *Sec.* 36.—Pebbly yellow clay, with a bowlder 3 feet in diameter, 13 feet. Soft, tenacious dark blue clay, with a stick 3 inches in diameter and smaller woody fragments, 3 feet.

94. *SW.* ¼ *SE.* ½, *Sec.* 36.—Unstratified yellow clay, with pebbles and bowlders, 15 feet. Blue clay, with an undetermined stump 2 feet in diameter, apparently in situ, 19 feet from the surface, 10 feet. Brown sandy clay, with water, 2 feet.

95. *SE.* ¼ *SE.* ¼, *Sec.* 36.—Pebbly yellow clay, gravelly at base, 11 feet. Blue clay, containing a cedar stick 3 inches in diameter, resting on rock, 3 feet.

T. 88 *N.*, *R.* 1 *W.*

96. *NW.* ¼ *NW.* ¼. *Sec.* 19.—Loess, 15 feet sand and pebbles, 4 feet pebbly yellow clay, assorted above, 10 feet; laminated blue clay, 10 feet; compact, massive blue clay, with a few small greenstone pebbles, 12 feet; sand and gravel interstratified with brown clay, 3 feet.

The laminated clay was indurated and almost shaly in part, and sufficiently bituminous below to blaze freely when placed in a fire. Wood was found in considerable quantities, mainly in crushed fragments, throughout the stratum.

97. *Farley.*—Unstratified yellow pebbly clay with rounded erratics, 29 feet; blue clay, laminated above, 14 feet; brown sand and gravel.

Fragments of wood (willow recognized) and of unknown plants were found in dark silty earth with a marshy odor, yielding an inky fluid on compression, at the junction of the laminated and massive portions of the blue clay.

98. *Farley.*—Unstratified yellow clay, gravelly at base, 10 feet. Laminated silty blue clay with many pieces of wood, 4 feet.

99. *Farley.*—Unstratified pebbly yellow clay, 5 feet; laminated blue clay, indurated and shaly in portions, with several rolled fragments of wood, 15 feet; yellowish brown sand and gravel.

100. *Farley.*—Unstratified yellow pebbly clay with rounded erratics up to 15 inches, 21 feet; laminated blue clay, 7 feet; massive blue clay, 3 feet; yellowish brown sand and gravel and clay resting on rock, 4 feet.

The laminated clay was indurated and shaly below, and sufficiently bituminous along certain dark lines to blaze freely. Fragments of wood (usually crushed, part carbonized) of different species, ferruginous nodules, lines of peroxide, and a 3-inch nodule of massive pyrite were found in the same horizon.

101. *Farley.*—Pebbly yellow clay, unstratified, 15 feet. Laminated blue clay, 2 feet. Red and brown clay, with rounded erratics, 10 feet. Brown granular clay, with rounded blocks of limestone and silicified casts of Niagara fossils resting on solid rock, 6 feet.

102. *SW.* ¼ *SE.* ¼, *Sec.* 18.—Loess, 9½ feet. Obscurely stratified sandy and gravelly yellow clay, with 10-inch erratics, 6 feet. Compact laminated blue clay, with dark soil, carbonaceous matter, and fragments of wood at two horizons, 9 feet. Massive and homogeneous or obscurely laminated blue clay, 9 feet. Water-worn gravel of greenstone pebbles with a little brown sand and clay, 3 feet.

103. *NW.* ¼ *NW.* ¼, *Sec.* 16.—Partially stratified sandy and gravelly yellow clay, with rounded erratics, 20 feet. Compact blue clay, obscurely laminated, with a few pebbles below and rolled fragments of wood above, 22 feet. Water-bearing sand and gravel, 3 feet.

104. *SW.* ¼ *NE.* ¼, *Sec.* 9.—Obscurely stratified sandy and gravelly yellow clay, with small bowlders, 10 feet. Plastic blue clay interlaminated with a few lines of fine sand, containing several fragments of wood and an 8-inch log (cedar) extending across the well near base, 14 feet. Coarse gravel, mainly of greenstone, resting on rock, 2 feet.

105. *SE.* ¼ *NE.* ¼, *Sec.* 9.—Unstratified yellow clay with several rounded bowlders, 12 feet. Plastic blue clay, with rolled fragments of wood, 13 feet. Brown sand interstratified with hornblendic gravel, 2 feet.

106. *SW.* ¼ *NW.* ¼, *Sec.* 34.—Loess, 6 feet. Assorted pebbly yellow clay, 3 feet. Laminated blue clay, with rolled fragments of wood, 20 feet. Brown sand, 2 feet. Massive blue clay, with a very few striated pebbles, 23 feet.

107. *NW.* ¼ *SW.* ¼, *Sec.* 10.—Partially stratified yellow clay, 24 feet. Slightly bituminous indurated and shaly dark blue clay, 2 feet. Brown sand and gravel.

108. *NW.* ¼ *SE.* ¼, *Sec.* 15.—Loess, 5 feet. Stratified fine and coarse sand and gravel, 5 feet. Extremely compact blue clay, laminated, indurated and shaly in part, with many fragments of wood, 25 feet. Brown sand and gravel, with water rising 10 feet, 6 feet.

109. *NE.* ¼ *SE.* ¼, *Sec.* 14.—Loess, 12½ feet. Stratified sandy an pebbly yellow clay, 4½ feet. Obscurely stratified yellow clay with rounded bowlders, 18 feet. Plastic blue clay, 6 feet. Sand and gravel, 3 feet.

110. *Epworth.*—Yellow clay, pebbly below, 15 feet. Laminated blue clay, indurated, shaly, and bituminous in part, 4 feet. Brown sand and gravel, 2 feet.

111. *NE.* ¼ *SW.* ¼, *Sec.* 36.—Loess, 6 feet. Pebbly yellow clay, assorted above, 11 feet. Laminated dark blue clay, 6 feet. Clean and finely laminated plastic white clay, 6 feet. Brown sand, 1½ feet.

112. *NE.* ¼ *SW.* ¼, *Sec.* 36.—Pebbly yellow clay assorted above, 5 feet. Soft and tenacious laminated blue clay, 8 feet. Sand and gravel.

110 and 111 are contiguous.

Miscellaneous.

113. *NE.* ¼ *NE.* ¼, *Sec.* 6, *T.* 89 *N.*, *R.* 1 *E.*—Loess, growing slightly sandy below, 14 feet. Gravel and stratified sand, 2 feet. Obscurely stratified yellow gravelly clay, with rounded erratics up to 8 inches, 4 feet. Black peaty soil, with woody fragments and rootlets apparently in situ, 2½ feet. Jointed blue clay, clean and homogeneous, 10 feet. Yellow sand, resting on Maquoketa shale, 2 feet.

This is regarded as a representative section.

114. *SE.* ¼ *SE.* ¼, *Sec.* 17, *T.* 89 *N.*, *R.* 2 *E.*—Loess, arenaceous and laminated below, 18 feet. Dark earth with fragments of cedar, 2 feet. Clean and homogeneous blue clay.

115. *NW.* ¼ *SE.* ¼, *Sec.* 15, *T.* 88 *N.*, *R.* 2 *W.*—Loess, 10 feet. Sandy yellow clay assorted above, with rounded bowlders below, 30 feet. Dark friable blue clay with much decayed wood.

116. *SE.* ¼ *SE.* ¼, *Sec.* 2, *T.* 88 *N.*, *R.* 2 *W.*—Unstratified yellow bowlder clay, 17 feet. Laminated dark blue clay, 4 feet. Dark silty clay, with several pieces of wood up to 7 inches in diameter with lignite, ferruginous nodules, thin laminæ of a soft whitish mineral with a pearly luster supposed to be ozokerite, and spherical nodules of massive pyrite, 2 feet. Compact blue clay, with a few striated pebbles, 3 feet. Water-bearing sand and gravel.

117. *SW.* ¼ *NE.* ¼, *Sec.* 24, *T.* 88 *N.*, *R.* 2 *W.*—Loess, passing into fine laminated sand, 11 feet. Unstratified yellow clay, with sand, gravel, and bowlders disseminated, 9 feet. Blue clay, with a few rounded and striated greenstone pebbles, rolled fragments of wood, ferruginous nodules, etc., 10 feet. Brown stratified sand.

118. *Farley.*—Unstratified yellow clay, with bowlders 2 feet in diameter, 12 feet. Obscurely laminated blue clay, with a few pebbles and an occasional line of sand or gravel, and with dark silty clay and wood at 50 feet, 60 feet.

119. *SE.* ¼ *SW.* ¼, *Sec.* 33, *T.* 88 *N.*, *R.* 1 *E.*—Loess, 15 feet. Partially stratified sandy and pebbly yellow clay, 5 feet. Partially laminated clean blue clay, with a line of brown sand at base resting on rock, 15 feet.

120. *NE.* ¼ *Sec.* 4, *T.* 87 *N.*, *R.* 2 *W.*—Somewhat sandy yellow clay, with striated bowlders and a few lines of gravel, 15 feet. Tenacious blue clay with a few greenstone pebbles, in part laminated, 20 feet.

121. *NW.* ¼ *SE.* ¼, *Sec.* 16, *T.* 87 *N.*, *R.* 2 *W.*—Unstratified yellow

clay overlain by a little dark alluvial soil, 5 feet. Compact blue clay, laminated and shaly in part, with rolled fragments of wood, 7 feet.

122. *SW. ¼ SW. ¼, Sec.* 13, *T.* 87 *N., R.* 2 *W.*—Loess, 6 feet. Coarse yellow clay with pebbles and small bowlders, assorted above, 14 feet. Black sandy friable loam, 2 feet. Compact blue clay with small pebbles, most abundant below, 26 feet. Yellowish brown sand, with greenstone pebbles up to 10 inches, 2 feet.

123. *SW. ¼ SW. ¼, Sec.* 13, *T.* 87 *N., R.* 2 *W.*—Loess, 10 feet. Sandy yellow clay, with pebbles, 1½ feet. Jointed and friable dark blue clay, 2 feet.

122 and 123 are perhaps 50 yards apart. Branches, twigs, and numerous woody fragments were scattered through the dark soil and the base of the superjacent clay. 122 is regarded as a perfect section.

124. *SE. ¼ SE. ¼, Sec.* 6, *T.* 87 *N., R.* 1 *W.*—Fine laminated sand, passing beneath loess near by, 4 feet. Rather sandy and partially stratified yellow clay, containing local and erratic bowlders, 15 feet. Fine laminated dark blue sand and loam, with carbonaceous lines, 2 feet. Compact shaly blue clay, 2 feet. Brown gravel.

125. *SE. ¼ NE. ¼, Sec.* 26, *T.* 87 *N., R.* 1 *W.*—Sandy alluvium, 4 feet. Sandy and gravelly yellow clay with striated bowlders, 17 feet. Plastic blue clay with a few small pebbles and woody fragments, 36 feet.

126. *SE. ¼ NW. ¼, Sec.* 18, *T.* 87 *N., R.* 1 *E.*—Loess passing into fine laminated sand, 16 feet. Coarse pebbly yellow clay, 4 feet. Compact blue clay with fragments of wood and 2 or 3 small pebbles, 4 feet. Clean and plastic white clay, very finely laminated, 6 feet. Water-bearing sand.

127. *SW. ¼ SW. ¼, Sec.* 8, *T.* 87 *N., R.* 1 *E.*—Loess, 10 feet. Laminated sand and gravel, 1½ feet. Coarse pebbly yellow clay, 4 feet. Laminated blue clay with crushed fragments of wood, 6 feet. Clean and plastic white clay finely laminated, 4 feet. Sand and gravel.

128. *SE. ¼ SW. ¼, Sec.* 29, *T.* 87 *N., R.* 1 *E.*—Coarse unstratified yellow clay, with superficial bowlders up to 4 feet, 11 feet. Clean, fine, and plastic blue clay, with many small fragments of wood, mainly cedar, scattered throughout, 20 feet.

129. *SW. ¼ SW. ¼, Sec.* 28, *T.* 87 *N., R.* 1 *E.*—Coarse, unstratified yellow clay with several large bowlders, 16 feet. Laminated blue clay, passing downward into silty black earth with much wood (walnut, cedar, willow, etc.) in large pieces, 5 feet.

The last two wells are within the insulated drift area in the southern portion of Dubuque County.

TAMA COUNTY.

130. *Tama.*—Partially stratified buff clay, with erratic pebbles and bowlders, 4 feet. Slightly sandy plastic blue clay, with small striated pebbles, 8 feet. Brown sand with pebbles.

131. *Northern part of Tama.*—Pebbly yellow clay, clean above, 12 feet. Compact unstratified blue clay, with striated pebbles, 16 feet. Water-bearing gravel.

132. *Stickney House, Toledo.*—Yellowish buff clay, clean above, pebbly below, 16 feet. Compact blue clay, with striated pebbles and with rolled fragments of wood in its upper portion, 30 feet. Gravel, with water rising 20 feet.

133. *Town well, Toledo.*—Yellow clay as above, 20 feet. Blue clay, 33 feet. Brown sand and gravel, with an abundant supply of water.

134. *Railway well, Dysart.*—Pebbly yellow clay, sandy toward base (where wells usually find water), 32 feet. Compact blue clay, indurated in places, with occasional layers of sand and several pebbles, 150 feet. Sand, with water rising 50 to 75 feet.

This well was drilled. The sequence was furnished by the station agent.

BENTON COUNTY.

135. *Blossom House, Belle Plaine.*—Buff clay, clean above, pebbly medially, and sandy below (where water is usually found), 20 feet. Compact blue clay, 2 feet.

A well drilled in drift in this town in 1886 gave a strong artesian flow, considered by Chamberlin (Science, vol. 8, 1886, p. 276) to originate in the drift upland to the northward.

136. *Blairstown.*—Gravelly yellow clay with a few bowlders, 20 feet. Compact blue clay, with occasional pebbles and horizontal sand veins, exhibiting a dark earthy stratum with many pieces of wood at 175 feet from the surface, 200 feet.

The shaft was put down in search of coal. The succession was reported by one of the proprietors.

137. *Section* 30, *T.* 83 *N.*, *R.* 9 *W.*—Coarse yellow sandy clay with two or three striated bowlders and a few lines of pebbles, 20 feet. Compact unstratified blue clay with a few striated pebbles, 30 feet.

The well was unfinished at the time of examination.

JONES COUNTY.

138. *SW. ¼ NW. ¼, Sec. 7, T. 83 N., R. 4 W.*—Loess, 15 feet. Fine laminated sand, becoming coarse and gravelly below, 15 feet. Coarse yellow sandy clay, with striated erratics, 8 feet. Plastic blue clay with seams of gravel, 12 feet.

The well is in the Martelle paha. The water has the characteristic taste of that from the forest bed, though no carbonaceous accumulations were noted.

139. *Martelle.*—Rather compact clay drab, then whitish, and finally blue in color, with small striated pebbles and bowlders, 20 feet. Sand and gravel, with water.

Over a considerable area near Martelle the upper till is thin or absent, and the lower till approaches the surface.

140. *NW.* ¼, *Sec.* 7, *T.* 84 *N.*, *R.* 4 *W.*—Loess, 18 feet. Fine laminated gray sand, 4 feet. Coarse yellow sandy and pebbly stratified clay, 2 feet.

141. *NW.* ¼, *Sec.* 7, *T.* 84 *N.*, *R.* 4 *W.*—Loess, 6 feet. Fine laminated gray sand, 4 feet. Cross-stratified coarse sand and gravel, 3 feet. Water-worn erratic gravel.

140 and 141 are contiguous, the first on the bluff overlooking the Wapsipinnicon River, and the second part way down the slope. Still lower, and on the opposite side of the river the succession is as shown in figures 53 and 54 pp. 455, 456.

142. *SW.* ¼, *Sec.* 2, *T.* 85 *N.*, *R.* 4 *W.*—Loess, 12 feet. Fine laminated buff and bluish sand, 3 feet. Brownish yellow gravelly clay.

143. *SW.* ¼, *Sec.* 2, *T.* 85 *N.*, *R.* 4 *W.*—Loess, 25 feet. Fine laminated buff and bluish sand, 10 feet. Compact blue clay with pebbles and bowlders, 10 feet.

144. *SE.* ¼ *SW.* ¼, *Sec.* 36, *T.* 85 *N.*, *R.* 4 *W.*—Coarse unstratified yellow clay with striated pebbles, 25 feet. Compact blue clay, with a few small pebbles throughout, 75 feet. Brown gravel.

The last three wells are not far apart. If 142 were placed between the others and the homologous formations connected, the resulting section would indicate the general relation of loess-covered to drift-covered areas.

145. *NW.* ¼, *Sec.* 17, *T.* 83 *N.*, *R.* 3 *W.*—Pebbly yellow clay, with striated bowlders, 20 feet. Partially stratified blue clay, with occasional lines of coarse sand and fine gravel, 10 feet. Laminated blue clay, with lines of dark earth, and with some hundred fragments of wood (oak, ash, walnut, cedar, pine, hickory, etc.), part carbonized, and spherical nodules of massive pyrite as well as nodular concretions, the whole emitting a marshy odor, and yielding water forming a brown precipitate and an iridescent superficial film on exposure in open vessels, 10 feet. Yellowish-brown clay, sand, and gravel.

146. *SW.* ¼ *SE.* ¼, *Sec.* 27, *T.* 83 *N.*, *R.* 3 *W.*—Coarse yellow clay with pebbles and bowlders, 10 feet. Tenacious blue clay, with small bowlders and fragments of wood (willow), 5 feet. Brown gravel.

147. *SW.* ¼ *SW.* ¼, *Sec.* 26, *T.* 83 *N.*, *R.* 3 *W.*—Coarse yellow clay with bowlders up to 2 feet, 8 feet. Compact blue clay, with lines of pebbles above and bowlders up to 14 inches below, with fragments of coniferous wood at 40 feet from the surface, 37 feet. Gravel and brown sand.

148. *NE.* ¼ *NE.* ¼, *Sec.* 24, *T.* 84 *N.*, *R.* 3 *W.*—Loess, 7 feet. Buff laminated sand, 1 foot. Compact yellow clay, with rounded bowlders and striated pebbles, 7 feet. Fine, clean, ash-colored loam with calcareous spots, finely laminated, 4 feet. Extremely compact blue clay, 14 feet.

149. *NE. ¼, Sec. 17, T. 84 N., R. 2 W.*—Unstratified pebbly yellow clay, 7 feet. Tenacious blue clay with a few small pebbles and rolled fragments of wood, 10 feet. Gravelly, brownish red clay and sand, 29 feet. Fine sand with water rising 23 feet.

150. *Junction House, Center Junction.*—Loess, passing downward into fine buff sand, 7 feet. Partially stratified yellow sandy and gravelly clay with bowlders, 5 feet. Compact blue clay with a few pebbles and small bowlders, 93 feet. Brown sand with water rising 60 feet.

151. *Center of Sec. 21, T. 85 N., R. 2 W.*—Coarse unstratified yellow clay with pebbles and bowlders up to 2½ feet, sandy and obscurely stratified at base, 29 feet. Unstratified blue clay with rounded bowlders up to 20 inches, 9 feet. Brown gravelly clay with greenstone pebbles resting on rock, 3 feet.

152. *NE. ¼ NE. ¼, Sec. 16, T. 85 N., R. 2 W.*—Fine laminated buff sand, coarser and occasionally interstratified with gravel below, 10 feet. Clean sandy yellow clay, 28 feet. Plastic blue clay, 6 feet. Red ocherous clay with limestone fragments, 10 feet.

150 is just at the southern margin of the Onslow drift basin, though no less than 50 feet below the highest loess-covered summits at Center Junction; 151 is near the center of the basin, and 152 is on its northern rim. The difference in level between loess and drift in this basin is less distinctly marked here than farther to the eastward, as shown by Fig. 55 (p. 457).

153. *Southern part of Wyoming.*—Unstratified yellow clay with striated bowlders, 30 feet. Plastic blue clay, silty in part, with occasional lines of sand and gravel, with rolled fragments of wood but with no pebbles larger than 1 inch, 37 feet. Black peaty soil containing much vegetal matter, with sticks, twigs, leaf impressions, etc., emitting a marshy and sulphurous odor, 3 feet. The water which flowed in from this stratum was always unpleasant to taste and smell, though abundant, and was suspected to have occasioned illness in the family supplied from it.

154. *NE. ¼, Sec. 17, T. 86 N., R. 1 W.*—Loess, 15 feet. Fine laminated, grayish buff sand, growing coarser below, 8 feet. Pebbly yellow clay, 2 feet. Compact blue clay with a few small pebbles, 12 feet. Yellowish brown sand.

155. *NE. ¼, Sec. 17, T. 86 N., R. 1 W.*—Obscurely stratified yellow clay with erratic pebbles and bowlders, 8 feet. Clean and plastic blue clay, 8 feet. Brownish red gravel.

154 and 155 are contiguous; the former being situated on an elevated loess-covered ridge and the latter in an adjacent valley of erosion.

156. *SE. ¼, SW. ¼, Sec. 9, T. 86 N., R. 1 W.*—Loess, 8 feet. Laminated gray sand, 5 feet. Sandy yellow clay, 7 feet. Plastic blue clay with a few pebbles, 15 feet. Brown gravel.

LINN COUNTY.

157. *Near Center Point.*—Gravelly yellow clay, 9 feet. Blue clay with bowlders and a fragment of cedar 2 by 6 inches, 7 feet.

158. *Center Point.*—Sandy and gravelly yellow clay, 8 feet. Blue clay with bowlders and fragments of wood, 10 feet. Brownish yellow gravel and sand with a 3-foot bowlder, which it was found impracticable to remove, 18 feet.

These sections were furnished by Mr. F. M. Hedger, of Quasqueton. The surface in the vicinity was previously examined by the writer.

159. *Marion.*—Upper till, 15 feet. Lower till, 17 feet. Forest bed and brown sand resting on rock.

The above general section is based on the observations of Owen,[1] who says: "In sinking wells on the prairie on which Marion stands a schistose limestone is struck at a depth of from 30 to 35 feet.' The soil and subsoil are usually 15 feet deep. Beneath these a stiff blue clay sets in, sometimes passing into yellow clay, inclosing waterworn pebbles. Under this clay is an ancient vegetable mold, intermixed with sticks, leaves, and timber. This soil rests upon the above mentioned limestones." Personal observation in the vicinity indicates that it is exceptional to find the forest bed resting upon the rock without the infraposition of at least some feet of pebbly blue clay, though this clay may be considerably impregnated with humus. The yellow clay may be loess-like above.

160. *NW. ¼, Sec. 9, T. 82 N., R. 5 W.*—Yellow clay with a few small pebbles, 4 feet. Tenacious blue clay, 6 feet. Brown gravel and sand.

161. *Prairieburg.*—Unstratified pebbly yellow clay with striated bowlders, 16 feet. Compact blue clay with small greenstone bowlders and occasional lines of pebbles and sand, 14 feet.

Dark friable earth with vegetal matter and a marshy odor is rather common in this village at 25 feet; and water standing at that level is unfit for use.

JACKSON COUNTY.

162. *NE. ¼, Sec. 15, T. 86 N., R. 3 E.*—Loess, 12 feet. Laminated buff and gray sand, fine above, coarse below, 8 feet. Brownish-yellow gravelly clay with rounded greenstone pebbles, 4 feet. Red granular clay with nodules of chert, resting on rock, 17 feet.

163. *SE. ¼ NE. ¼, Sec. 34, T. 84 N., R. 5 E.*—Loess, 12 foot. Fine laminated sand, coarser below, 7 feet. Extremely compact reddish-yellow clay, somewhat gravelly and pebbly, 14 feet. Black peaty earth much impregnated with iron protoxide and weathering into earthy limonite on exposure, containing vegetal remains and humus, resting on rock, 3 feet.

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[1] Geol. Survey Wisconsin, Iowa, and Minnesota, 1852, p. 84.

164. *Sterling.*—Yellow clay, clean above, arenaceous medially, and pebbly below, 14 feet. Soft and plastic finely arenaceous blue clay, with occasional worn fragments of wood, 30 feet. Coarse sand and gravel resting on rock.

The well was subsequently drilled 400 feet in the rock; but unfortunately no record of the succession was kept. The section was furnished by the party making the excavation.

165. *NW. ¼ SW. ¼, Sec. 7, T. 84 N., R. 7 E.*—Stratified sand, gravel, and yellow and brown clay, 18 feet. Sandy blue clay, 42 feet. Dark soil with much vegetal matter (including a much decayed log 18 inches in diameter) passing into pebbly blue clay, 4 feet.

CLINTON COUNTY.

166. *Sec.* 28, *T.* 81 *N., R.* 1 *E.*—Loess, 6 feet. Laminated sand, 2½ feet. Pebbly and gravelly yellow clay, 2 feet. Clean laminated blue clay, 8 feet. Soft dark peaty soil containing abundant plant-remains and wood of several species, as well as ferruginous lines, with a marshy odor when first exposed, changing subsequently to a foul odor somewhat resembling that of sulphuretted hydrogen, 2 feet. Compact blue clay with striated bowlders up to 25 inches, 26 feet.

167. *Delmar.*—Partially stratified yellow clay with striated pebbles and bowlders, sandy and gravelly toward the base (where water is usually found), 26 feet. Compact blue clay with pebbles and small bowlders, largely of greenstone, 28 feet. Brown sand and gravel, with water.

168. *Sec.* 17, *T.* 83 *N., R.* 5 *E.*—Yellow clay, clean above, arenaceous medially, and pebbly below, 25 feet. Rather clean jointed blue clay with several fragments of wood, twigs, etc., in a dark stratum at 30 feet from the surface, resting on rock, 8 feet.

169. *Sec.* 27, *T.* 82 *N., R.* 5 *E.*—Yellow clay with lines of sand and gravel, 12 feet. Fine, clean and plastic arenaceous blue clay, 22 feet. Dark peaty soil with bark, twigs, rootlets, and larger woody fragments, 2 feet. Compact blue clay with pebbles and bowlders, 8 feet.

IOWA COUNTY.

170. *Victor.*—Loess, 5 feet. Fine laminated gray sand, gravelly below, 3 feet. Gravelly and pebbly buff clay, sandy and stratified below, 12 feet. Rather compact blue clay with occasional pebbles and seams of brown sand or gravel, 130 feet. Fine brown sand, with water rising 120 feet.

The well was drilled with an 8-inch bit. At 140 feet from the surface a softer stratum was struck and dark peaty matter, as well as partially mineralized wood, was brought up. When water was reached, a section of a coniferous log, 4 inches in diameter and 8 inches long, was forced up. The water has the characteristic forest-bed taste and odor except when freely pumped. The locality was not visited until after the work was completed; and the above information, except as to taste and odor of water, was obtained from parties connected with the drilling.

JOHNSON COUNTY.

171. *NW.* ¼, *Sec.* 1, *T.* 81 *N.*, *R.* 6 *W.*—Coarse yellow clay with striated bowlders, 15 feet. Compact blue clay with a few small pebbles and rolled fragments of wood, 13 feet. Brown sandy and gravelly clay, 2 feet.

172. *NW.* ¼, *SE.* ¼, *Sec.* 1, *T.* 80 *N.*, *R.* 5 *W.*—Loess, 15 feet. Fine and clean greenish buff laminated marly sand, slightly gravelly at base, 15 feet. Coarse pebbly yellow clay with striated bowlders, 6 feet. Laminated blue clay with a few lines of sand and pebbles, 4 feet. Black friable soil with woody fragments and ocherous stains, 2 feet. Unstratified blue clay with a few small bowlders and a large number of striated pebbles, 11 feet. Water-washed gravel.

173. *Near NW. cor. NW.* ¼ *SE.* ¼, *Sec.* 26, *T.* 79 *N.*, *R.* 6 *W.*—Surface soil, 2 feet. Loess, rather silty, but otherwise normal above, becoming sandy below, 7 feet. Rather coarse dark blue sand, 2 inches. Buff sand, 1 foot 8 inches. Finer sand and loess-like material, 4 inches. Fine buff sand, 8 feet.

Record of a section developed by boring. The sand in the lower part of the section may be regarded as the coarser basal part of the loess.

174. *NW.* ¼ *SE.* ¼, *Sec.* 24, *T.* 79 *N.*, *R.* 6 *W.*—Silty loess, 15 feet. Quicksand, 2 feet. Sandy clay, 2 feet. "Chip pile" (a mass of peaty matter, charged with sticks, leaves, twigs, roots, etc.), 3 feet. Sandy blue clay, containing a few small pebbles, 27 feet.

Based on statement of owner and examination of the materials removed from the dug well.

175. *Near center of SE.* ¼, *Sec.* 30, *T.* 79 *N.*, *R.* 5 *W.*—Soil, 2 feet. Loess, becoming silty below, 15 feet. Silty loess, containing *Succinea*, etc., 2 feet. Same, without fossils, 1 foot. Sandy bed, 2 inches. Black silty and loamy loess, 2½ feet. Peaty soil, 2 feet. Brownish peaty matter, largely made up of decayed wood, 1 foot. Decayed wood, 6 inches. Fine black compact vegetal mold, 1 foot. "Gumbo," 2 feet. Homogeneous silty clay, dark blue above, greenish blue below, 6 feet.

Record of a section developed by boring.[1]

CEDAR COUNTY.

176. *Mechanicsville.*—Loess, 4 feet. Stratified sand and fine gravel with small pebbles, 3 feet. Obscurely laminated blue clay, with a

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[1] The apparatus used in making the borings in Johnson County is described in the Ninth Annual Report of the U. S. Geological Survey, 1889, p. 106.

few small bowlders, mainly in its lower portion, 30 feet. Fine brown sand.

177. *SE. ¼ NE. ¼, Sec.* 16, *T.* 82 *N., R.* 3 *W.*—Loess, 4 feet. Stratified sand, fine above, coarse and gravelly below, 10 feet. Blue clay, containing seams of gravel and crushed fragments of wood above, unstratified, and containing striated pebbles and bowlders below, 32 feet. Brown gravel and coarse sand.

These wells are in low paha.

178. *NE. ¼, Sec.* 3, *T.* 82 *N., R.* 2 *W.*—Alluvial soil, 5 feet. Unstratified pebbly yellow clay, 5 feet. Extremely compact blue clay, with many pebbles and bowlders up to 15 inches, 15 feet.

MUSCATINE COUNTY.

179. *Wilton.*—Somewhat sandy and gravelly yellow clay, partially stratified at base, 15 feet. Blue clay with a few sand veins, 9 feet. Brown peaty soil with sticks, logs, roots, branches, etc., mainly of coniferous woods, 20 inches. Compact blue clay, 2 feet. Brown gravel.

A substantially similar sequence was observed in two wells and reported in a third; though in only one was the vegetal accumulation considerable. In this well the water was so foul that it was filled up.

SCOTT COUNTY.

180. *Eldridge.*—Somewhat pebbly yellow clay, sandy and often obscurely stratified toward the base, 8 to 15 feet. Plastic blue clay, interlaminated with sand and gravel veins containing occasional fragments of wood, 12 to 15 feet. Black peaty soil with logs and sticks as well as ocherous lines and ferruginous nodules, 1 or 2 feet. Compact blue clay with pebbles and bowlders, often striated, 20 to 25 feet. Brown sand and gravel resting on rock.

The above is a general section based on several wells reported and the railway well personally examined. Residents say that water may be found at either of three different horizons, viz: (1) In the stratified sandy clay forming the base of the upper till; (2) in the ancient soil or associated gravel seams; or (3) in the brown sands and gravels resting on the rock. In the first case the water is fairly good but not abundant; in the second it is generally scanty and never good, while in the third it is both abundant and good.

ILLINOIS.

181. *Eight miles northeast of Palo, Ogden County.*—Unstratified gravelly yellow clay with striated bowlders, 23 feet. Clean and plastic blue clay, 2 feet. Water-bearing brown gravel.

182. *One mile east of Palo.*—Coarse unstratified yellow clay with pebbles and bowlders, 10 feet. Plastic blue clay with a few small pebbles, 10 feet. Brown sand and gravel, 5 feet.

183. *Palmyra Township, Lee County.*—"(1) Black mold and subsoil, 6 feet. (2) Finely laminated buff-yellow clay, 12 feet. (3) Blue compact laminated clay, 10 feet. (4) Black oozy marly mud, full of sticks, etc., 5 feet." (Geological Survey of Illinois, vol. 5, p. 136). "At this point an abundance of rather brackish * * * water was struck, and the well up to the present time is never-failing, and the water growing sweeter and purer." Where the drift deposits are thickest "the blue clay is usually the heaviest deposit, and is often underlaid by the black mud of the above section, * * * or by a bed of gravel and dirt of variable thickness."

184. *Wyanet, Bureau County.*—Coarse yellow clay with several bowlders, 9 feet. Somewhat sandy blue clay, obscurely stratified and containing crushed fragments of wood above, unstratified and with small pebbles below, 10 feet. Water-bearing sand and gravel.

185. *Mendota, La Salle County.*—Coarse unstratified yellow clay, with bowlders exposed in neighboring shallow excavations, 14 feet. Washed gravel, 6 inches. Rather compact blue clay with horizontal sand-veins, 75 feet. Extremely compact blue clay, 2 feet. Reddish and yellow clay, 69 feet.

186. *Mendota.*—Unstratified yellow pebbly clay, 6 feet. Obscurely laminated blue clay with lines of sand and gravel, 150 feet.

187. *Mendota.*—Somewhat pebbly yellow clay, 12 feet. Blue clay, 55 feet. Gravel, 3 inches. Blue clay, 7 feet. Water-bearing gravel.

188. *Mendota.*—Yellow clay, 18 feet. Laminated blue clay with horizontal lines of brown sand and gravel, 14 feet. Dark crumbling clay with crushed fragments of coniferous wood and a willow stick, 2 feet. Compact blue clay, 3 feet. Water-bearing sand and gravel.

These Mendota sections illustrate the difficulty of classifying the superficial deposits at any point without complete sections. 188 was first observed personally, and was supposed to represent both tills with forest bed and water bed complete; 186 was, however, at the same time reported by the well-diggers, with the forest bed indicated in its place; but it was regarded as anomalous. Subsequently 185 and 187 were observed by Mr. L. R. Curtis, and the records, with samples from various depths, were transmitted by Dr. J. D. Moody. The somewhat gravelly blue clay from 60 feet below the surface in 187 contains many minute crushed fragments of coniferous wood, apparently cedar; and when first received and unpacked, the peculiar marshy odor of the old soil as well as dark stains in the clay could readily be detected. Still later the same gentleman reported the occurrence of an ancient peat bed a foot or more in thickness at 100 feet beneath the surface; and mounted samples of the mass were transmitted. The sequence of deposits in the well in which the peat bed was found was not reported, but the position of the peat corresponds with that of the forest bed shown in 186.

Quite recently Mr. Curtis has reported that the occurrence of a peat bed at about the horizon indicated is not at all unusual in the vicinity of Mendota. It therefore seems probable that the true position of the ancient soil is about 100 feet beneath the surface, and that the wood and humus at 60 feet in 187 and at 30 feet in 188 has been disturbed; and it is also probable that the water-bearing gravels in 187 and 188 are merely intercalated layers, such as were reported in 185 and 187 and seen in 188. It should be noted that Freeman recognized a water-bearing gravel layer of somewhat indefinite horizon within the blue clay and apparently near its upper margin. The occurrence of such intercalated seams has also been noted by the writer in sections in La Salle County not illustrated in Pl. LI. It is suspected that here the iron of the lower portion of the upper till has been changed from ferric to ferrous oxide; and in the basal portion of the lower till in 185 a reverse alteration with partial hydration of the sesquioxide appears to have occurred.

The moss from the peat bed was submitted for examination to Prof. Thos. P. James, of Cambridge, who says: "It is a *Dichelyma*, and appears to be a distinct species; but being barren it can not be described."

189. *General section, La Salle County.*—"The records of many wells and some borings were obtained in the northern half of the county, and some in the southern part, from which it appears that the order of stratification of the drift is, first below the soil a yellow, marly clay, 3 to 10 feet, usually about 5 feet; gravel from a few inches to 5 feet of very variable thickness, from a few feet to 40; then a gravel bed, thickness not known, as where this is found there is an invariable supply of good water. Although this seems to be the general order of deposit of the lower portions of the drift, it varies in different places, and the blue clay reaches a much greater thickness, the gravel bed being absent, and the blue clay above and below the gravel being united in one stratum. The gravel bed, however. is widely extended and generally found."[1]

190. *NW. ¼ NW. ¼, Sec. 26, T. 35 N., R. 2 E.*—"Soil, 1 foot. Yellow clay and small stone or gravel, 15 feet. Blue clay, 85 feet. Gravel, 20 to 103 feet, to St. Peter's sandstone."[2]

191. *Winona, Marshall County.*—Coarse unstratified yellow clay containing erratic pebbles and bowlders, 8 feet. Rather compact obscurely laminated blue clay with small pebbles, 13 feet. Brown; gravel and sand.

192. *Minonk, Woodford County.*—"(1) Soil, 2 feet. (2) Yellow clay, 14 feet. (3) Blue clay, 18 feet. (4) Sand and gravel, 15 feet. (5) Cemented sand and gravel, 76 feet."[3]

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[1] Geological Survey Illinois, vol. 3, p. 262.

[2] Ibid., p. 263.

[3] Ibid., vol. 4, p. 336.

193. *Sec.* 21, *T.* 28 *N.*, *R.* 2 *W.*—"(1) Soil and yellow clay, not measured. (2) Purplish clay or hard pan, not measured. (3) Blue sandy clay containing fresh water shells, 6 feet. (4) Rotten driftwood or peaty matter, 3 feet 6 inches. (5) Blue clay, 3 to 4 feet. (6) Driftwood or peaty matter, 5 to 6 feet. (7) Blue clay, not measured." (Geological Survey Illinois, vol. 4, p. 336.)

Succinea and *Limnea* were recognized by Meek from No. 3, and "American white birch, black or double spruce, American larch or tamarack, and one variety of cedar" were identified by Lesquereux from No. 4 of this section. "In this vicinity, on the uplands, wells are reported to have been sunk to a depth of 50 to 60 feet, and the hard pan or purple clay not reached," though so great depth for the yellow clay appears to be unusual.

194. *Bloomington, McLean County.*—"(1) Surface soil and brown clay, 10 feet. (2) Blue clay, 40 feet. (3) Gravelly hard pan, 60 feet. (4) Black mold with pieces of wood, etc., 13 feet. (5) Hard pan and clay, 89 feet. (6) Black mold, etc., 6 feet. (8) Blue clay, 34 feet. (8) [bis] Quicksand, buff and drab in color, and containing fossil shells, 2 feet. 9. Clay shale (Coal Measures)." (Geological Survey Illinois, vol. 4, 1870, p. 178.)

The upper portion of this section hardly corresponds with the sequence personally observed in much shallower excavations in and near Bloomington, which sequence is about as follows: Loess, homogeneous, and without visible stratification, sometimes light blue below where thick, 8 to 20 feet. Fine, laminated marly sand, mainly yellowish buff, but sometimes bluish above and brownish below, 5 to 16 feet. Unstratified yellow clay with striated erratics. It is, however, possible that the members described in Bannister's section are wrongly interpreted, since the description is but general, and since, further, no distinction between the homogeneous upper portion and the sandy and laminated lower portion of the loess was recognized by the Illinois geologists. The section is apparently anomalous, and at the same time of unusual interest, in that it unquestionably penetrates an important glacial or interglacial channel.

The abnormal position of the forest bed in such channels is shown by well sections 136 and 170.

"The quicksand, number 8 [bis] of the above section, resembles somewhat in appearance the sands of the loess, and the only species of the contained shells which could be identified was the *Helicina occulta*, which is also not uncommon in the loess of the river valleys in this State. Beds of black vegetable mold are met with at less depths than in this section in various places in the district, as for instance in the vicinity of Pekin, Tazewell County, where it is said, in a few instances, to have tainted the wells which penetrated it to such an extent as to almost render the water unfit for use."

Quite recently, borings at Bloomington have encountered strong flows of inflammable gas in the drift. In one case the gas pressure was sufficient, according to the press reports, to blow the tools out of the well.

195. *Decatur, Macon County.*—Loess, sandy and obscurely laminated near the base, 8 feet. Yellow clay, clean above, pebbly and unstratified medially, and sandy and stratified below, 12 feet. Plastic blue clay interstratified with lines of sand and gravel, 15 feet. Dark crumbling jointed clay with many pieces of wood and a log 9 inches in diameter extending across the well 3 feet. Gravel and sand with water.

The log was not personally identified; but it exhaled an aromatic odor, which led to its recognition as sassafras by the well-digger and others familiar with that wood.

196. *Harristown, Macon County.*—"At this place a well was dug through 10 feet of yellow clay, then 70 feet of blue clay, with no sand and only surface water obtained." (Geological Survey of Illinois, vol. 6, p. 191.)

197. *Williamsburg, Shelby County.*—"The first 38 feet was through clay to sand, then a muddy sand, with occasional leaves and sticks and one log; from 52 to 75 feet bored to [misprint for through ?] stiff clay." (Geological Survey of Illinois., vol. 6., p. 165.)

Guided to some extent by personal observations in the vicinity, this rather definite statement has been interpreted (possibly too freely) as signifying: Loess, say 20 feet. Laminated marly sands constituting the basal portions of the loess, say 18 feet. Coarse sand or gravel (the equivalent of the upper till, which is here greatly modified) from 38 feet to, say, 48 feet. Muddy sand, etc. (forest bed) to 52 feet. Lower till, from 52 to 72 feet.

198. *Vandalia, Shelby County.*—Loess, 10 feet. Quicksand, 20 feet. Blue clay hard pan with wood and bowlders, 8 feet. Gravel and sand resting on rock, 14 feet.

The foregoing is a general section kindly communicated by G. W. Bassett, M. D., of Vandalia, who reports in addition that the forest bed is general, and that when penetrated gases are sometimes emitted with considerable force and noise. Personal observation here was unsatisfactory from the fact that no deep excavations were found. In the Vandalia coal shaft reported by Dr. Bassett to the Illinois Geological Survey[1] the aggregate thickness of the superficial deposits is considerably greater, though the succession is essentially the same. In the following section also, observed by Broadhead, the sequence is similar except that the homogeneous portion of the loess appears to be mainly absent and that the water bed was not reached.

199. *Near Vandalia.*—Red clay, with coarse sand and gravel below, 15 to 20 feet. Blue clay, 30 to 35 feet. "The blue clay is very hard

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[1] Vol. 6, p. 146.

and compact and contains small rounded pebbles." (Geological Survey of Illinois, vol. 6, pp. 137, 138.)

200. *Near Greenville, Bond County.*—"A shaft was sunk 87 feet to the rock, when the water broke in and checked any further work. The upper 10 feet passed through was yellow clay; below it blue clay extending to the bottom, becoming darker as they descended; at 25 feet a large lump of coal was found, and wood at 20 feet from the surface." (Geological Survey of Illinois, vol. 6, p. 130.)

SECTION VI.—RÉSUMÉ.

Of the 16,500 square miles of surface in Northeastern Iowa, a scant half is formed of glacial deposits and displays glacial configuration little modified by later water sculpture. Over nearly all of this area there are two well defined glacial deposits. Over something more than another quarter of Northeastern Iowa there are two practically continuous glacial deposits buried beneath a distinctive deposit—the loess; and over an area of a thousand square miles or so, one glacial deposit alone lies buried beneath the loess. This, in brief, is the distribution graphically represented elsewhere (Pl. XLIV).

The uppermost glacial deposit, which forms the surface over half of the territory, is a generally continuous ground moraine or sheet of bowlder clay, yellow, buff, or brown in color and interspersed with subangular or rounded and sometimes striated pebbles and bowlders, much the greater proportion of which came from far beyond the limits of the State; its surface not only exhibits characteristic ice molding, but is, particularly in the northwestern portion of the territory, dotted with immense granitic bowlders; its continuity is commonly interrupted only by post-glacial erosion along a few streams and by a few protruding crags of indurated rock, though it sometimes thins to a bare veneer upon the older deposit. The structure, like that of ice-formed deposits elsewhere, is fairly homogeneous in the large way, though heterogeneous in detail; and its thickness ranges from a veneer to probably 100 feet, averaging perhaps 20 feet. It is noteworthy that the element of pebbles and bowlders is much less than is commonly found in homologous deposits in northeastern United States, but that at the same time the bowlders reach exceptionally large dimensions. Thus the soil is so nearly free from pebbles as to yield readily to the plow, and the fields are easily cleared of other bowlders than the scattered granitic masses which are so large as to be quarried and constitute a valuable source of building material.

Toward its periphery in general, but particularly toward the south, the upper drift sheet undergoes modification; the superficial bowlders disappear, the materials become finer, the surface assumes a characteristic longitudinal ridging, the superficial portion passes into a loam, and the glacial deposit either grades upward into a superimposed mantle of loess or is overlain with a certain unconformity by that deposit, commonly with an intervening bed of intermediate character; and only rarely do local terminal moraines mark the margin of the deposit.

The lower till, or older glacial deposit, is the homologue of the upper and newer, and its distribution is much the same, though its continuity is more frequently broken. Its materials are much the same, though the prevailing color is blue and the alternative color brown; the pebbles are more numerous and smaller; there is a dearth of huge granitic bowlders, and there is throughout the mass a larger proportion of greenstones than in the newer deposit; and its thickness runs from a veneer to more than 200 feet, so that despite its more frequent and larger breaks of continuity its average thickness is perhaps twice that of the upper till.

There is a peripheral modification of this drift sheet more decided than that of the newer. Toward its margin it differentiates into a lower member much like the mass of the deposit in the interior, and an upper member consisting of clean plastic clay, sometimes laminated and bearing other indications of water-laying. There is also a more general division of the deposit into a main body of bowlder clay and an inferior bed of gravel, pebbles, cobbles, and bowlders. No traces of a terminal moraine are found about the margin of this drift sheet.

The older glacial deposit is seldom exposed save in artificial excavations; but these indicate that over half the area the deposit passes upward into a soil or bed of humus charged with remains of arboreal vegetation. The identifiable remains of the ancient trees are chiefly sticks, logs, and stems of coniferous woods; but fragments of other hard woods, and also impressions of leaves and traces of other vegetation are frequently found. The abundance of these vestiges of an ancient soil and its products are so abundant, so widely distributed, and so related to the indications of subsequent glaciation as to prove that the older drift sheet was covered with soil and largely clothed with forest before the later ice invasion commenced; and the indications are that the old soil was much thicker and the ancient flora much more luxuriant than those of to-day.

The older glacial deposit commonly rests either on the indurated rocks or on a mantle of residuary material derived therefrom; yet few and scant traces of antecedent vegetation have been found at its base. The general destruction of the ante-Pleistocene surface and the greater thickness of the inferior glacial deposit suggest that the earlier glaciation was the more energetic and the longer continued.

Toward the margin of the glaciated area, both drift sheets occasionally pass into local deposits exhibiting glacial structure, though made up largely of local materials which are found only in valleys; and these deposits and the associated land forms are supposed to indicate that the attenuated margin of the ice first filled and afterward rode across transverse valleys.

The whole of Northeastern Iowa lies beyond the great terminal moraine marking the limits of a certain later Pleistocene invasion; yet the greater part of the territory is mantled by two distinct ice deposits; and it is specially noteworthy that in general the two deposits rest respectively upon a disintegrated rock surface or an unconsolidated clay derived therefrom, and upon an old soil passing into an unconsolidated deposit. Elsewhere the continental ice sheets were commonly engines of rock destruction, and attacked and planed and striated the indurated rocks over which they passed; but here they were agents of construction, seldom reached the rocks over which they passed, and built deposits from materials transported from hundreds of miles beyond the limits of the region.

CHAPTER VIII.

THE ICE MARKINGS.

SECTION I.—THE GLACIAL STRIÆ.

At only one locality in the 1,400 glaciated square miles of Northeastern Iowa have glacial striæ been found. This locality is on the west side of the Iowa River, immediately opposite Iowa City. The 80-foot river bluffs here expose cliffs of Cedar Valley limestone to midheight of their rise, overlain by glacial drift, sometimes largely made up of local residua, as illustrated in Figs. 118 and 119. In places the drift rests upon little disturbed residua derived from decomposition of the subjacent rock; but elsewhere, particularly north of the upper bridge, the rock surface was bared and sometimes worn into pot holes before the deposition of the drift.

Here, too, the rock surface is frequently striated and polished, the ice-carved surface truncating the knobs and crests between the pot holes and thus diminishing their depth. The characters and relations of pot holes and associated striæ have been described and illustrated by Webster.[1] The direction of striation varies from south 65° east to south 70° east.[2] This direction is more easterly than the general direction of ice-flow in this part of the territory; but the striæ doubtless represent a late episode, when the ice was cut off above the North Liberty basin and the southlying lobes were thereby deflected eastward, as illustrated in the third tectonic mad forming Pl. LVII.

The dearth of striæ in the territory is not due to lack of observation; for thousands of contacts between drift and rock have been examined by a dozen trained geologists and scores of competent amateurs, always without success save in the single instance. Neither is the dearth of striæ due to decomposition of the rock surface and consequent obliteration of ice markings since the recession of the ice sheet; for the striæ and polish in the single locality are as fresh in appearance as those of other parts of northern United States, though the rock is no more obdurate than elsewhere in the territory. The firm dolomites of the Niagara and the hard, splintery

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[1] Am. Nat., 1888, vol. 22, pp. 408–419, Pl. v.

[2] These striæ were not found until long after the study of Northeastern Iowa was practically completed. They are interesting in that they corroborate other and far more voluminous and conclusive testimony concerning the direction of ice-flow over the territory.

limestones of the Cedar Valley formation are admirably adapted to the preservation of ice-markings, as shown by the condition of similar rocks elsewhere; yet here their faces are blank, and in scores of sections the relations between drift and geest are such as to prove that the older mantle was in essentially its present condition before the advent of the ice and the deposition of the drift. Indeed, it is evident to the student of the superficial phenomena of the territory that, however the ice may have plowed and planed rock surfaces elsewhere, here it generally rode over unconsolidated deposits and failed to reach the indurated strata below.

SECTION II.—ROCK MOLDING.

In several portions of the ridged drift area, notably in eastern Jackson and Clinton Counties, the uplands and divides exhibit the rounded forms characteristic of ice molding, while the lowlands and valleys exhibit the rugged and precipitous forms characteristic of water sculpture; and it is noteworthy that the evidently ice-molded belts are invariably elongated in easterly directions. Toward the driftward side of the drift border belt about Cresco; in northern Fayette County; between Dyersville and Rockville; in the Bear creek valley south of Baldwin and Nashville, and in many parts of the drift plain and ridged drift areas as well, where the entire surface is glaciated, knolls of rock rise from the general drift-covered surface. With the rounded contours characteristic of the *roches moutonnées* of the Swiss and the tors of the Scotch geologists, these knolls—veritable tors, though fashioned by constructive processes combined with the sweeping away of isolated crags and pinnacles rather than by energetic rock grinding—are generally elongated in easterly directions; and in nearly every case the westerly slopes display the more decided indications of ice work, in the removal of isolated crags and pinnacles, and in general smoothing without striation or polish of the surface. The prevailing trends of the ice-molded forms vary from place to place, yet are singularly consistent throughout the entire territory. The trends are sufficiently indicated by the tectonic maps, which are in part based upon the evidence of the roundbacked divides of the extreme drift margin and the isolated tors found just within.

A mile or two north of Farley, in the northwestern corner of Winneshiek County, and in several other localities about the drift margin in the northern half of the territory, obscure indications of ice molding diverging somewhat from the prevailing trend may be detected. This is notably the case at the first named locality in the NE. ¼ SW. ¼, Sec. 31, T. 89 N., R. 1 W., and in a larger way throughout the southern half of the same township. There is here a singular uniformity in the direction of the minor drainage making the principal member of the Little Maquoketa. The prevailing directions of gentle swells and deeper ravines occupied respectively by storm waters and by permanent streams is almost exactly southeasterly; yet the stoss sides of tors and the general trend of the drift molding in the vicinity indicate an ice flow not more than 5° or 10° south of east. There is some reason to believe that these obscure and erratic moldings, presumptively due to ice work, represent the earlier ice invasion of the Pleistocene and are coeval with the lower till; and the direction of ice flow which they indicate is consistent with the course of the earlier ice margin indicated by other phenomena.

Let it not be imagined that the ice molding of the divides reached by the ice or of the tors overwhelmed by it is conspicuous and unmistakable; for in truth the divides and knolls are but faintly impressed by the outlines of the ice mold and indicate that it ground only feebly and indolently when it ground at all; and the faintness of the ice molding is consistent with the dearth of ice grooving and polish.

SECTION III.—SURFACE MOLDING.

The general absence of striæ and the dearth of rock molding in Northeastern Iowa is richly compensated for in widespread and essentially unique molding of the land surface. This surface molding is notably distinctive and conspicuous in the ridged drift area; but the characteristic contours impressed upon the land by the ice are upon too generous scale to be clearly caught by the camera or well portrayed by the pencil; and they have been so far modified by post-Pleistocene erosion that the accurate topographic map fails to show the original graceful curves intuitively restored upon the ground by the actual beholder. Yet some of the ice-molded forms are fairly shown in the accompanying illustrations. A typical profile is shown in Pl. XL; the plan of typical paha appears in connection with the surrounding ice-molded surfaces in Pl. XLI; the characteristic corrugation of the ice-molded surface and several minor ridges (modified albeit by modern erosion) are represented upon smaller scale in the map of the hypsography of part of the ridged drift area forming Pl. XLIII; the elongated, curvilinear and slightly divergent ridging of the surface and the consequent symmetric determination of drainage of the southern-central part of the territory are imperfectly illustrated in the map showing the hypsography of Northeastern Iowa, in the stereogram constructed therefrom (Pls. XXX and III), as well as in the relief map of the same area (Pl. IV); but most clearly of all does the map of the superficial formations, forming Pl. XLIV, illustrate the distinctive ice-molding of the ridged drift area: for though but a part of the ice-fashioned ridges are loess mantled, the number is sufficient to illustrate the remarkable length, approximate parallelism, and systematic divergence of the positive forms left by the ice plow.

There is a distinction between the miniature molding displayed by the glaciated surface of a few square inches and the magnified molding displayed by a glaciated surface many square miles in extent—a distinction growing out of the wide difference in scale in connection with the varying part played by the graving tools clasped by the ice. If ground by clean ice, the hand specimen is simply smoothed and polished; if the ice is armed with sand grains, it is striated, each grain engraving a separate line; if the ice is armed with larger pebbles the surface is grooved, each pebble leaving an individual groove proportionate to its size; and commonly the armature of the ice is such that the hand specimen represents a series of positive forms (generally broad ridges) with polished crests, separated by fine striæ and narrow grooves; and the surface is approximately plane but interrupted by negative lines and grooves engraved within it.

But the countryside is ground by a sheet of ice which may be supposed uniformly armed with sand, pebbles, and bowlders, and the local effect of the armature may be disregarded. Other things equal, the surface is ground to a degree varying inversely with the obduracy of the material—soft rocks and materials making depressions, and hard rocks making eminences in the ice-attacked surface. Other things equal, the grinding is proportional to the thickness of the ice and the velocity of its motion, each ice lobe making a furrow, and each interlobate line making a ridge; and where the ice is thin in proportion to its extent—as was the case in Northeastern Iowa—the surface left by it represents a series of negative forms (usually broad valleys) with smooth bottoms dividing narrower ridges; and the surface is approximately plain, but interrupted by narrow ridges and shorter eminences embossed upon it. Thus the glaciated countryside is not simply an enlargement of the glaciated hand specimen, but rather a complement or negative on an enlarged scale; the elevated planes and polished ridges of the hand specimen are complementary to the lowlying planes and longitudinal troughs of the countryside; the striæ of the one are complementary to the paha of the other, and the miniature grooves in the one are complementary to the magnified river ridges of the other; but the mark of the ice mill is as distinctive and significant in the one case as in the other.

Throughout the ridged drift area of Northeastern Iowa, and to some extent in contiguous areas, the surface is reduced to a series of broad troughs separated by narrow ridges—more or less modified by hydrodynamic erosion, it is true, absolutely unique among the various types of configuration thus far known upon the earth's surface, it is true, yet unmistakably illustrating surface molding on a scale elsewhere unparalleled. The paha—the magnified complements of striæ—are huge hills, miles or scores of miles in length; the ice-smoothed planes—the magnified complements of finger-wide ridges in the pygmy illustration of ice work—form natural geographic divisions; and these magnified markings of the surface indicate the course of ice flow in Brobdignagian characters so clear and decisive that the student cares little for the absence of the Lilliputian striæ upon which great generalizations must rest elsewhere.

Although the record of ice flow in Northeastern Iowa is unique, it would seem to be trustworthy beyond those commonly employed in differently conditioned regions, in very nearly the ratio of relative magnitude of the characters; and if so, there is no other region in which the direction of ice flow may be so readily and reliably determined as in the one throughout which the common track of the glacier fails.

CHAPTER IX.

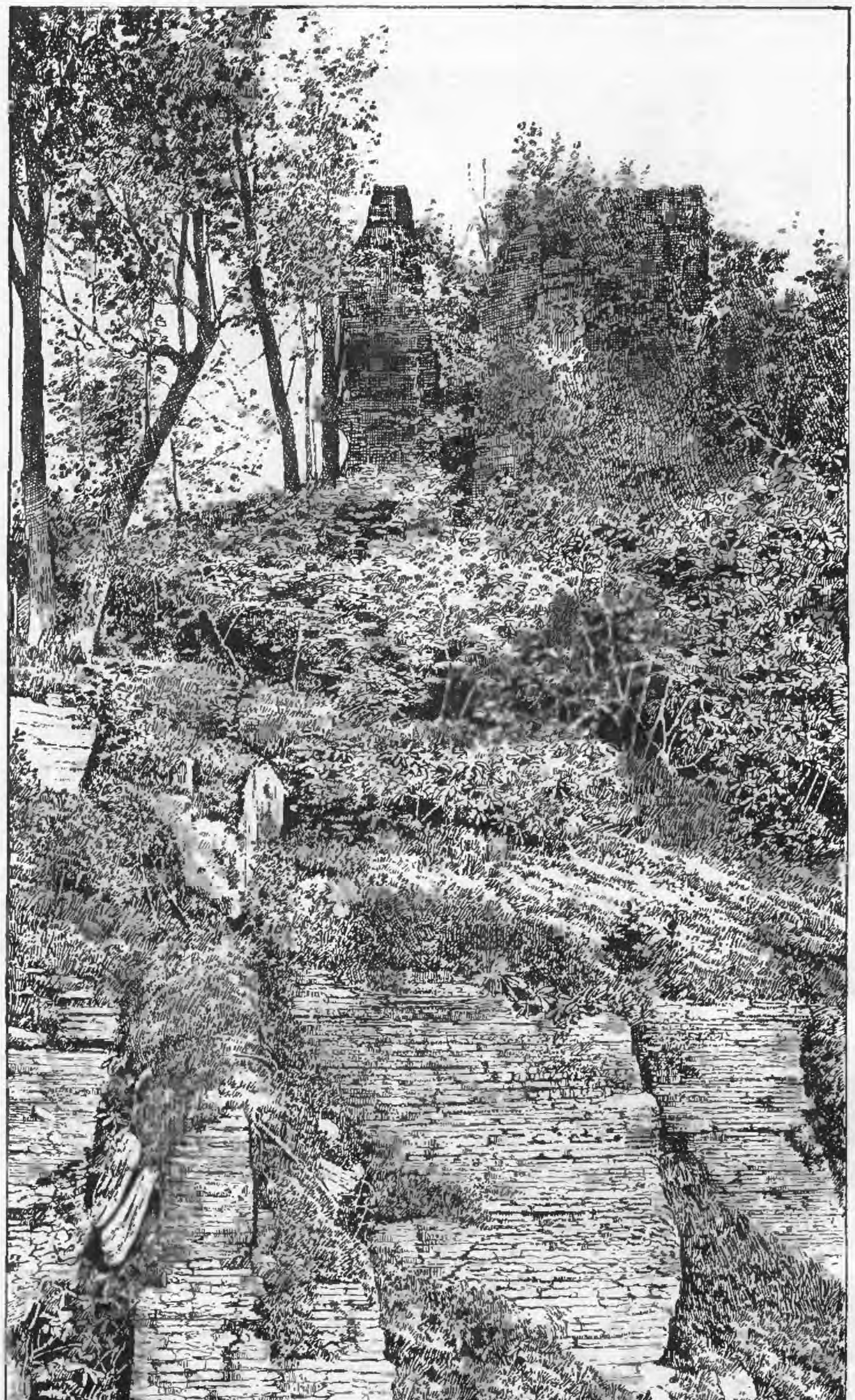
THE RESIDUARY PRODUCTS.

SECTION I.—THE GEEST OF THE DRIFTLESS AREA.

Throughout the driftless area the Paleozoic strata are generally overlain by a mantle of rock débris, which is itself overlain by loess. The characteristics of this mantle are dependent upon those of the rocks from which it was derived; yet certain characteristics are practically constant throughout the area. Thus, where undisturbed it rests upon a rugose and deeply-ravined rock surface, contains siliceous nodules and, occasionally, silicified fossils distributed as in the ledges it represents; it is notably ferruginous, and, in its lower portion at least, exhibits structure lines corresponding to the original bedding.

The Potsdam, Oneota, and St. Peter terranes constitute a narrow zone of high hills and sharply incised ravines; the residua left on the decay of their friable sandstones, sandy shales, and more obdurate dolomites, consist chiefly of sandy and little-coherent clays and sometimes almost wholly of sand; and by reason of the steepness of the slopes and incoherence of the materials, the prevailing mantle of rock débris is here interrupted and hangs about the slopes and over the narrow crests in shreds and patches, and bare rock stands forth in every cliff and hillside. It is only over the divides formed by the Oneota limestone that the geest attains notable volume or represents the product of complete decomposition. In central Alamakee County it is well developed over the divides between the Oneota and Village Creek, and also on the headwaters of Paint Creek, which takes its name from local ocherous phases of the geest. It is a moderately tenacious, but always somewhat sandy red clay, with disseminated nodules of chert; and in some localities, particularly 3 miles northeast of Waukon, the iron, by which it is everywhere stained, is accumulated in exceptional quantity in plates, pipes, and irregular nodules of limonite.

The argillaceous or pure limestone forming the greater part of the Trenton terrane appears to be less deeply covered with geest than are the dolomites of the Galena and Niagara—partly no doubt by reason of the strong relief in the region of its outcrop, but chiefly because of its greater solubility and the proportionally less volume



EROSION TOWERS OF TRENTON LIMESTONE, NEAR TURKEY RIVER.

of the residuum left on decomposition. Accordingly, pinnacles and crags rise not only above the surface but even above the tops of the trees by which the surface is clothed, as in Pl. LIII, particularly toward the greater waterways; while smooth rock surfaces may lie within reach of the plow over considerable areas in the interior. The material of the geest over this terrane is commonly a dense, tenacious red clay or lithomarge. This clay appears to be as richly charged with iron as that yielded by the dolomites above and below, yet, probably by reason of the impermeability of the compact mass, the mineral is seldom definitely segregated. The ordinary stratigraphic relation of the clay is exhibited in Fig. 104, representing a road-

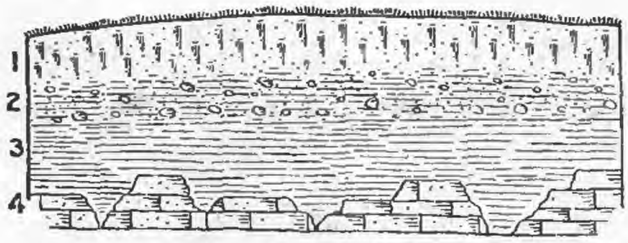


FIG. 104.—Typical exposure of residuary clays of the Trenton terrane, Allamakee County: (1) Dark, loamy loess; (2) pebbly loam, containing both local and erratic pebbles; (3) brown clay, plastic, tenacious, becoming granular on drying; (4) Trenton limestone. Exposure, 6 feet.

cutting in SW. ¼ NW. ¼, Sec. 31, T. 97 N., R. 6 W., Allamakee County.

The common product of the disintegration of the Trenton and Maquoketa shales is a tenacious clay, blue, buff, white, drab, orange, or brown in color; but the residua are sometimes discriminated only with difficulty from the clays of which these formations locally consist. The fully decomposed residuum may generally be recognized, however, by a peculiar granular texture exhibited on drying, and in good exposures by a dark line marking its base. The Trenton and Maquoketa terranes are generally overlain by loess, and the loess and the residuary clays sometimes intergrade in such manner as to indicate that the former is in part made up of materials derived from the latter; but in the section represented in Fig. 105 the pebbly

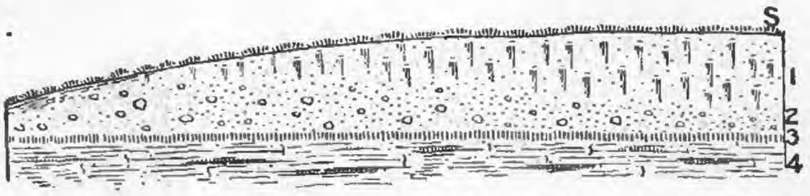


FIG. 105.—Unconformity between loess and residuary clays, Clayton County: (1) Loess; (2) reddish brown sand and gravel containing local and erratic pebbles up to 3 inches in diameter; (3) an ocherous line weathering into earthy limonite; (4) light buff jointed clay, containing ferruginous nodules, with jointage planes stained brown. Exposure, 6 feet.

basal stratum of the loess is clearly separated from the clays by an ocherous band doubtless representing an ancient surface; and the subjacent clays are mottled with brown stains running down from this band to the base of the exposure, and spreading laterally along certain lines probably representing original bedding. This section is exposed in a road-cutting in the SE. ¼ NW. ¼, Sec. 34, T. 94 N., R. 5 W., Clayton County. In an otherwise similar exposure in the NW. ¼ SE. ¼, Sec. 15, T. 92 N., R. 3 W., in the same county, the sand and gravel stratum is quite absent, the ocherous band less distinct, and the loess reposes directly upon a mass of bluish white clay which, 4 or 5 feet beneath its summit, yielded numberless small spherical or flattened concretions formed around the calcareous shells of Maquoketa brachiopods and cephalopods.

Throughout the Galena terrane the dolomites are everywhere concealed beneath a heavy bed of tenacious red clay, except in the ravines and gorges of the waterways and in the precipitous cliffs by which they are overlooked. This clay is commonly sand-free and homogeneous, and on partial drying exhibits finely jointed or granular structure, the jointed surfaces being sometimes lustrous or glossy. On complete drying, the clay crumbles readily into a mass of cubical or irregularly angular grains, themselves not readily pulverulent. When the granular texture is destroyed by freezing and thawing or by other means, the clay becomes plastic and extremely tenacious when wet, and firm and compact when dry, like the "gumbo, of Muscatine County and the southwest. This clay is identical in appearance and texture with that found beneath the stalagmitic floor in the limestone caverns and in the deeper fissures of the lead region in Iowa, Wisconsin, and Illinois. Sometimes it contains nodules of chert and crystals of galenite, as well as bands, plates, pipes, and irregular nodules of earthy limonite and pockets of red ocher. In some localities the galenite is so abundantly distributed that the "clay diggings" of eastern Dubuque County were at one time famous. The relation of the clay to the magnesian limestone from which it was derived is illustrated in the accompanying Fig. 106, exposed in a quarry on Eagle Point in the northern part of

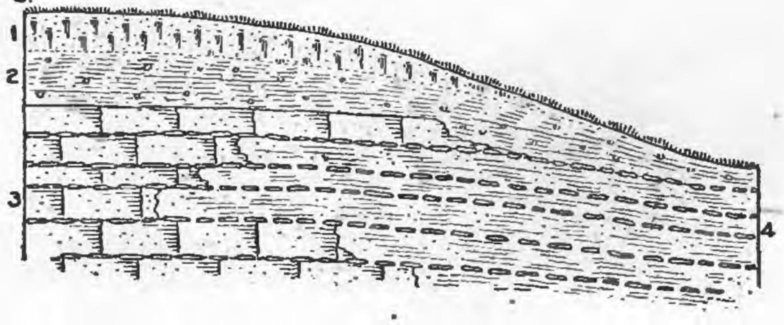


FIG. 106.—Residuary clays of the galena limestone, Dubuque: (1) Somewhat sandy and clayey loess; (2) obscurely stratified red loam containing chert, rounded fragments of limestone, and a few erratic pebbles; (3) Galena limestone with elongated nodules and plates of chert at partings; (4) red clay, finely jointed, with nodules and plates of chert in lines corresponding to those of the rock. Exposure, 9 feet.

Dubuque. This section is of interest in that it indicates the relative thickness of the residua and of the original strata. The thicknesses of the second, third, and fourth ledges (from bottom) of limestone and of the corresponding layers of clay are respectively as follows·

Limestone.	Clay.
Inches.	*Inches.*
16	14
13	10
12	9
41	33

Thus the limestone (here somewhat sandy and so less pure than the average) appears to have lost only 20 per cent of its volume on decomposition; and the total loss in volume of the entire mass of dolomite and chert is still less, since the latter element remains intact.

In general, the surface of the Galena geest, like that derived from other formations, is more or less disturbed and its materials are intermingled with superjacent deposits, as illustrated in Fig. 107, ob-

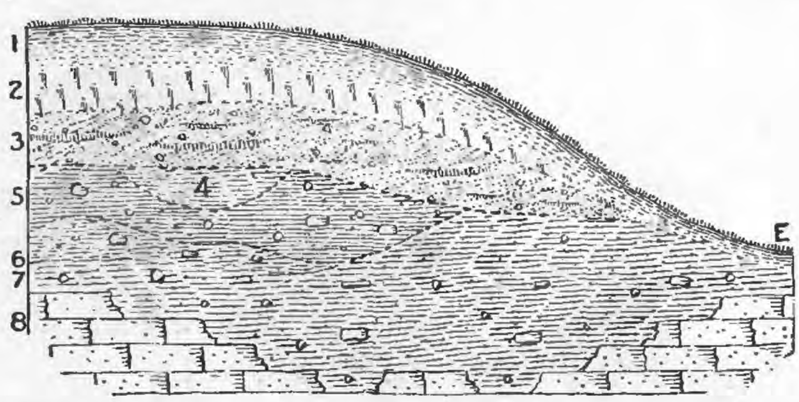


FIG. 107.—Residuary clays of the Galena limestone, Dubuque: (1) Surface soil; (2) slate-colored loess; (3) stratified and cross laminated sand; (4) hard calcareous white clay; (5) tenacious red clay containing fragments of chert and small blocks of limestone; (6) similar clay, brown and even black, flecked and streaked with white; (7) red clay, similar to 5, containing fragments of chert and somewhat worn bits of limestone; (8) Galena limestone. Exposure, 18 feet.

served on the east side of the ravine running south from Linnwood Cemetery, Dubuque. Here the loess is sandy and passes down into stratified and cross-laminated sand containing a few local pebbles and in part cemented by iron oxide; this sand rests in part upon undisturbed residuary clays, in part upon a mass of similar but evidently redeposited clays containing a few erratic pebbles, and in part upon an irregular pocket of residuary clay unlike that beneath, and evidently transported some yards or rods. Fig. 108, illustrating a section observed half a mile north of Elkader, is representative of the sections exposed in roadside gullies. Here the upper portion of the residuary clay is deeply ferruginated and irregularly eroded, and the nearly pure lithomarge of which it in part consists disappears on weathering, leaving thin but firm crusts of dark brown limonite either in the form of irregular nodules or coating the subjacent

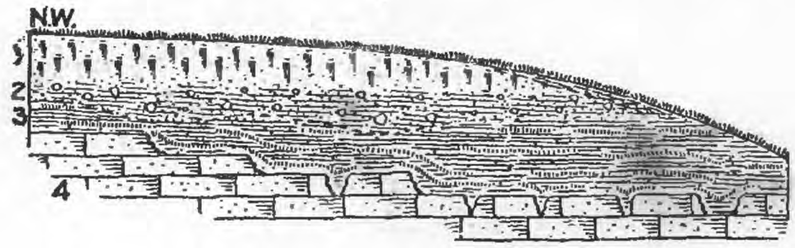
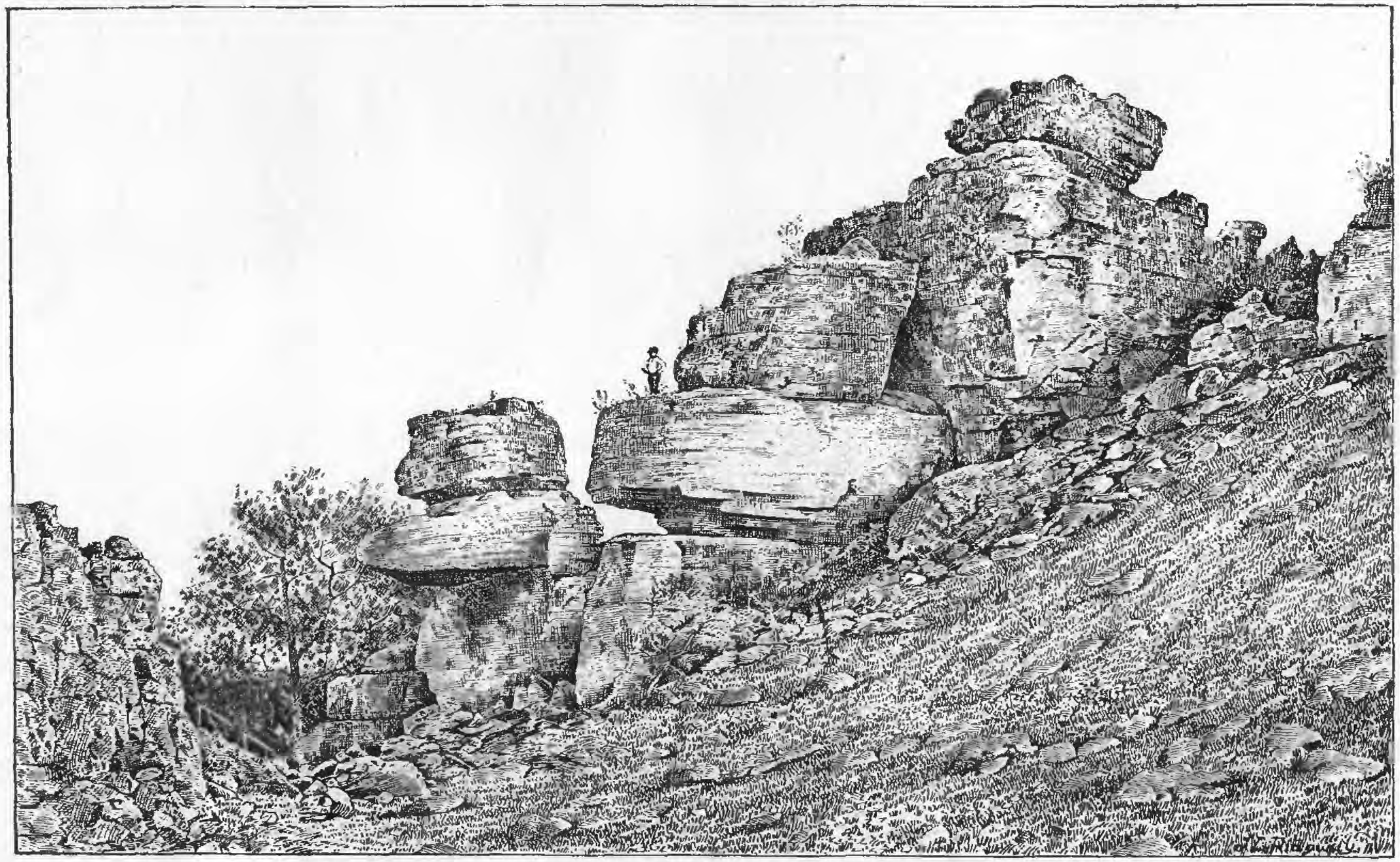


FIG. 108.—Typical exposure of residuary clays of the Galena, Elkader; (1) Brownish loamy loess; (2) reddish sandy clay containing nodules and spalls of chert and rounded and subangular fragments of both local and erratic rocks; (3) unctuous red clay marked by brown and white streaks conforming roughly to underlying rock surface; (4) Galena limestone. Exposure, 6 feet.

rock surfaces. Along the larger waterways the Galena dolomites have been bared by erosion and crop out through the mantle of geest in great crags and cliffs. Types of these are illustrated in Pl. LIV and Fig. 109.

FIG. 109.—Cliff of Galena limestone, near Dubuque.

Although the Niagara terrane is sheeted with glacial drift throughout nearly the whole of its extent in the territory, there is ample



CRAGS OF GALENA LIMESTONE, MINERAL STREET, DUBUQUE.

evidence that its surface was deeply decayed before the ice invasion. The relation of the residua formed by this decay of the loess was clearly exhibited in a well in the NE. $\frac{1}{4}$ SW. $\frac{1}{4}$, Sec. 32, T. 89 N., R. 1 W., Dubuque County, illustrated in Fig. 110. Here the loess forming the upper part of the section exhibits the features normal to the driftless area. It passes below into stratified and cross-laminated sand. This sand rests upon an irregular ferruginous band, evidently representing an ancient surface. Below this line there is found dense, homogeneous, plastic red or brown clay, with a few disseminated nodules of chert; toward its base regular bands of cherty nodules divide the clay into layers corresponding to the ledges of limestone exposed still lower, the considerable inclination of the strata being quite local, and of no special significance. Like relations are exhibited in a railway cutting in the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$, Sec. 18, T. 84 N., R. 1 E., Jackson County, as illustrated in Fig. 111. Here again there is a well-marked plane of division between the sandy loess above and the geest below; and here, too, coarser drift deposits are lacking.

In this part of the terrane (i.e., toward the Niagara escarpment in Jackson and Dubuque Counties) the basal portion of the clay may be a nearly pure ocher or lithomarge; within it considerable quantities of limonite are occasionally accumulated in bands or nodules. In pioneer days this limonite was sometimes wrought in a small way, and is even now occasionally reduced in ordinary blacksmith's forges; but the quantity is insufficient for systematic exploitation, although it is sometimes found filling rock cavities or even lying loosely upon the surface where the rocks have been laid bare by erosion in such amount as to excite prospectors. The limo-

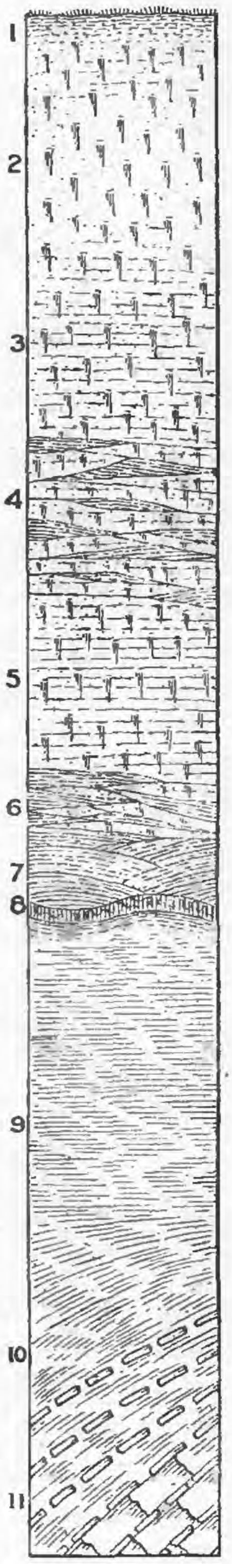


FIG. 110.—Well section exhibiting relation between loess, residuary clay, and Niagara limestone, Dubuque County: (1) Surface soil passing into loess, 2 feet; (2) fine clean homogeneous, and perfectly unstratified buff-colored loess, 4 feet; (3) the same faintly laminated, 3½ feet; (4) the same interlaminated with bluish lines, the buff predominating, 3 feet; (5) the same as in 3, but more distinctly laminated, 2 feet; (6) the same as 4, but with the blue predominating, 2 feet; (7) the same, slightly coarser in texture, especially at base, more distinctly laminated, and wholly blue, 2½ feet (6 and 7 contain cylindrical ferruginous concretions); (8) a thin band of iron oxide, pretty firm above, incoherent and ocherous medially and less firm below than above, with brown stains passing downward several inches; (9) clean, red granular clay, dark and structureless for 2 feet at top, horizontally laminated below (generally obscurely, but toward the base more distinctly), 9 feet; (10) red granular clay in oblique layers separated by cherty or ferruginous partings above, and by heavy lines of chert below, 5 feet; (11) Niagara limestone, with heavy partings of chert.

nites of this character were first examined by Whitney in 1858; and it was by him supposed that the iron was originally distributed irregularly throughout the dolomites in the form of nodules of pyrites. It is true that the ore masses sometimes contain nuclei of sulphide of iron or are even pseudomorphs after that mineral; but it is evident that portions of the iron were originally disseminated

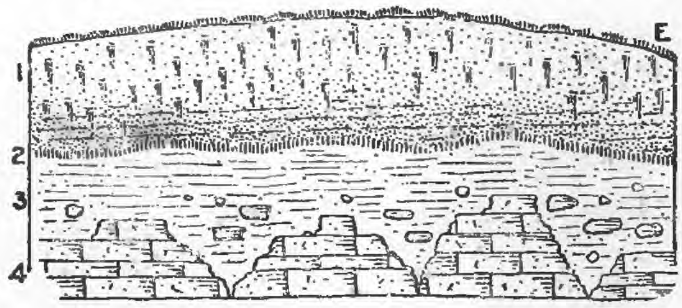


FIG. 111.—Unconformity between loess and residuary clays. Jackson County: (1) Loess, stratified and sandy at base; (2) an ocherous band, forming a firm crust above but passing into the clay below, indurating on exposure so as to form a projecting crust or ledge which eventually breaks off and becomes imbedded in the talus; (3) red granular clay, flecked and streaked with brown, passing into lithomarge in cavities, containing a few nodules of chert and fragments of limestone; (4) Niagara limestone. Exposure, 16 feet.

throughout the rock and underwent segregation after the decomposition of the rock; for an indefinite number of gradations between the slightly ferruginous undecomposed rock, the residuary clays in chert-divided layers corresponding to the original ledges, the same clays more deeply ferruginated, ocher and lithomarge, hollow nodules of impure limonite, and solid masses of ore, may readily be observed.

When glacial drift is superimposed upon geest about the margin of the driftless area, the two deposits may or may not be distinct. In the section shown in Fig. 112 (exposed in a railway cutting half

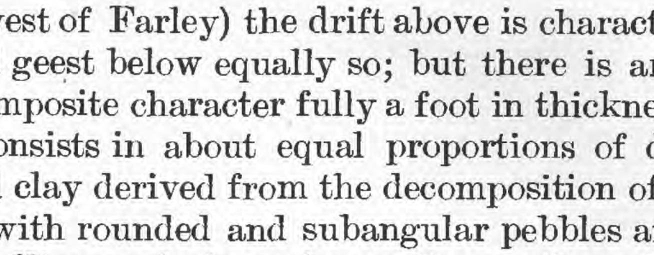


FIG. 112.—Apparent transition between drift and residuary clays, Farley: (1) Unmodified glacial drift; (2) compact red clay charged with nodules and spalls of chert. Exposure, 9 feet.

a mile southwest of Farley) the drift above is characteristic and the chert-charged geest below equally so; but there is an intermediate stratum of composite character fully a foot in thickness. This composite band consists in about equal proportions of drift materials and of the red clay derived from the decomposition of the dolomite; it is charged with rounded and subangular pebbles and small bowlders of crystalline rock from far to the northward from base to summit, but nodules and spalls of chert from the subjacent strata are still more abundant; and the sandy drift clays and the rounded erratics decrease and the sand-free residuary clay and cherty débris increase downward so gradually that it is impossible to demark the deposit save by a purely arbitrary line. And this is by no means an isolated case. In northeastern Delaware County and in western Dubuque County, in southern Jackson and northern Clinton Counties, the Niagara formation is frequently made up largely of chert either segregated in abundant nodules or accumulated in definite ledges alternating with dolomite; and on complete decay of the dolomitic matter the nodules and layers of chert break up into sharply angular chips and spalls, and thus become imbedded in a matrix of tenacious red clay sometimes so meager as barely to fill the interstices. These masses of chert or cherty clay are exceedingly obdurate; they are much more difficult of removal in making roadways or excavating wells than solid rock; they sometimes form natural roadbeds which have borne the traffic of the country ever since its first settlement without yielding perceptibly to the beating of hoofs or the grinding of wheels; yet into these obdurate masses the ice-sheet by some means insinuated itself and pushed its bowlders and pebbles to such an extent that it is impossible to say where the disturbed residuum ends and the undisturbed mass begins. Two miles north of Farley, just at the north line of T. 88 N., R. 1 W., shallow road-cuttings excavated at great cost in such a chert mass exhibit pebbles and bowlders up to 1½ feet in diameter partially or wholly imbedded within, and sometimes buried as much as 2 feet below the surface of, the intractable terrane. Half a mile farther north, where the matrix of clay is more abundant, bowlders were found in wells 3 or 4 feet below the summit of a cherty mass which would have otherwise been regarded as undisturbed. Here the geest is 10 to 20 feet in thickness, and the clays are charged not only with chert but with silicified fossils characteristic of the Niagara formation; and it is noteworthy that the fossils were found in nearly as great perfection above as below the deepest bowlder in one of the wells. Elsewhere, however, the ice-plow appears to have slipped over the clays, even where they are not stiffened by chert but remain plastic, without materially affecting their composition and structure. Thus, in

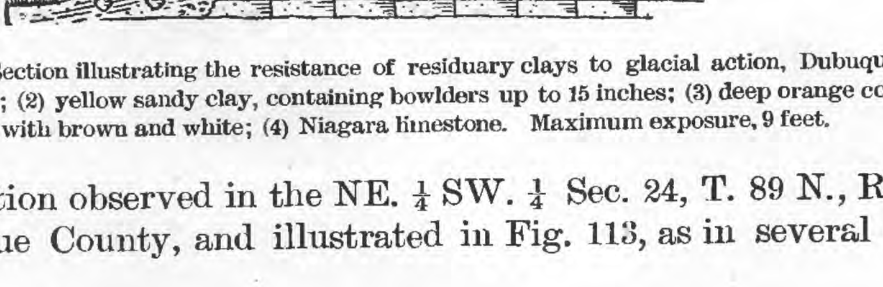


FIG. 113.—Section illustrating the resistance of residuary clays to glacial action, Dubuque County: (1) Loess; (2) yellow sandy clay, containing bowlders up to 15 inches; (3) deep orange colored clay streaked with brown and white; (4) Niagara limestone. Maximum exposure, 9 feet.

the section observed in the NE. ¼ SW. ¼ Sec. 24, T. 89 N., R. 2 W., Dubuque County, and illustrated in Fig. 113, as in several others, the clay is sand-free, granular but easily made plastic by kneading when wet, and spotted and streaked with iron stains, perhaps indicating either original structure lines or lines of progressive decay; but although the mass has undoubtedly been partly removed, the remnant is quite undisturbed, distinctly parted from the superjacent drift, and its surface quite unmarked.

In some cases the work of the ice-plow is definitely recorded in the crumpling and distortion of the partially or wholly disintegrated strata over which it pushed. Fig. 114 represents a section exposed

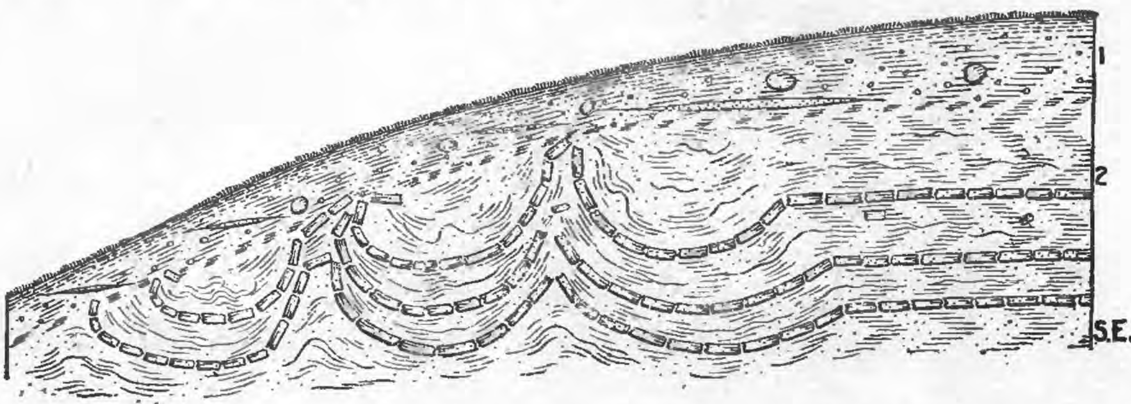


FIG. 114.—Deformation of residuary clays by glacial action, Delaware: (1) Soil, passing into sandy brownish yellow clay containing erratic pebbles and bowlders with a few bits of local chert; (2) compact red clay with nodules and spalls of chert and three definite beds of the same material, contorted. Exposure, 12 feet.

in a railway cutting a mile north of Delaware, in which the plane of contact between drift above and geest below is indistinct, yet in which the whole subjacent mass was thrust upon itself, compressed longitudinally and at the same time crumpled and contorted as indicated by the disturbed siliceous ledges representing original stratification. It is noteworthy that such witnesses to the energy of ice-work increase in number and in the eloquence of their testimony northwestward; and one such, observed far beyond the limits of Northeastern Iowa, is introduced for comparison (Fig. 115). It is

FIG. 115.—Section in St. Paul exhibiting deformation of Paleozoic clays by glacial action: (1) Surface soil and débris from slope; (2) gray or ash colored loamy clay with a few small erratics and numerous angular and subangular fragments of Trenton limestone varying in abundance in different parts as shown; (3) compact orange and chocolate-colored clay, with much-worn erratic pebbles; (4) jointed blue or bluish buff clay containing Trenton fossils. Maximum height of exposure, 15 feet; length. 60 feet.

revealed on the east side of Huffman avenue, between Second and Third streets, St. Paul, Minnesota. The materials beneath the drift are not, indeed, strictly residuary, in that they represent a non-indurated bed of clay within the lower part of the Trenton limestone, and have suffered little if any weathering. A few yards distant the same clay bed yielded abundant characteristic Trenton fossils (*Orthis testudinaria*, *Rhynchonella capax*, *Murchisonia milleri*, and numerous specimens of *Chætetes* representing two or three species). The divisions numbered 2 and 3, respectively, are both of glacial origin, yet quite distinct.

Although nearly the entire Niagara terrane is drift-sheeted, a few slender salients and isolated knobs lie beyond the drift margin; and in such outliers the dolomite, like that of the Galena, is often weathered into castellated crags and pinnacles along the water-ways, as illustrated in Fig. 116.

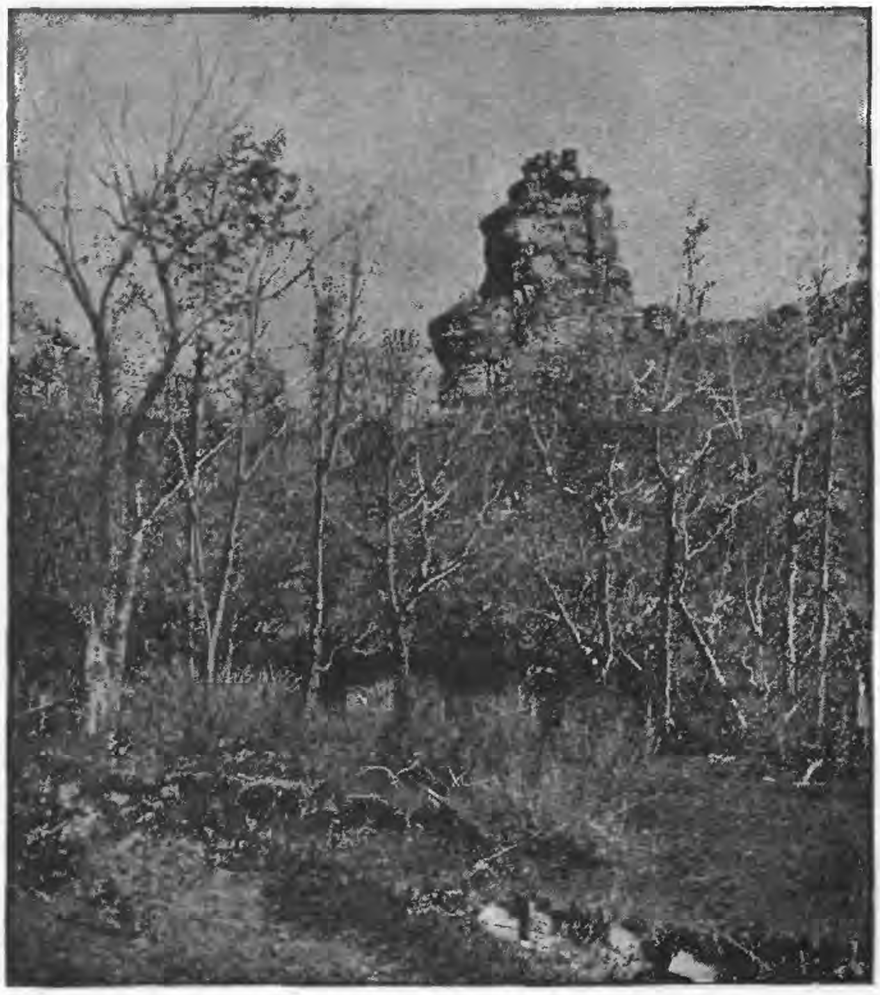


FIG. 116.—Castellated crag on Little Maquoketa River, Dubuque County.

The Cedar Valley limestones have everywhere suffered glaciation and are generally overlain by drift, and seldom exhibit the products of secular decay. So far as seen the prevailing product is a tenacious clay, generally deep red or dark brown; but sometimes the iron is segregated in ocherous nodules or pockets, when the surrounding clay may be lighter or even whitish in color. In the section illustrated in Fig. 117, representing the "stripping" of a quarry near Osage (NW. ¼ NW. ¼, Sec. 35, T. 98 N., R. 17 W.) the clay is not decidedly ferruginous, and contains a small amount of disseminated siliceous matter derived from the parent rock, and so is less dense

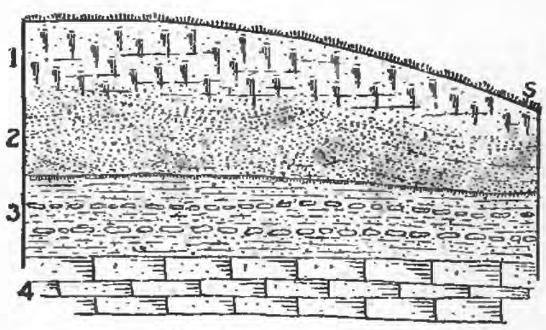


FIG. 117.—Residuary clays of the Cedar Valley terrane, near Osage: (1) Loess, obscurely laminated below; (2) fine sand, buff, gray, golden yellow, and yellowish brown in color, faintly cross-stratified; (3) light orange-colored clay, with discontinuous siliceous bands marking original bedding planes; (4) Cedar Valley limestone. Exposure, 17 feet.

and compact than the prevailing residua of the Galena and Trenton formations. It exhibits a ferruginous line at its summit, apparently representing an ancient surface, and so would appear to have been undisturbed by the later ice sheet. Measurements made in two contiguous sections here indicate that the volume of the layers of clay between the lines of siliceous nodules is but 60 per cent of that of the ledges they represent.

Well differentiated residua have not been observed over the terranes newer than the Cedar Valley limestone.

The products of secular decay in the terranes of the territory were evidently accumulated in considerable volume before the Pleistocene ice invasion, and contributed materially to the volume of the glacial deposits. The wealth of this contribution can seldom be determined even approximately, because the finer materials of local and erratic origin either are alike or can not be discriminated by reason of the fineness of comminution; but upon the Niagara terrane some idea of the relative volume of local erratic materials may be formed from the abundance of the indestructible chert; and in some other cases the glacier only partially kneaded the residua over which it ran without destroying all of their characters, so that the local clays may be recognized either in bowlders or as beds within the glacial deposits. Such a case is illustrated in Fig. 118, representing a section on the west side of the Iowa River below the upper bridge at Iowa City. Here the great mass of clay overlying the rock is jointed and exhibits a peculiar granular texture characteristic of the residuary clays in general; yet lenticular sheets of sand and erratic gravel and striated pebbles and bowlders are distributed through it in diminishing abundance from the summit to within a few inches of the subjacent limestone. Practically the whole of the mass is unquestionably glacial drift; yet its principal element is geest, perhaps not far removed from its original situation. This section is intermediate

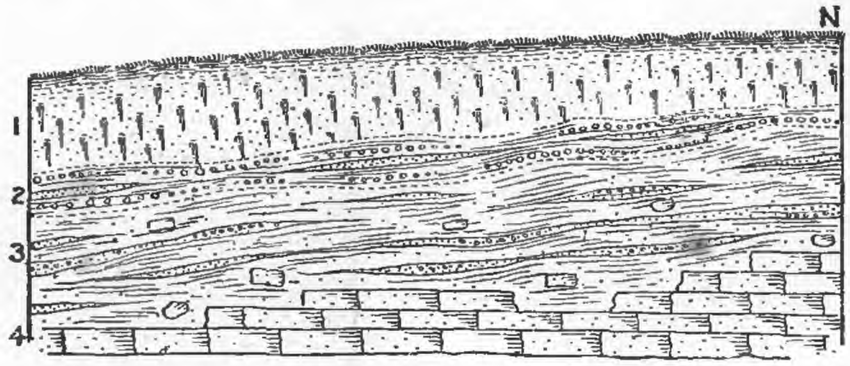


FIG. 118.—Section at Iowa City illustrating partial incorporation of residuary clays in glacial drift: (1) Brown surface soil passing into loess; (2) coarse sand, gravel, and pebbles, irregularly stratified; (3) jointed clay containing a few scattered pebbles, interstratified with fine sand; (4) Devonian limestone. Exposure, 18 feet.

between one in the neighborbood in which the surface was first washed into pot holes and subsequently striated by the ice sheet, as noted elsewhere,[1] and that illustrated in Fig. 119, observed in the same

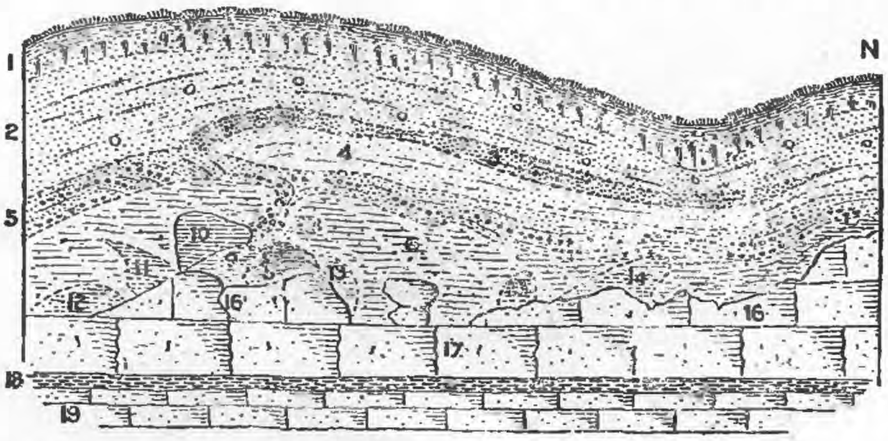


FIG. 119.—Section at Iowa City illustrating relation between residuary clays and glacial drift: (1) Loess-like soil, increasing to 8 feet in thickness farther north in the same quarry; (2) partially cemented reddish brown sand, obscurely laminated, of medium fineness, with an occasional local pebble, weathering first to brownish red and becoming more firmly cemented, then to dark brown and becoming incoherent; (3) the same, coarser and darker; (4) the same, finer than either of the last; (5) coarse red sand gravel of both local and erratic constituents, distinctly laminated, with a prolongation downward; (6) irregularly jointed clay with a little fine sand disseminated throughout, generally brownish buff in color, and with faint traces of lamination in the northern part of the exposure; (7) clean granular black clay, apparently highly corbonaceous; (8) red sand, much like 2; (9) fine white jointed clay; (10) fine and clean horizontally laminated yellow clay; (11, 12, 13, and 14) clean and plastic or granular clay or lithomarge, dark brown or reddish brown; (15) orange-red sand, like 8 and 2; (16) irregular masses of Cedar Valley limestone; (17) a smooth heavy ledge of the same, (18) black bituminous shale, forming a thin parting; (19) medium ledges of the same. Height of exposure, 20 feet; length, 60 feet.

bluff face but below the lower bridge. In the last section the mass of the jointed clay is commonly homogeneous and uniform and without conspicuous horizontal structure; but in its upper portion erratic pebbles occasionally appear. The lower portion of the bed is, how-

[1] Cf. Webster, Am. Nat., 1888, vol. 22, pp. 408–419, pl. v.

ever, made up largely of immediate products of rock decay, little if at all disturbed by glacial action, as indicated by the presence of the pockets of distinctive materials indicated in the figure; yet here, as in other cases, it is impossible definitely to demark the disturbed and undisturbed portions of the geest.

Toward the drift margin in the northern part of the territory, certain puzzling accumulations occasionally lie beneath the well-characterized glacial deposits, commonly as isolated remnants of a rock mantle wrapped around the bases of knobs, lining depressions and filling crevices of the subjacent Niagara limestone; the structural relations being those of the ordinary residua, while the composition differs in the essential particular that pebbles of quartz, jasper, etc., are more or less abundantly disseminated through the mass, which is sometimes cemented by iron. A representative section, observed in the northeastern part of Dyersville, is introduced in Fig. 120. Here the materials are semi-indurated, and rounded fragments are incorporated in the overlying lower till as pebbles and bowlders. Analogous exposures have been observed in Delaware, Fayette, Chickasaw, and Howard Counties. The presence of northern rocks in the form of much worn pebbles suggests glacial origin,[1] but anterior to the first ice invasion of the Pleistocene. Since the erratic material is similar to that found in the Rockville conglomerate, it would seem more probable that the accumulation is a slightly rearranged re-

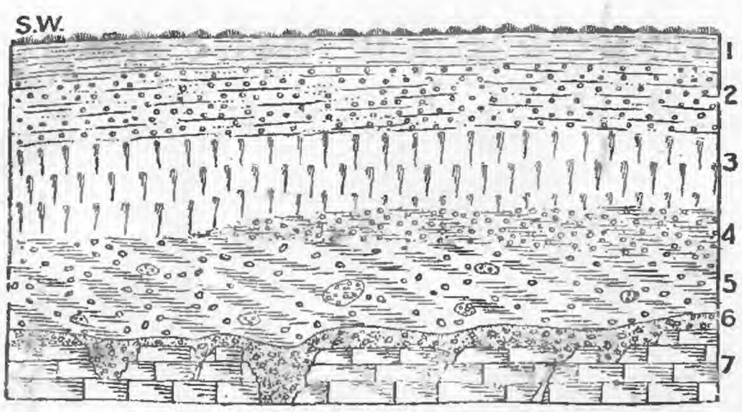


FIG. 120.—Pebbly residuary accumulation, Dyersville: (1) Yellowish sandy and pebbly alluvium, probably formed since the erection of a neighboring dam, 15 inches; (2) brown and black sandy and pebbly alluvium, partially stratified, 5 feet; (3) light buff loess, possibly redeposited, 5 feet; (4) yellow sandy gravelly and pebbly clay, 2 feet; (5) compact blue clay with a few hornblendic pebbles and small masses of puddingstone irregularly scattered through it (lower till), 5 feet; (6) imperfectly cemented brown puddingstone of quartz, chert, and jasper pebbles and coarse quartz sand in a matrix of earthy limonite, becoming nearly clean and passing into brown granular clay in places, 1 to 3 feet; (7) Niagara limestone.

siduum of both the Cretaceous conglomerate and the Silurian limestone, the pebbles being derived from the former and the matrix mainly from the latter.

[1] This view was stated in Geological Mag., N. S., Decade II, 1879, vol. 6, p. 353.

The general increase in the volume of residuary products in passing from north to south is not exhibited under the limited range in latitude of Northeastern Iowa; but it is conspicuous when the phenomena of this territory are compared with those of other latitudes under the same meridian. In central Minnesota, as indicated by Fig. 115, the clays commonly found beneath the drift are not truly residuary, and in the northern part of the driftless area in Wisconsin and Minnesota the veritable residuary clays are commonly of limited volume; in the southern part of the same area in Iowa and Illinois the volume is notably greater; and still further southward, beyond the limits of glaciation, the volume is still greater.

No analyses of the geest of Northeastern Iowa have been made. It suffices to say that, as shown by Russell, the chemic composition of residua generally varies with the rock from which they are derived.[1] The physical characteristics of the residuary products of the driftless area have been well set forth by Chamberlin and Salisbury.[2]

It is noteworthy that the chemic and physical differences between the residua of formations are much less than among the formations themselves—sandstones, pure limestones, dolomites, and shales all yielding clays which sometimes correspond fairly, both in composition and physical characters.

SECTION II.—THE HISTORY RECORDED IN THE RESIDUARY PRODUCTS.

Certain conditions are essential to the secular decay of rocks and the transformation of the solid strata of the earth into unconsolidated earth; but all of these conditions are related and some of them interdependent in such manner that it is difficult if not impossible to determine the efficiency of each from the joint product.

The primary and essential condition is time. Polished marble and granite retain their surfaces for decades or generations, and the blocks themselves remain intact for centuries or milleniums; the rock scorings and polish of the last ice invasion are in many localities as fresh as when the ice melted away from them thousands of years ago; many roadside cliffs and more distant mountain peaks have been observed by successive generations of men since the birth of history, and no change in their form or height has been noted; and so well does the rock resist destructive processes that it has come to be accepted as an emblem of stability and permanence. Yet if sufficient time be given the rock decays as completely as the most perishable tissue; and the rocks of the earth have decayed in such volume that the products of their destruction mantle the continents and line the sea bottoms. So any accumulation of residuary products is proof of a long period of accumulation.

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[1] Bull. U.S. Geol. Surv., No. 52, 1889.

[2] U.S. Geol. Surv., Sixth Ann. Rept., 1885, p. 240.

A secondary but equally essential condition is that the surface of decay shall be land surface and subject to the action of the air, to change of temperature, and to percolating air and ground-water. Upon the bottoms of lakes and seas sediments are laid down, and the subjacent rock surface is protected from decay and perhaps altered in an antagonistic direction; the rocks rising above sea level but covered by newer formations or other accumulations are thereby protected, and if the covering is thick they escape attack by the agents of destruction. Everywhere the activity with which rock decay progresses depends upon the exposure of the rocks and the absence of protective covering. So the presence of residuary products is proof that the region in which they were formed was a land surface during the period of their formation.

A subordinate condition, but one essential to the accumulation of residuary products in large volume, is that the climate shall be warm and humid. In the tropics rocks are concealed save in the steepest mountain sides by a coating of their own débris; throughout the lower latitudes the products of rock decay are accumulated in greatest volume, reaching thicknesses of scores if not hundreds of feet; in the middle latitudes the volume of such products is notably less, and bare rock surfaces are notably more common; while in certain high latitude localities in which the climate is cold and the precipitation limited (e. g., in Labrador) the rock surfaces left bare upon the withdrawal of the last ice-sheet are concealed by frost-scattered fragments with scarcely a trace of completely decomposed rock. Everywhere the rate at which the secular rock decay progresses varies (other things being equal) directly with the warmth and humidity of the climate. So any considerable volume of secular residua indicates a warm and humid climate during the period of its accumulation. This may be called the *condition of climate*.

Another condition which is essential to the accumulation of residuary products in large volume, and which generally accompanies the last, is that there shall be luxuriant vegetation. The roots of growing plants cleave mechanically and dissolve chemically the mineral substances with which they come in contact; the acids formed by the decay of plant-remains energetically attack mineral substances and decompose them more efficiently than any other natural agent; the plant thereby creates soil and the soil supports the plant, and thus the agency is cumulatively efficient. Everywhere the depth of soil and the accumulation of decayed rock vary (other things equal) with the luxuriance of the local vegetation. So any considerable accumulation of residuary products suggests that the surface supported a luxuriant vegetation during the period of its formation. This may be called the *condition of vital action.*

Now, while the volume of residua at present existing in Northeastern Iowa is perhaps inconsiderable, it is possible to ascertain approximately the total volume formed. It is known from the relations among the several formations that several hundred or perhaps a thousand feet of rock strata have been degraded; and it is known from the peculiar configuration that during at least a considerable part of the period of this degradation the surface stood so low that transportation of rock débris always lagged far behind rock decay, so that the degradation was not effected by corrasion; and it is known from the ratio between rock volume and residua volume that a given thickness of rocky strata leaves, upon its decomposition, an insoluble residue amounting to more than half of their thickness. Accordingly, the aggregate volume of residua formed and now largely removed from Northeastern Iowa must amount to somewhere about 300 or 500 feet. Now, this vast volume may represent either a vast period of accumulation or exceptionally favorable conditions of climate and vegetal action; and, viewed in the abstract, this problem of three variables is insoluble, and there is no means of determining which condition or conditions were of greatest potency. But there are other data bearing upon the problem.

It is known from the practical absence of Mesozoic and Cenozoic formations that the region has stood above sea level nearly all the time since the close of the Paleozoic; and it is known from analogy with observed processes that during this immense period rock decay must have been in progress at a rate depending upon the efficiency of the subordinate conditions. Moreover, it is known that by far the greater part of the residua formed within the region have been transported seaward, despite the low altitude at which the land is shown to have stood by the topographic configuration. So the period of formation of the geest of Northeastern Iowa was long—how long may not be stated in familiar time-units; but so long that if it were thus stated the figures would convey no clear conception of the amount.

Now, in view of the vast period represented thereby, a somewhat vague but yet useful conception may be formed concerning the potency of the subordinate conditions of secular rock decay. Thus, it is manifest that the two subordinate conditions combined were no more than moderately efficient; for the aggregate thickness of residua present and removed is no greater than the present volume of similar residua formed within the tropics since middle Tertiary times. But it is impossible to determine from the residua whether the condition of climate or that of vegetal action was the more important in forming them. Yet, here again, there is collateral evidence. With a given rainfall and a given height above base level there is a certain relation between disintegration and transportation by which a certain definite topographic configuration is produced; with increased rainfall valleys are widened, divides narrowed, slopes steepened, and concavity in surface profiles produced; and with diminished rainfall the valleys contract, the divides widen and flatten, the slopes remain steep only in the immediate valley sides, and convex profiles are produced. This is the law of land profiles, which is set forth elsewhere. Now, in Northeastern Iowa the prevailing profiles are convex, and moreover, the uplands are mantled to considerable depths by residua, and limited precipitation is thereby indicated. At the same time the accumulation of residua is neither so sparse about the brows and scarps of the uplands and abundant over the interiors as to indicate modern increase, nor so meager in the interiors and abundant in the valleys as to suggest modern decrease in rainfall; but everywhere the accumulation appears to be accurately adjusted to the configuration under the existing climatal conditions. So it would appear that the climate has remained practically unchanged for ages, save during the brief periods of modified degradation accompanying the two ice invasions. It would therefore appear illegitimate to ascribe any inequality in rate of secular rock decomposition to secular variation in climate; and thus the potency of this agency may be at least vaguely determined.

Again, there is some fragmentary but curious and significant evidence that the process of secular rock decay in Northeastern Iowa and other parts of the country has not progressed uniformly. The residuary clays of the driftless area are identical in composition and texture with the red clay lining caverns and rock fissures, or with the typical "cave earth" of other parts of this and foreign countries. In the driftless area, as elsewhere, the "cave earth" is fossiliferous; and here as elsewhere it is frequently, if not commonly, covered with a floor of stalagmite. Thus, the principal caves of the world afford a singularly consistent record of their own formation; all represent a period of rapid solution during which the chambers were hollowed out and the "cave earth" accumulated, and a subsequent period of sluggish solution during which the destruction of the chambers declined, and the stalagmitic floor was formed of partially dissolved but not completely decomposed rock material; and by their fossils they give a record not only of identical sequence of events, but of contemporaneity—for although it is sometimes called Pliocene and sometimes Pleistocene, there is no better defined fauna known to the paleontologist than that of the caves of Europe and America. The coincidence in cave history as recorded in the deposits is too close, and the contemporaneity of cave formation indicated by the fauna is too exact, to be considered fortuitous; indeed, cave records are already so voluminous and consistent as to demand the recognition of a well defined *cave period* among the episodes of geologic history. Now, the cave period was one of exceptionally energetic rock decomposition beneath (and evidently also upon) the surface, as indicated by the volume of residua. It coincides approximately with the Pleistocene as indicated by the distinctive cave fauna. The cave fauna reveals a wealth and magnitude of herbivorous and carnivorous animal life which could only go with luxuriant plant life; and a rapid growth and decay of the vegetation of the period is indicated as well by the exceptional rapidity of rock decomposition. So the caves tell of a period of prodigality in life, both vegetal and animal, occurring about the close of the Pliocene or the beginning of the Pleistocene.

Singularly consistent evidence is afforded by the record of the glacial deposits. Between the first and second great ice invasions there was a long period of mild climate, during which the surface of the plains drained by the Mississippi became clothed with luxuriant vegetation; the trees and stumps and wide-branching roots of the forest were overridden by the later ice sheet and hermetically sealed beneath the ground moraine, and yet remain intact in such number that the aggregate volume of buried wood probably exceeds that growing on the surface to-day; the morasses in the intervals were possessed by the hypnum and sphagnum and other mosses, and great beds of peat were formed; the subsoil was penetrated by roots of trees and grasses and permeated by the products of vegetal decay until there was formed a soil so deep and rich that its remnant to-day is commonly thicker than the soil of the modern surface; and the acids generated by vegetal decomposition were set free in such volume that practically the whole of the thick, lower drift sheet was permeated and decolored like the newer drift sheet beneath the modern morass or barnyard.

So the geest of the driftless area is identical in composition, appearance, in every feature indicating age, with the "cave earth." The cave earth tells of a Pleistocene or Pliocene period of prodigal life; and the interglacial forest bed tells of a period of prodigal vegetation during the early Pleistocene, during which the cave fauna roamed over the land, and during which the "cave earth" and the associated residua might have been formed. There is thus a collateral indication that the efficiency of vegetal action as a factor in producing secular rock decay has varied from time to time, and that the process went forward with exceptional rapidity during a certain epoch. The cause of this probably temporary activity in vital process need not now be sought. As already noted, the cause can be ascribed only in small part to climatal vicissitude.

The stratigraphy tells little of the period of most rapid geest formation. The residuary clays underlie the margin of the newer drift sheet save where evidently or presumptively removed by the ice plow, and they underlie the fringe of aqueoglacial deposits in full thickness, and thus unquestionably antedate the second ice invasion. But it is significant that they are not known in considerable volume beneath the inferior ice sheet or beneath its marginal deposits, while in degree of ferrugination these deposits appear to be of antiquity as great as the geest of adjoining tracts.

Hunt, the pioneer in the study of residuary products, and Julien, a leading authority on the agency of the humus acids in promoting rock decay, are agreed that while secular decomposition has evidently been in progress on the land surface of the globe throughout the ages, there have been certain periods of special activity in the process. It is true that some students have not found evidence of such variability in the secular process ; yet the phenomena of the caves and of the forest bed alike make for the opinion held by Hunt and Julien, and indicate that there was, early in the Pleistocene, a period of exceptional luxuriance in vegetation and activity in rock decomposition, during which a considerable part of the present mantle of geest of Northeastern Iowa must have been accumulated.


TECTONIC MAP No. 1.
NORTH EASTERN IOWA
BY W J McGEE
Scale 1:950,400 - 15 miles: 1 inch
1889.
DISTRIBUTION OF ICE AND WATER
AT CULMINATION OF FIRST ICE INVASION
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CHAPTER X.

THE GLACIAL HISTORY.

Let the period of written history be represented by a day; then a month or a year of such days will measure the period that has elapsed since the first Pleistocene ice sheet invaded Northeastern Iowa. The uncertainty as to the date of the invasion is great; but it was so long ago that the date would be but vaguely conceived even if it were possible to write it.

With respect to the details of the invasion as well as its date the record is shadowy ; yet it is not an entire blank. An ice sheet was pushed down from the north-northwest, from the region now a land of lakes, beyond the parallel of 44° 30′, to-day the line between Iowa and Minnesota. The ice pushed forward in a strong, thick lobe of rounded front, overflowing the valleys and pressing hard upon the divides of an undulating rock surface mantled with the products of rock decay, and perhaps shadowed by forests; and the advancing ice must have been preceded or accompanied by boreal or arctic climate, for if the red clay mantling the rock surface had not been frozen at and beyond the ice front it would surely all have been thrust aside or washed away by the weighty ice mass, or the waters flowing from its edge. The day of the huge herbivores of the Tertiary, the mammoth and mastodon, the giant buffalo and the great beaver, and the magnificent ancient elk in the glades of the interior, and of the rhinoceros and the camel on the western plains, was not yet set; but the giants of the plain and the forest were driven southward by the yearly chilling of earth's secular winter, never to return to their former haunts, never to regain their former prestige.

Thus began the first ice invasion.

So obscure are the characters of the record that the rate of advance or the length of stay of the first ice sheet may not be measured; but if the period of written history be represented by a day, it would seem fair to estimate the period of advance at a half hour and the period of retreat at nearly as much more. It is known that the ice crept into what is now the State of Iowa from the north in lobate form, flowing southward or a little to the eastward of that direction in its center, with its lines of flow diverging laterally; so that the territory under study was invaded by the gelid mass creeping southeastward and gradually diverging to the left toward the present course of the Mississippi, and finally terminating in a series of lobelets commonly pushed out upon the divides; and many of the lobelets ended on the crests of transverse scarps, at which the ice became crevassed and melted under the blaze of the sun and the breath of the south wind. The distribution of the ice and its direction of flow are depicted in tectonic map No. 1 (Pl. LV). There is much of hypothesis in this graphic illustration; but hypothesis is guided and controlled by knowledge concerning the ice and its movements during the later episode.[1]

So thick was the ice mass and so long did it remain that the land sank beneath it; perhaps the ocean waters encroached far beyond the present limits of the Gulf, so as to form a mediterranean sea about the ice margin; perhaps the depression was but a tilting northward so that the land beyond the ice margin became a fresh-water marsh or shallow lake; but certain it is that as the ice melted the waters accumulated about its margin, and the clay, sand, and gravel frozen within it were washed about by waters and laid down in sheets and beds; and so the ice-formed deposits merge at their margin into water-laid deposits. The ice-formed deposit is the lower till; and the water-laid deposit is that which the disheartened landholder contemns as "gumbo."

The Minnesota-Iowa ice lobe was longer than that of Wisconsin and Illinois, as Chamberlin has well shown; yet it pushed down the faster as well as the farther during each great ice invasion, and in Northeastern Iowa the western lobe had evidently retreated dozens or scores of miles before the eastern lobe reached its limit; and after the western ice had retreated from the Mississippi channel about "Cromwell's Nose," that channel seems to have been dammed by the eastern ice, so that the waters of the great river—a giant now, but then a pygmy—were diverted and a new channel cut directly from the present mouth of the Maquoketa by way of the present mouth of the Wapsipinnicon to the present mouth of Rock River; the tip of "Cromwell's Nose" was sliced off, and nearly 1,000 square miles of what is now Iowa was taken by what is now Illinois. During the time of this dam a lake must have been formed in which the marginal ice deposits overlooking the Mississippi gorge in the middle latitude of the territory were water-laid as in the south. But the damming was of short duration; as the eastern ice retreated, the Mississippi may have resumed its normal course from the mouth of the Maquoketa to the mouth of the Wapsipinnicon, reclaiming

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[1] For the artistic execution of the accompanying tectonic maps the author is indebted to others. The first two represent the last work of Mr. John H. Klemroth, a skillful draftsman possessing remarkable facility in grasping and portraying conceptions originating in other minds, who fell a victim to la grippe (his death occurred October 29, 1890); the next two were executed, partly under Mr. Klemroth's directions, by Mr. John B. Torbert; while the smaller sheets forming the last two of the series are the handiwork of the artist De Lancey Gill. The work was, however, carried forward upon lines laid down by the author, and his acknowledgment of indebtedness to the artists whose skill enabled him to portray his conceptions does not relieve him from full responsibility for the fidelity of the portrayal in general effect as well as in local details.

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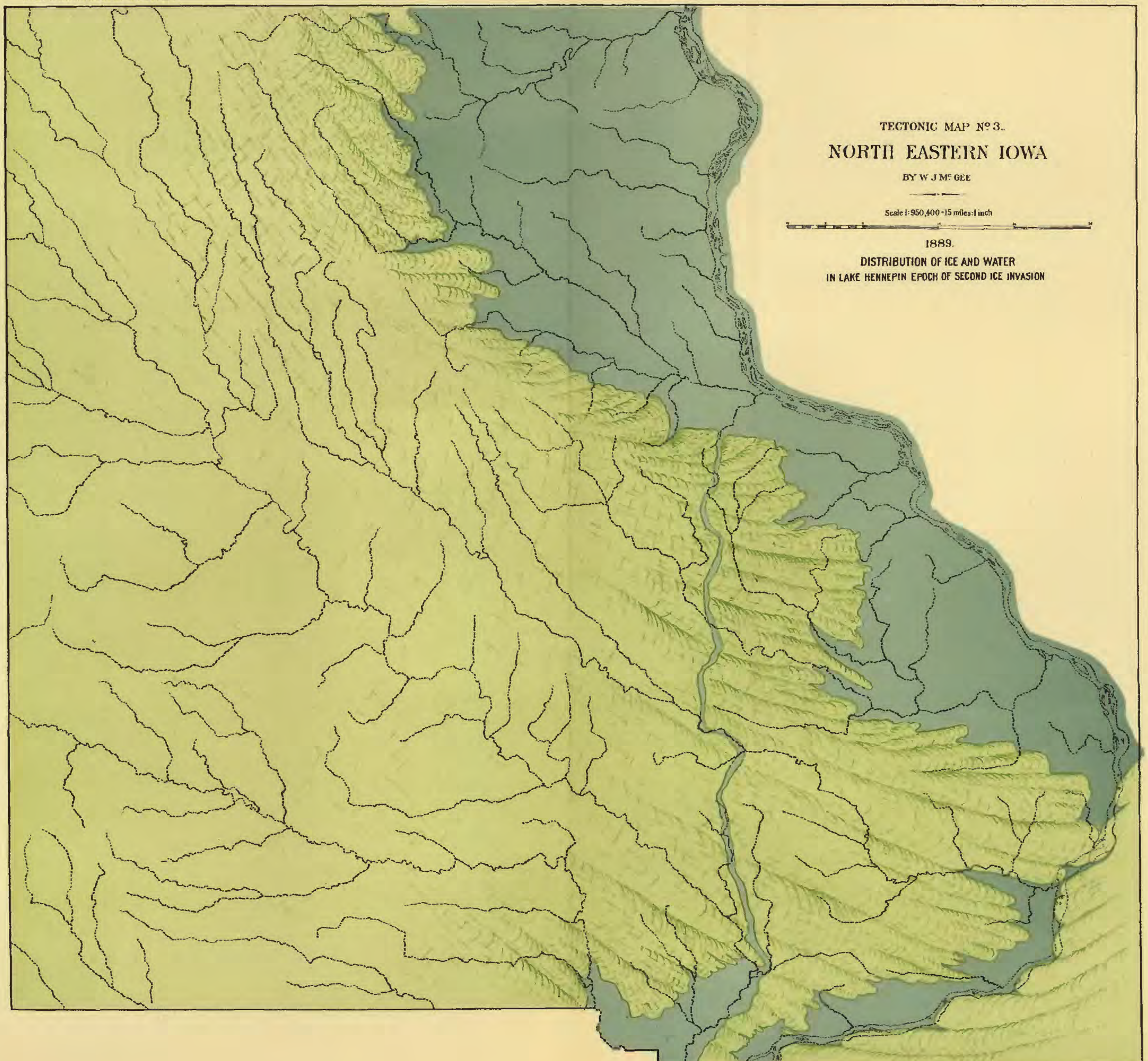

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half of the lost territory; yet it certainly held to the new channel thence to the mouth of the Rock, and the waters busied themselves in cutting down the ledges of the rapids now called Le Claire and Rock Island. After the opening of the barrier, and after the retreat of the ice for some distance, the main portion of the Northeastern Iowa ice sheet seems to have slowly softened and dissolved en masse under the sun and south winds of a secular summer.

Thus ended the first ice invasion.

The territory was now mantled by ice débris; its surface must have been undulating after the fashion of drift plains; lakes must have collected upon it; streams must have gathered; rivers must have been formed; but the undulations are lost, the lakes are gone, the streams are obliterated, even the river channels have disappeared from the face of the earth—the geography of the interglacial time is all but unknown. Thus much only is known: Knolls and bosses and occasional ridges of limestone protruded through the drift mantle to inscribe lines on a later ice sheet which were in turn transferred to another land surface. Yet it is known of the interglacial land that it was forested by the cedar and the pine, that much of its surface was marshy, that peat bogs abounded, and that a thick vegetal soil was formed; and from records beyond the limits of the territory it is known that scattered representatives of the giant herbivorean fauna of the preceding eon reappeared in the coniferous forests.

The interglacial period was long: how long may not precisely be said; but if the period of written history be a day, then this period must have been near 4 weeks or fully 10 months, according to the scale adopted—certainly most of the time from the first great ice invasion to the present elapsed before the interglacial period ended.[1]

The record of the second ice invasion is distinct and easily legible. The ice came down from the north in lobate form as before, sweeping over what is now Minnesota and Iowa, following nearly the same direction as that pursued by its predecessor. Again boreal or arctic climate must have heralded the invader, and the ice-formed and water-laid deposits must have been frozen, for they were wonderfully little disturbed by the later ice action. But the second ice sheet was thinner than the first, perhaps because it pushed forward more easily over the comparatively smooth interglacial surface; certainly it was so thin that wherever a crag protruded through the older drift sheet the ice flow was retarded and the great lobes partially or wholly divided into lobelets. Certainly, too, the direction of flow was somewhat more easterly than during the earlier period; and at least partly for this reason the newer sheet sometimes fell far short of the limits reached by the older, though sometimes these limits were overrun.

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[1] Detailed estimates are graphically represented in the Seventh Annual Report, U. S. Geological Survey, 1888, p. 639; and more fully in the Am. Jour. Sci., 1888, vol. 35, p. 466.

The distribution and direction of flow of the second ice sheet are quite well known, with respect at least to its peripheral portion. They are depicted in the second tectonic map (Pl. LVI). The extremities of the lobelets are recorded on the ground by the limits of ice work; and it is clearly apparent that this ice sheet, like the earlier, commonly flowed farthest on divides, and after pushing up gentle slopes to crests of escarpments there broke down and melted; from which it is inferred that the ice received its impetus from behind.

The positions of the lobes are recorded on the ground in the present positions of streams, of rocky ridges, and of the peculiar, gracefully molded accumulations of glacial mud called paha. Above and in the lee of each protruding crag the ice flow was checked, the surface was lowered by surface melting, and there a stream formed on the icy surface; along the stream line the ice melted fast and became so thin that the thicker parts of the sheet forced the subglacial water into a second stream, which flowed under the first; both carved their way into the ice until it was cut through, when both dropped their glacial mud in long ribbons on the gentler slope of the earth surface; and there the original progenitors of the streams and the rocky crags which initiated the process remain to-day. Some doubt there is as to the length of the lobation; some doubt there is as to the direction of flow in the interior of the sheet; some doubt there always must be as to the direction of ice flow at the extremities of the lobelets; some doubt there is as to the position and characteristics of a few of these lobelets; but in general the graphic illustration represents, not a vague generalization nor an idle speculation, but a consistent series of legitimate inferences made on the ground from thousands of local observations.

Such was the second ice invasion.

Though the movements of the ice and the manner of its advance during the second secular winter are well known, the rate of its advance and the length of its stay have not been determined; but there are many reasons for concluding that it came quicker and went sooner than its predecessor. Moreover, it left a record of the manner of its going, and this record is nearly as legible as that of its advance.

During the second ice period, as during the first, the Minnesota-Iowa lobe outran its Wisconsin-Illinois neighbor, and pressing down to the Mississippi, reclaimed the territory about the tip of what is now called "Cromwell's Nose," and pushed the Mississippi out of its channel and into Rock River. During this period, too, the land was depressed beneath the ice, yet so slowly that the sinking was not felt until the ice had stood for a time; and as the ice was thicker in the interior, so there the sinking was greater. Thus the longest lobelets of the ice were pushed out to a greater length than they could have attained with the attitude of the land subsequently assumed, and the way was prepared for cutting off at their sources these longest lobe-

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lets. So when the sluggish eastern ice at length reached the channel of the Mississippi the western ice was already weakened, but it held its own in contact with the thicker and stronger eastern lobelets until the two series merged, completely filled the channel of the Mississippi, and transformed the driftless area wholly or at least in large part into a lake; and this lake drained not over the barrier formed by the contiguous ice sheets, but over the western sheet along a line made lowest by the progressive sinking of the ice-weighted land in that direction. Within this lake the ice-born streams dropped their glacial mud in a mantle thickest near the ice margin, which the waters, indeed, sometimes overflowed, sometimes lifted and floated away as débris-dropping bergs, and sometimes melted This is the episode represented in the third tectonic map (Pl. LVII).

How long the ice-bound lake lasted may not be stated in years; but the period was short, for the deposits are of limited thickness; and the level of the waters was variable, for they left no shore lines on the northeast within the present State of Wisconsin. It is indeed passing strange that the evidently water-laid deposit skirting the former ice margin in Iowa should feather out so completely and be so imperfectly represented beyond the Mississippi, and it is only less strange that shore lines should not be found; but parallel cases are not unknown. The shore lines of Bonneville and Lahontan are far more continuous, yet the deposits sometimes fail many feet beneath what is known to have been the old water level; and the shore lines of the Columbia ocean in eastern United States fail for dozens if not for scores of miles, and the deposits die out over considerable areas only to reappear in undiminished strength perhaps at greater altitudes. Certain it is that the gravel and finer sediments overlying the drift margin in Northeastern Iowa are water-laid; certain it is that they overlook by dozens or scores, or even hundreds of feet any existing barriers by which the depositing waters could have been held in position. Moreover, there is a mass of local evidence too voluminous for easy record or ready comprehension, that the loess was deposited against ice occupying a certain position. The third map, like the second, represents not a hasty generalization or a vague speculation, but a series of legitimate inferences made on the ground from local phenomena.

The evidence as to the position and course of the river draining the lake is discursive and sometimes ambiguous. Certain it is, however, that a great ice-born river first occupied the immense alluvial bottom of the Cedar below its elbow; certain it is, too, that the greater part of the water came from the northward along lines roughly marked by pygmy streamlets flowing in disproportionately broad channels; and certain it is that toward the head of the ancient river fields of bowlders and washed rock surface abound as they do nowhere else in the territory, save in certain restricted localities known to have been subjected to exceptional wash from the melting ice. Moreover, along this line occur the most notable morainal and semi-morainal accumulations of the territory between the Maquoketas in the north, and between the Cedar and the Wapsinonoc in the south, though these areas were far from the ice margin; and the building of these débris masses is analogous to that known to have occurred elsewhere in the territory when the ice was partially or wholly cut off by transverse drainage. Again, midlength of the river the paha commonly terminate, and by their distribution and general behavior indicate that a new lobation was introduced along this line. Still further, the line is marked by the distribution of the loess, which crosses it only in a comparatively narrow belt between the Maquoketa and the Wapsipinnicon; and it might be shown that this interruption is accordant with the view that the river existed during the stage indicated, and that it can not otherwise be readily explained. Then there is the general fact that the line of the ancient river coincides with a general topographic depression. Discursive as is the evidence, and ambiguous as is a part of it, it is thoroughly consistent and cumulative, and appears to warrant the inference that the driftless area lake drained directly southward across the Iowa ice lobe from a point near the mouth of Turkey River.

The driftless area lake is represented by an extensive deposit of profound scientific interest and great economic importance; and it represents a notable episode in the geologic development of the region. Let it be christened in honor of the intrepid explorer who first traversed its basin two centuries before its history was read, Père Hennepin; and let the river which drains it take the name of the same explorer.

The Minnesota-Iowa ice lobe was robbed of its energy by the sinking of the land beneath its thicker interior, and its most ambitious segments were cut off by the River Hennepin. Its flow was checked; the process of dissolution by slow decay under the potent sun and blandishing breezes of a secular springtime was initiated; but the minor lobation impressed upon the ice by protruding bosses and ridges of rock remained, and the ice dissolved not as a smooth topped mass, but as a series of parallel ridges and isolated outliers; and the geography of these left markings which persist to-day. Meantime, the more dilatory but more robust Wisconsin-Illinois lobe pressed hard upon it, and as the ice thinned a new outlet was formed for Lake Hennepin along the line of the river, born with the melting of the first sheet, cutting off the tip of the "Cromwell's Nose." Through this channel the lake was drained. But many other lakes were formed, either on the surface of the ice or in basins formed by its melting around congeries of protruding knobs, such as gave origin to the paha, and in these ice-bound lakes glacial mud was dropped

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AN EARLY STAGE IN THE DEVELOPEMENT OF TYPICAL GEOGRAPHIC FEATURES IN NORTH EASTERN IOWA.

in lines and greatly elongated belts. Most of the lakes were small, and their name is legion; but some of them were large. There was the lake formed by the Farley lobelet of an earlier stage in ice melting, now nearly cut off; there were other lakes west of it; there was a larger lake on the Maquoketa River, and one of still greater dimensions about the present course of the Wapsipinnicon; and an important lake existed about the great bend of the Iowa. All of these water bodies are represented by deposits of scientific interest and economic importance, and all represent in turn noteworthy episodes in the geologic development of the region. Some at least are worthy of specific designation. Let them take the names of the rivers by which the ancient basins are traversed. These lakes, and some of the lesser members of the same numerous family, are represented upon the fourth tectonic map (Pl. LVIII), and the principal members, together with Lake Hennepin, are grouped upon a single sheet, in Pl. LXI.

The fourth tectonic map is in one respect more largely hypothetic than the second and third of the series; for while it is, like them, the expression of legitimate and necessary inference from significant phenomena in all of its portions, and is thus far from being a hasty generalization or a vague speculation, it has been found impossible to certainly correlate the successive stages in ice melting in different parts of the territory. So, Lakes Maquoketa and Iowa may not have been contemporaneous; perhaps not all of Lake Wapsipinnicon existed at the same time; and perhaps the lakes along the Cedar were relatively larger during the period of maximum extension of Lake Iowa than is represented; but each small area of the map may be regarded as reliable, and the general grouping taken as illustrative rather than actual.

The mode of ice melting is illustrated, and the validity of the interpretation herein written is demonstrated, by the phenomena about Lake Iowa during a somewhat earlier stage than that represented in the fourth tectonic map. The progenitor of the Iowa River was outlined above a series of rocky eminences forming the present plateau north of Iowa City; and while one stretch of this stream ran parallel with the ice flow, another stretch cut obliquely across a series of lobelets. Now, the ice cut off by the oblique stream-stretch lost the impetus from behind necessary to ice motion in this flat-lying land; and it lay immovable, slowly melting under sun and wind—so slowly that before it was gone the nascent Iowa River had carved for itself the greater part of the cañon which it occupies. As it melted, glacial mud was deposited about its flanks to form the modern loess mantle, but beneath it lay the bowlder-charged ground moraine which the ice had pushed down from the far north. The grave of this ice mass is the North Liberty basin; and it has scores of monuments in the great drift bowlders to-day standing guard over the plain.

While the mass melted, the living lobelets, truncated by the oblique stream-stretch, continued to push down from the northwest and built semi-moraines, while between them ice cañons were formed and filled with glacial mud, which yet lies where originally dropped as elongated fingers of loess jutting out upon and overlooking the Iowa-Cedar divide.

The mode of ice melting is still more clearly illustrated, and the validity of the interpretation herein written still more conclusively demonstrated, by the assemblage of typical geographic features developed after the ice had retreated a few miles farther and the curiously eccentric stream, Prairie Creek, came into being. The original Cedar River was outlined as a series of ice-bound lakes, each marking the position of a subglacial rock eminence, with a stream connecting the lakes and carrying their overflow. The superglacial lakes varied in extent with the prominence of the rock eminences, the largest of the series coinciding with the present rock-lined and loess-mantled plateau east of Vinton. From time to time, as the effluents melted and corraded their way through the ice sheet, the lakes were successively drained and their sediments became land. The original Prairie Creek was a trifling tributary of the Cedar, flowing in a short ice cañon setting off at right angles from the cañon of the main river just after the draining of the lakelets and larger water bodies in which the Cedar Rapids paha were formed. This tributary waxed and quickly robbed its neighbors of their share of tribute to the main stream, because its line marked the transition from earth slope in the direction of ice flow to the contrary slope culminating in the plateau of the Iowa River elbow, and so it extended its cañon farther and farther across the faintly ridged ice sheet until it, like the progenitor of the Iowa River, cut off a section of the ice field to slowly dissolve under the vernal zephyrs and summer rains of recurrent seasons. Meanwhile the active portion of the ice sheet pushed forward—perhaps the more energetically because of the milder climate and lessened resistance following the melting of its margin—and the partial lobation determined by the subglacial rock eminences became more and more clearly defined. At the same time the rugose rock surfaces above the lake of the present plateau and to the left of the nascent Prairie Creek so obstructed the ice that it was divided into lobelets, between each pair of which a rock boss lay below while a stream flowed above; and these lobelets of living ice pushed down and built semi-moraines at their extremities, while the interlobate streams prepared the way for the building of paha.

This stage in the development of typical geographic features is depicted in the small tectonic map forming Pl. LIX.

As the warm sunshine and moist winds of the secular springtime did their work, the cañon of the river deepened and widened and ate its way into the ice field until the lake of the modern plateau was

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A LATER STAGE IN THE DEVELOPEMENT OF TYPICAL GEOGRAPHIC FEATURES IN NORTH EASTERN IOWA.

drained and the sediments of its bottom became land—albeit the floor of an ice-bound basin—to be attacked and sculptured in distinctive fashion by the streams born of storms, the melting of the ice cliffs, and the dissolving of isolated ice remnants. The ice cañon in which Prairie Creek was cradled also waxed apace; the streams upon the surface sloping toward the sun outgrew their neighbors on the flat surface of dead ice on the right of the cañon, and the cañon slowly curved in the direction whence came the larger streams, each of which in its turn became the principal tributary, since each in its turn drained the broad ice expanse to the northwest. Meantime the living lobelets near the mouth of the tributary cañon accumulated débris at their snouts and the interlobate streams sank through the ice and dropped the sediments which make the modern paha, while the rock eminences farther westward clove the moving margin of the living ice and prepared the way for further moraines and other paha.

This is the stage depicted in the second small tectonic map of a typical area, Pl. LX.

As time passed the ice melted away, the last of the lakes was drained, and the cañons widened to valleys; yet the thicker lobes and lobelets lay so long that the Cedar carved stretches of cañon aggregating miles in length, scores of feet in depth, and half a mile in average width, while yet the gelid mass protected the flanking lowlands; and other streams did proportionate work. Yet, long as the ice lay, it finally yielded as the springtime of the secular season gave way to summer. There then remained about the confluence of the infant Prairie Creek with its principal some knobs of rock by which the ice was first riven, each enwrapped in the mantle of sediments laid down in the lake to which it gave birth; but some of these plateaus were cut through and some rock knobs laid bare by the Cedar. There remained also the rock-founded plateau, with the sheet of sediment dropped upon it by the broad lake which it engendered—the sheet rent and the plateau riven, albeit by the cañon of the stream which drained the lake. There remained, as well, the semi-morainic débris heaped up on the left of Prairie Creek and the paha into which the semi-moraines merged; and other paha and semi-moraines above the site of the plateau lake and beyond the course of the Cedar to the northeast marked other lineaments of the former ice face. So, too, there remained the lowlying plains upon which the tattered remnants of the ice sheet, cut off by advancing drainage, lay stagnant until wasted away by winds and sun, and the plains remained burdened by the bowlders easily borne by the Ice King in his prime. Finally, there remained the great river flowing in the cañon selected when the ice sheet first halted and carved while the ice remnants yet persisted, and the lesser river, Prairie Creek, born upon the continuous ice sheet, cradled between living ice on the one side and dead ice on the other, and still occupying the bed made while the ice constrained its course.

This third stage in the development of a typical region is illustrated in the hypsographic map of a representative topographic area, forming Pl. XLIII. That map is a reduction of nine atlas sheets constructed from minute surveys on the ground.

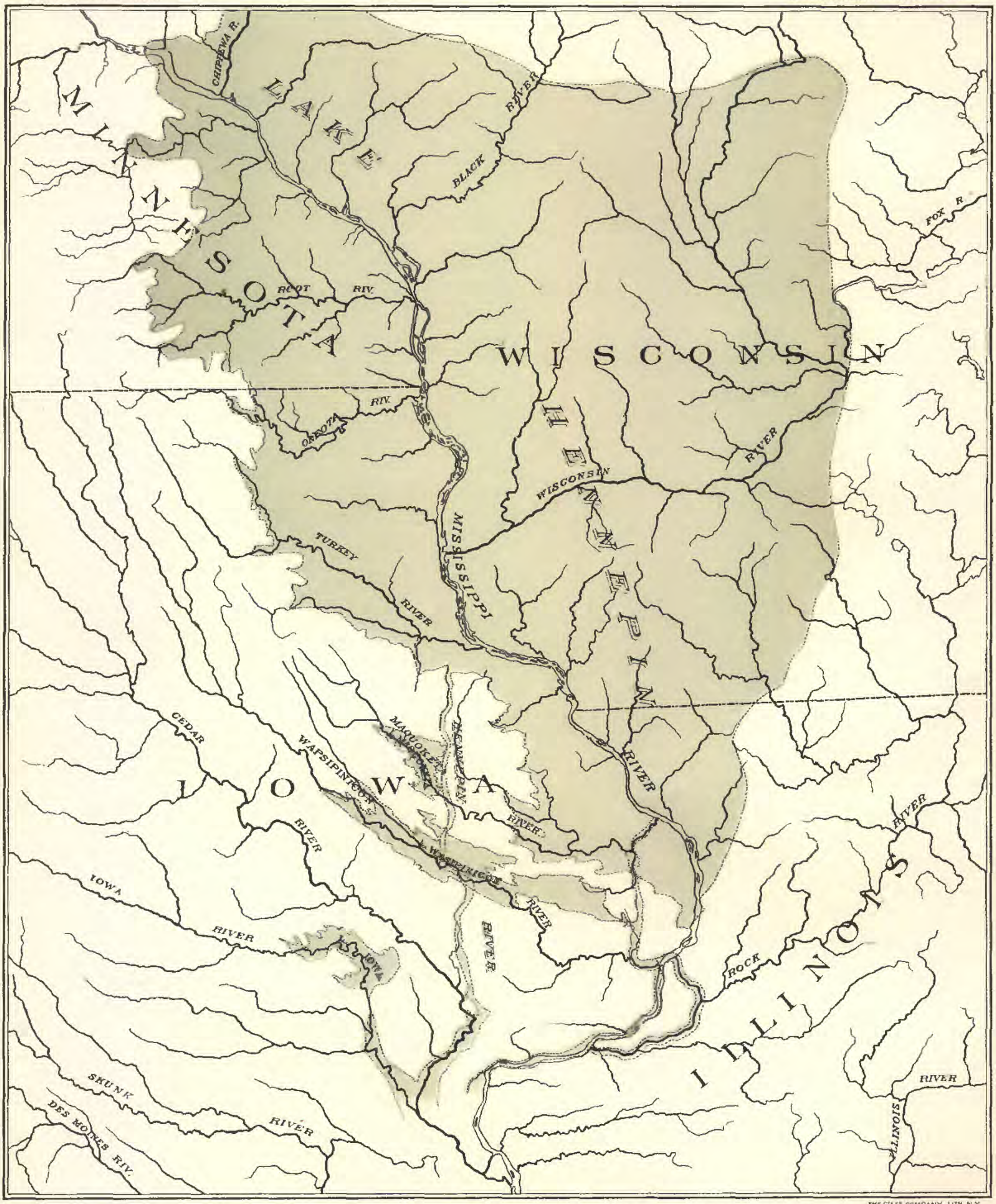
Let it be noted that, perhaps because of the shorter duration of the second ice period, perhaps because of the thinness of the second ice sheet, the land was less profoundly depressed than before, and the homologue of the gumbo was scarcely formed; yet it may be just to regard the loess-drift of the southwestern part of the territory, which is certainly a water-laid deposit blending with an ice-formed deposit, as such.

Another episode should be noted. Although the Wisconsin-Illinois lobe was far more robust than that west of the Mississippi, it began to withdraw not long after the culmination of the second ice epoch of Northeastern Iowa; and perhaps because of the land depression beneath its interior the running waters followed it. So the Mississippi abandoned the Maquoketa-Wapsipinnicon channel and went back to its original course between the mouths of these rivers; and even below the latter a part at least of its volume went over to the preglacial channel, flowing through the present Marais d'Ogée and Rock River, though a sufficient part remained in the present channel to constitute this the permanent drainage way.

As the dominion of the Ice King waned his phalanx was pushed forward less energetically, so that when the marginal lobelets disappeared a third or a half of the ice was melted, and the motion was no longer sufficiently energetic to lobe and ridge the sluggish mass. Thus radiate rivers were no longer formed on the ice surface; paha no longer mark the erstwhile lineaments of its upturned face; even the rivers of to-day are measurably independent of the drainage above and below the ice. The whole mass, indeed, must have lain in majestic inactivity until devoured by the hungry sun and thirsty wind. The bowlder-dotted surface of the northwestern part of the territory is its epitaph. But before the motion entirely ceased a few small lakelets were formed when the ice flowed against the low ridges marking the present divides of the drift plain, the most notable being that on the Cedar River at Waverly; and there the decadent ice left a more elaborate record in the form of a once wooded plateau now largely given over to the vine and the fruit tree.

Thus ended the second ice invasion.

So Northeastern Iowa has been twice invaded by northern ice. The first ice sheet was thick, pressed hard on the land, lay long, and slowly melted. It displaced the magnificent fauna of the Tertiary,



THE GILES COMPANY, LITH. N.Y.

PRINCIPAL LAKES AND RIVERS OF NORTH-EASTERN IOWA DURING THE SECOND ICE INVASION

BY W J McGEE

few representatives of which survived its disappearance; and it was followed by a vast period of forest growth and soil accumulation. The second ice sheet entered the territory very long after the first; it was only a few hundred feet in thickness at the most, ran quickly to its farthest limit and quickly melted. Before its destruction it met the Iowa-Wisconsin ice lobe, and behind the two a great lake formed which drained over the Iowa sheet; and as this sheet melted, rivers ran between its lobelets, lakes accumulated on its surface, and glacial mud gathered in the channels of rivers and basins of lakes; and thus there was developed a combined topographic configuration and aqueo-glacial structure without parallel elsewhere on the known earth.

Thus ends the glacial history of Northeastern Iowa; for, although the Ice King again gathered strength and sent out his gelid phalanx, the third invasion fell short of this territory.

THE NATURAL GAS FIELD OF INDIANA.

BY

ARTHUR JOHN PHINNEY.

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DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
POTOMAC DIVISION,
Washington, D. C., March 18, 1890.

SIR: Herewith I transmit a report by Dr. A. J. Phinney upon the Natural Gas Field of Indiana.

When, in 1885, it was found that natural gas existed in the rocks of western Pennsylvania and West Virginia beyond the limits of the well known petroleum field, a decided impetus was given to prospecting for both gas and oil; and when, in 1886, gas was found in great volume at Findlay and elsewhere in Ohio, the drilling fever passed all reasonable bounds, sweeping over not only Ohio, but Indiana, Illinois, and other interior States; and in hundreds of towns test bores were put down as quickly as manufacturers could supply apparatus and operators could be imported or trained. There was at first no wise direction of the work, and the drill was started at random in all formations alike; under the feverish excitement of the time, machinery and men were kept in operation day and night; but unfortunately the prospectors seldom realized the value of boring records and samples, and few were kept.

Appreciating their unexampled opportunity for obtaining data concerning the structure of the regions perforated by the drill during the prevalence of the gas fever, the official geologists of Pennsylvania and Ohio early began collecting records and borings; but the tide of excitement swelled and it was difficult for the limited number of geologists to keep up with the large number of prospectors. Yet a rich aggregate of figures and samples was assembled and systemized, and finally the laws of the distribution of gas and oil were made known by the geologist; and the prospector and capitalist were repaid a hundredfold for the slight cost of keeping records of their work.

When the drill began its operations in Indiana it fell to Dr. Phinney, an amateur geologist of Muncie, to observe and study the boring records; and to him belongs the credit for commencing and carrying well forward, at his own cost. a comprehensive investigation of the data brought to light by the test borings in that State. In the fall of 1887, while the drilling excitement was at its height, I visited him in accordance with your instructions and effected with him an arrangement for completing the work he had so well begun and putting it in form for publication. His results are contained in the following pages.

I have prepared a brief account of rock gas and the related bitumens, including a discussion of the constitution, distribution, and origin of gas and oil, as an introduction to Dr. Phinney's report.

I have the honor to be, with great respect, your obedient servant,

W J McGee,
Geologist in charge

Hon. J. W. Powell,
Director U. S. Geological Survey.

INTRODUCTION.

By W J McGee.

ROCK GAS AND RELATED BITUMENS.

SECTION I.—THE CONQUEST OF THE BITUMENS.

Animal existence depends upon the utilization of potential energy stored up in the two forms of food and fuel. The first of these sources is utilized by all animals alike; but man has risen above his ancestral kindred and made conquest of nature through the use of fuel. Man may indeed be defined, perhaps more accurately than in any other way, as the fuel-using animal. In common with him, the ant and wasp build habitations well adapted to their wants; the mouse, the squirrel, and the bee store up provision against the inclement season; the immature butterfly spins a delicate strand, albeit from his own substance; the oriole weaves a strong, smooth fabric to protect its young, and the tailor-bird prepares thread and sews seams; the ant enslaves kindred races that he may be relieved of labor, keeps kine for their milk, and is supposed to plant and cultivate and known to harvest; the beaver cuts canals and dams rivers, and the monkey bridges the stream with his own body that his young may pass safely over; the spider lays snares, and the ant-lion sets traps for game; certain monkeys use missiles in battle, and the gorilla arms himself with a rude weapon; many animals effect organization for offensive and defensive purposes and the laws of organization are enforced and obeyed; and in all other respects the habits, industries, and institutions of the other animals grade into those of man, save that he alone utilizes fuel in securing comfort, preparing food, and overcoming obstacles to progress; and by the use of illuminants he turns night into day and thus lengthens life. Next to food, fuel is the most important subject of thought to-day as in the days of the discovery and worship of fire.

In the history of the subjugation of natural forces for human weal there is no more interesting episode than that of the utilization of the gaseous and liquid carbon compounds as fuels and illuminants. Wood and various woody plants have been used as fuel and animal fats and vegetal oils as illuminants from time immemorial, and there is scarcely a savage tribe to which they are unknown. The advance from the use of wood and charcoal to the burning of mineral coals was an easy one and was probably made gradually and independently in many centers during both historic and prehistoric time. The last step in the utilization of potential energy stored up in mineral substances was far longer and was made within our own memory; and, in consequence of the ready communication of recent years between distant lands, it was taken in many parts of the world at about the same time. It is true that natural gas vents were known to and were for ages venerated by the fire-worshipers whose cult they inspired; it is also true that springs of mineral oil have been known from history's dawn, and that the oil was utilized sometimes as a fuel or illuminant, though more commonly as a medicine or lubricant; and it is equally true that natural oils and tars were extracted by primitive means and used for primitive purposes by barbarous oriental peoples long before their fame spread to the Occident; but it is only within a few years that these natural products have been utilized so extensively as materially to modify the course of human progress. Yet so rapidly have the applications of these carbon compounds spread that to-day most of our houses are lighted, many of our engines driven, and most of the bearings of our innumerable mechanical contrivances lubricated by petroleum, while within the last lustrum the manufacture of such widely used substances as glass and iron has been largely improved and at the same time reduced in cost by the use of rock gas. Still the utilization of this and allied products is only in its infancy. Within our memory philosophic thought has been revolutionized by a scientific conception—the docrine of evolution; and it would appear that we are now in the midst of an equally important industrial revolution growing out of the recognition of the mechanically unstable carbon compounds as fuels and illuminants.

Pari passu with the industrial development accompanying the utilization of rock gas, geologic science made an unparalleled stride within a few months. During the last thirty years Hunt, Newberry, Peckham, Lesley, and several other geologists in this country, and Binney, Coquand, Daubrée, Lartet and others abroad, have indeed made important contributions to our knowledge concerning the constitution and origin of petroleum and its associates; and the exploitation of the Pennsylvania-New York fields afforded valuable additional data relating to these minerals. Nearly four years ago Prof. I. C. White deduced from the Pennsylvania well records and vigorously maintained the theory, now recognized as a fundamental law in gas prognostication, that gas, oil, and brine are accumulated in the order of their weight within inverted basins and troughs formed by flexures of the rocky strata. The importance of these contributions to our knowledge of the lighter bitumens must not be underestimated; yet when exploitation for gas began in Ohio in 1886 the geologist literally sat at the feet of the prospector gathering such crumbs as fell from his hands, and found himself utterly unable either to guide efforts or to predict results. Less than two years later the laws governing the distribution and accumulation of gas and oil were so fully developed that the rock-gas problem claimed a solution as satisfactory as that of the well known artesian water problem; and to-day the geologist predicts the success or failure of a prospect bore for gas or oil about as readily and reliably as he can prognosticate artesian water or coal. Greater advance was probably never before made in such limited time in any economically important branch of knowledge. The solution of the problem of rock gas and petroleum marks an area in science no less than in industry. Vast sums of money, probably reaching into the millions, were spent by prospectors in gathering data; but the credit for the solution of the problem belongs chiefly to three individuals: I. C. White, of the University of West Virginia; Edward Orton, State geologist of Ohio, and A. J. Phinney, a practicing physician and amateur geologist of Indiana.[1]

The conquest of the light hydrocarbons ranks among the most exciting episodes of mining exploitation. When the oil fever broke out in Pennsylvania wells were put down without adequate preparation, and the oil poured forth in such volume as to burst the barriers erected against it and overflow by the thousand barrels, tainting the air, befouling the land, and poisoning the waters. In the great Russian field of Baku the flow of petroleum is still more difficult to control, and more than once has it swept away the heaviest derricks, blown out well-casings, and flowed for days in jets as thick as a man's body and 200 feet in height. It was charged with sand, which dropped about the orifices in vast cones, burying neighboring houses and farms; and as it flowed seaward it literally formed rivers of oil many miles in length. In the fields of Pennsylvania, Ohio, and Indiana the pressure of rock gas is sometimes sufficient to blow out drills nearly a ton in weight and to burst the double riveted tanks and heavy iron mains in which it was sought to confine it, and the belief that its force was uncontrollable was at one time prevalent. In scores of cases the roar of the escaping gas could be heard for miles and compelled the closing of schools and the stoppage of business in the vicinity of the well. When the gas was ignited by accident or design the roar was augmented and workmen were sometimes permanently deafened, while by night the surrounding country was illuminated, the light from a single well being visible over a radius of 10, 25, and even 40 miles. The cause of the enormous pressure under which

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[1] The two gentlemen last named collected most of the information relating to Ohio and Indiana contained in these pages. The results of Dr. Phinney's work especially have been freely drawn upon.

gas and oil are confined was not at first understood, and the latter substance especially was regarded as mysterious and uncanny, if not diabolic; the various ills to which flesh is heir were attributed to it; its utilization was deprecated as impious; and the belief that its extraction was the cause of earthquakes prevailed widely two years ago. The gas fever of 1885-'86 spread over the Mississippi Valley as rapidly as the gold fever of 1849, affecting hundreds of towns and thousands of citizens, and involving the expenditure of hundreds of thousands of dollars in prospecting, which was carried on as rapidly as manufacturers could supply the necessary apparatus. Even to-day the industries growing out of the extraction and utilization of gas and oil have scarcely reached stability.

What? where? why? whence? whither? These are the principal questions inspired in any intelligent community by the discovery of gas and oil, and daily propounded by thousands of laymen; and since the closing months of 1888 the geologist has been able to answer them definitely, and in most respects satisfactorily.

SECTION II.—THE CONSTITUTION OF THE BITUMENS.

The rock gas now so generally recognized as "natural gas" in northern United States and in Canada has long been known technically as a light carburetted hydrogen. In composition it closely approaches the inflammable marsh gas frequently seen bubbling from the muddy bottoms of stagnant ponds or sluggish streams. Its composition, as indicated by the mean result of closely accordant analyses of four specimens from Indiana and three from Ohio, made by Prof. C. C. Howard, for the U. S. Geological Survey, is as follows:

Marsh gas	93·36
Nitrogen	3·28
Hydrogen	1·76
Carbon monoxide	0·53
Oxygen	0·29
Olefiant gas	0·28
Carbon dioxide	0·25
Hydrogen sulphide	0·18
Total	100·03

Marsh gas, the principal constituent of the rock gas of commerce and the arts, is a simple compound of carbon and hydrogen in the proportion of 75 per cent of the former to 25 per cent of the latter, the chemic formula being CH_4. It is one of a large number of carbon compounds running through petroleum, asphaltum, coal, jet, and graphite or plumbago, and ending with the diamond. The various compounds may be separated into two series, viz: (1) Those in which the carbon is predominantly fixed and which are commonly found where originally accumulated by organic or mechanical agencies; (2) those in which the carbon is predominantly hydrogenated, and which are more or less unstable mechanically and seldom found where originally accumulated. It is sometimes difficult to separate these series of compounds, since their extremities approach and perhaps unite, and since they are nearly connected at different points by divergent subordinate branches; but the distinction is a genetic one and logically valid.

The first class of compounds, which may be distinguished as the coal series, comprises, in order, carbonized and lignitized woods, brown coal, bituminous coal, cannel coal, anthracite, graphitic coal, jet, and some graphites. Most of these substances have been shown, and the rest have been logically inferred, to be products of arrested or incomplete decomposition in situ of organic (and generally woody) matter. The processes by which these compounds were transformed from the original to the present state in nature have been successfully imitated in the laboratory, and it has been ascertained that the essential conditions are that the decomposition shall be effected slowly and under some pressure, and that the free evolution of the ordinary gases of decomposition shall be prevented and their constituents largely retained, perhaps in new combinations. So the compounds of this series represent not only the original processes of aggregation by which the organic matter was accumulated, but later processes of integration or involution by which decomposition was effected with little loss of matter.

The second series comprises most of the compounds commonly classed as hydrocarbons, whether simple, oxygenated, or compound, viz: Marsh gas, the different varieties of rock gas, naphtha, petroleum, maltha (or natural tar), asphaltum, geocerite and other mineral waxes and resins, albertite and its allies, together with certain nonhydrogenated and approximately pure carbons, including some graphites and (perhaps) the diamond. While the origin of some of these minerals is doubtful and the exact relations among all are obscure, enough is known to justify the opinion that the various compounds belonging to this series represent processes of evolution and segregation of carbonaceous matter (perhaps accumulated elsewhere) within geologic deposits.

A divergent branch of the latter series, by which it is partially connected with the fixed carbons, appears to extend from petroleum through the paraffines to ozocerite, etc., and there are other subordinate branches of greater or less significance.

The lighter and mechanically unstable though chemically stable hydrocarbon compounds constitute the bitumens, which, in the order of their weight, are as follows:

1. Gaseous—marsh gas, rock gas, etc.
2. Volatile (or semi-gaseous)—naphtha.
3. Fluid—petroleum.
4. Semi-fluid—maltha.
5. Solid—asphaltum, geocerite, etc.
6. Rigid and brittle—"asphaltum glance," albertite, uintahite, etc.

Although the extremities of this group of bitumens are widely separated, the adjacent members are intimately related, sometimes interchangeable, and generally separable only with difficulty; and accordingly rock gas is simply the lightest known member of the bitumen family, which is itself the lighter part of the unstable hydrocarbon series. So closely are the several bitumens related that it is impossible to discuss the distribution or origin of any without considering the like attributes of all.

Unfortunately, it has not been found practicable to analyze the Indiana gas in the course of the present investigation, but a number of analyses of the Indiana and Ohio gas were made in July, 1887, for the U. S. Geological Survey, by Prof. C. C. Howard. These analyses were published by Orton,[1] but for the information of those to whom Orton's publication is inaccessible they are reprinted in the following table:

Composition of Trenton Limestone Gas.

Description.	Ohio.			Indiana.			
	Fostoria.	Findlay.	St. Mary's.	Muncie.	Anderson.	Kokomo.	Marion.
Hydrogen	1·89	1·64	1·94	2·35	1·86	1·42	1·20
Marsh gas	92·84	93·35	93·85	92·67	93·07	94·16	93·57
Olefiant gas	·20	·35	·20	·25	·49	·30	·15
Carbon monoxide	·55	·41	·44	·45	·73	·55	·60
Carbon dioxide	·20	·25	·23	·25	·26	·29	·30
Oxygen	·35	·39	·35	·35	·42	·30	·55
Nitrogen	3·82	3·41	2·98	3·53	3·02	2·80	3·42
Hydrogen sulphide	·15	·20	·21	·15	·15	·18	·20
	100·00	100·00	100·00	100·00	100·00	100·00	100·00

NOTE.—The Fostoria gas was taken from the water-tanks wells; the Findlay gas from the six wells of the Findlay Gas-light Company; the St. Mary's gas from the Wilkins well; the Muncie (Ind.) gas from wells Nos. 1, 2, 3, 4, and 6; the Anderson gas from the McCullough well; the Kokomo gas from wells Nos. 1 and 2, and the Marion gas from well No. 3.

SECTION III.—DISTRIBUTION OF THE BITUMENS.

General remarks.—Recent operations of the drill in Pennsylvania, and still more notably in Ohio and Indiana, have brought to light significant relations between the lighter hydrocarbons found in the rocks of these States. This relation can not be clearly set forth without a brief statement of the geologic and geographic distribution of these and other members of the series; so while it is impossible to describe all of the occurrences of bitumens throughout the world within the limits of this report, it seems desirable to give a brief review of the occurrences of gas and oil in the United States, and of the more im-

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[1] Eighth Ann. Rept. U. S. Geol. Surv., 1889, p. 592.

portant occurrences elsewhere. Fortunately the subject has been extensively treated by several recent authors, notably by Peckham, who, in the tenth volume of the Reports of the Tenth Census, discusses at length the origin, composition, distribution, and technology of petroleum and its allies. Still more recently the origin of the hydrocarbons of Ohio has been ably discussed by Orton in the Eighth Annual Report of the U. S. Geological Survey.

Recent deposits.—As the common use of its name implies, marsh gas is a well known natural product—indeed, it is the most widely known member of the bitumen series. It escapes more or less freely in every country from the muddy bottoms of ponds, shallow lakes, and sluggish streams, as well as through the stagnant waters of marshes and swamps. It is found in many localities in borings and excavations in recent deposits at the mouths of rivers and along the seacoast; e. g., quite recently considerable quantities of marsh gas have been found in the borings made in the process of reclaiming the Potomac marshes at Washington, where, as usual, it is liberated from stratified silt and mud charged with organic matter. Inflammable gas frequently escapes from peat bogs, notably in England, where it is sometimes found in sufficient quantity for utilization and is occasionally accompanied by petroleum. Marsh gas, sometimes accompanied by sulphuretted hydrogen, etc., is liberated in considerable quantities from the "salses," "mud lumps," and "mud volcanoes" frequently formed about the mouths of rivers and wherever else thick recent deposits charged with vegetal débris occur ; indeed, these outbursts are unquestionably due to the generation of gas within the deposits in sufficient quantity to elevate, tumefy, and finally rupture the strata ; and in Burmah, Trinidad, Aschperon, and elsewhere, the gas of the mud volcanoes is accompanied by petroleum in small quantities. In every case it is evident the amount of marsh gas generated within the recent deposits depends primarily upon the amount of contained organic or other carbonaceous matter, and secondarily upon temperature, and perhaps other conditions. The aggregate quantity of marsh gas constantly evolving from recent deposits and escaping into the atmosphere throughout the globe, particularly in the tropics, is incalculable but enormous—probably sufficient to appreciably affect the composition of the atmosphere.

Pleistocene.—During the last year or two a natural gas has been found in commercially valuable quantities at Bloomington, Kankakee, Mendota, and other points in Illinois, and in the forest bed intercalated within the glacial drift. Inflammable gas has also been found in the drift in sufficient volume for use in a small way at Herndon, Iowa, and at other points where the presence of the forest bed was not specifically noted, though the glacial deposits were found more or less carbonaceous and charged with disseminated organic matter. Drift gas also occurs under like conditions in various parts of Indiana and Ohio, and has proved an ignis fatuus for dozens of prospectors who supposed it to indicate the presence of great gas reservoirs in the underlying Paleozoic strata. In some cases this drift gas is accompanied by petroleum—e. g., in Delaware County, Iowa, a film of oil forms on the water of wells penetrating the forest bed and liberating gas; and recently a feeble spring of petroleum finding its source mainly in the Pleistocene-Columbia formation has excited attention in the District of Columbia. It is significant that in the Pleistocene, as in the recent deposits, the volume of gas is roughly proportional to the amount of contained carbonaceous matter and that the total volume annually evolved and lost in the air must be enormous.

Tertiary.—The richest available supplies of the various bitumens, except rock gas, come from Tertiary formations. Perhaps the most productive petroleum field in the world—that of Baku on the peninsula of Apsheron in southern Russia—finds its supply in undisturbed strata of the Aralo-Caspian formation of Murchison and his colleagues,[1] which is commonly regarded as late Pliocene and may be Pleistocene. As discharged from the wells at Baku the petroleum is without admixture of the heavier bitumens, though associated with considerable gas, by which the astounding flow appears to be determined; but asphaltum occurs abundantly (evidently as a desiccation product) in the same district, and both gas and naphtha escape in considerable volume through neighboring mud volcanoes and other natural vents.[2] The district has indeed long been known as the *field of fire*[3] by reason of the constant emission of inflammable gas, and was for centuries the goal of the longest pilgrimages of the fire-worshipping Parsees and Guebers from India and Persia, and the site of their largest temples, of which the ruins are still extant.

The richest asphaltum field in the world is in the island of Trinidad, where there is a lake of partially inspissated bitumen nearly a mile in circuit, apparently fed by springs of petroleum or maltha finding their origin in the slightly disturbed strata of the newer Parian (Miocene?) formation. The associated bitumens are gas, evolved not only on the inspissation of the heavier members of the series but from salses and other natural openings; "asphaltic oil," or petroleum; maltha and "asphaltum glance," which is "hard and brittle, of an intensely brilliant black luster and eminent conchoidal fracture."[4] The most extensive known accumulations of maltha occur in Tertiary rocks in the southern and southwestern counties of California. Here the

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[1] Geology of Russia in Europe, 1845, vol. 1, p. 297.

[2] Consular Reports 1887, vol. 74, pp. 400 et seq.

[3] Bischoff Chemical and Physical Geology (Works of the Cavendish Society), 1854, vol. 1, p 252.

[4] Report on the Geology of Trinidad (Memoirs of the Geological Survey of Great Britain), by Wall and Sawkins, 1860, p. 138 and elsewhere.

entire range of the bitumens from gas (seldom in sufficient volume for utilization), petroleum in such quantity as to form a valuable article of commerce, maltha in immense quantities, and some albertite[2] are found in association. Their source, as shown by Peckham, is a carbonaceous shale, with interbedded sandstones in which the oil is sometimes accumulated; both shales and sandstones being tilted and otherwise displaced by the movement accompanying the upheaval of neighboring mountains, according to Goodyear.[3]

Some of the largest known accumulations of albertite occur (generally in veins or "pockets") in greatly disturbed Pliocene beds in California, Mexico, and Albania. Perhaps the most valuable deposit of ozocerite in the world is found in Pleasant Valley, Utah, in the form of a vein intersecting Tertiary strata, little disturbed locally but rising into prominent ranges within a few miles. This ozocerite appears to be associated with a nearly complete series of the bitumens, ranging from rock gas in considerable quantities through petroleum (which issues from many springs) and asphaltum (evidently an evaporation product, and reaching thousands of tons in amount) to uintahite and gilsonite (rigid and brittle bitumens related to albertite). The rich petroleum fields of Burmese India, and those of Russia outside of Baku, find their supply in little disturbed Tertiary strata, and the oil is commonly associated with gas in greater or less volume and with asphalt occurring in such position as to indicate that it is an evaporation residuum; and in Dalmatia, Roumania, Albania, and throughout the Danubian principalities generally, considerably disturbed Tertiary strata yield bitumens commonly in the form of petroleum or maltha, accompanied by gas and in some cases by asphaltum, ozocerite,[4] etc. In Galicia "the petroleum is found saturating coarse and fine sandstone in zones or horizons, the lighter oils being found deepest."[5]

Cretaceous.—A richly productive oil field, and according to Dr. Newberry one of the most promising for the future in the United States, is that of Cottonwood Valley in southern Colorado. The oil of this field is heavy, in part approaching maltha in consistence; and there is so little associated gas that the oil flows quietly or requires pumping. Its source is the carbonaceous shale of the Fort Benton formation, here little disturbed, though greatly broken up in the contiguous mountain ranges. Oil springs and gas vents, generally of small yield, occur elsewhere in the Cretaceous formations of the western States and Territories. It is worthy of note that although the Cretaceous formations are, next to the Coal

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[1] Irelan, 7th Ann. Rept. State Mineralogist, 1888, p. 55; Weeks, Min. Res. of the U. S., 1887, p. 499.
[2] Peckham, Tenth Census U. S., vol. 10, p. 73.
[3] Seventh Ann. Rept. State Mineralogist, 1888, p. 71 and elsewhere.
[4] Peckham, op cit.
[5] Ibid., p. 72.

Measures, the richest formation in fixed carbons within the United States, they rarely yield oil or gas in considerable volume.

Jura-Trias.—Very little bitumen is obtained from the formations constituting this great group in any part of the world save in certain basins in Wyoming, where, according to Aughey, great volumes of gas and petroleum; with some viscid oils and considerable quantities of asphaltum, escape from Triassic sandstones and shales. The strata are here flexed and broken, and the richest oil and gas fields coincide with anticlines or quaquaversals; and as usual the asphaltum and maltha appear to be desiccation residua. The oil of the Washakie springs approaches maltha in consistence, and in the Shoshone basin gas and the lighter oils flow together or alternately from springs and artificial openings.[1] Small quantities of petroleum have been found in the Triassic of North Carolina, New Jersey, and Connecticut, and indurated bitumens have been found within or associated with the dikes by which the same rocks are intersected. It may be mentioned in passing that despite the presence of local coal beds within the Jura-Trias, its proportion of organic matter is probably lower than that of any other equally thick division of the geologic series. In eastern United States, particularly, the Triassic sandstones and shales are formed predominantly of materials which, as shown by Russell,[2] were completely leached and oxidized before deposition.

Carboniferous.—In portions of western Kentucky and Indiana, in Illinois, in western Missouri and eastern Kansas, and in many other localities, the Coal Measures yield either gas or petroleum or both, generally in limited quantities. The most promising western localities are in Kansas at Paola and Wyandotte, near La Cygne (where gas has constantly escaped since the days of the earliest explorers), at Girard and Pittsburgh, and notably at Fort Scott, where rock gas developed in the lower part of the Coal Measures or possibly at the summit of the Subcarboniferous, according to Hay, is used pretty generally throughout the city both as fuel and illuminant.[3] In Kansas the oils associated with the gas are generally heavy and occur in quite limited quantity; but the heavier bitumens are unknown. The richest oil and gas fields of the American Coal Measures occur in West Virginia and contiguous parts of Pennsylvania, Ohio, and Kentucky, and yield both bitumens in commercial quantities. The most extensive deposit of asphaltum thus far found in the Appalachian region occurs near the summit of the Carboniferous in Ritchie County, West Virginia; and petroleum, maltha and asphaltum have recently been discovered in such quantity as to warrant exploitation in the Coal Measures of northwestern Alabama. The

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[1] Ann. Rept. of the Terr. Geologist of Wyoming, 1886, pp. 33-83.

[2] U. S. Geol. Survey, Bull. No. 52, 1889.

[3] Trans. Kansas Acad. of Science, vol. 10, pp. 57-62.

limited volume of rock gas found in England comes from the Coal Measures.

The poverty in solid bitumens, gas, and oil of the great coal-bearing formation of the world is significant, and in view of popular belief in the association of bitumens with coal can not be too strongly emphasized.

The lower and non-coal-bearing part of the Carboniferous is a fruitful source of the lighter bitumens. The gas and oil of Mecca, Neff, and East Liverpool, in eastern Ohio, come from the Berea Grit, representing the Subcarboniferous; and several other Ohio wells find their supply in the same series of rocks. In general the bitumens of the lower part of the Carboniferous within the United States are light, comprising gas and petroleum; but there are occasional occurrences of the heavier bitumens, and one of the most extensive American deposits of albertite occurs in Subcarboniferous strata in New Brunswick.

No definite plane of demarkation separates the Subcarboniferous and Devonian sediments of the western flanks of the Appalachians in western New York and Pennsylvania, West Virginia, eastern Ohio, Kentucky, and Tennessee, and the upper part, at least, of the great Pennsylvania bitumen field might be referred to the Carboniferous perhaps as justly as to the Devonian; but to the latter formation it is generally assigned.

Devonian.—Probably the richest bitumen field in the world, measured by production up to date, and second only to that of Baku in oil (or that of Lima, Ohio, according to Orton) and to that of Indiana in gas, measured by its promise for the future, is that of western Pennsylvania and New York, which finds the greater part of its supply in the "oil sands" commonly referred to the Devonian. The bituminiferous rocks comprise a great thickness of carbonaceous shales, with three or four intercalated beds of sand. The first of these, or the "Venango oil sand," ranges from 300 to 325 feet in thickness in Venango and Butler Counties, and has yielded a great part of the oil and gas of Pennsylvania, including that of the great Murraysville district. Three hundred feet below lies the second or "Warren oil sand" of Warren and Forest Counties; and still lower occurs the famous "Bradford oil sand," which has been found nearly as productive as that of Venango. The several sandstones and associated shale beds are slightly affected by the undulations of the western flank of the Appalachian region; the bitumens are commonly believed to have been generated within the shales and to have escaped thence into and locally saturated the associated beds of sandstone; and, as shown by I. C. White,[1] they are imprisoned in anticlines and domes, the gas above and the oil below. The same series of deposits and their equivalents are petroliferous over an enormous area

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[1] Science, vol. 5, pp. 521, 522.

extending from central New York to or beyond Tennessee; and the Ohio shale, which corresponds in part to the Pennsylvania oil sands, has yielded a considerable aggregate volume of gas, though the flow from individual wells is commonly small. In general the bitumens found in the upper part of the Devonian are light, and neither maltha nor asphaltum has been found in noteworthy quantity; but the liquid may be said to predominate over the gaseous form.

The Corniferous and Hamilton limestones have long been recognized in Canada as a source of "an admixture of hydrocarbons differing in volatility"[1] ranging from gas through naphtha, ordinary petroleum, and asphalt, to a rigid and brittle bituminous mineral;[2] and during recent years the oil fields of Petrolia and Oil Spring have become noted as commercially important sources of petroleum, which is associated with some gas, originating in the same formations. In Canada, as generally elsewhere, the bitumens are accumulated along the crests of anticlines. A moderate flow of gas has recently been found in the Corniferous at Salem, Indiana; and the widely distributed black shale of the Devonian, which is everywhere more or less carbonaceous, is petroliferous in a small way.

Silurian.—Within the upper part of the Silurian, bitumens occur frequently in small quantities but are seldom accumulated in sufficient volume to warrant exploitation within the United States. In Indiana, petroleum was found at Terre Haute and gas at Vernon, in the Niagara limestone; the Niagara has yielded gas in small quantities at Chicago, and is frequently characterized by a bituminous odor throughout the Mississippi Valley; and the Clinton formation yields gas at Fremont and elsewhere in Ohio, one well at Lancaster having a daily flow of nearly a million cubic feet. Within the lower part of the Silurian, however, there have been found the most extensive accumulations of rock gas thus far known, the great Indiana and Ohio gas fields (the richest in the world) deriving their supply from the Trenton limestone. Here, as in Pennsylvania, the porous formation (there a sandstone, here a limestone) is simply the vehicle or reservoir for the hydrocarbons. The bituminiferous formations of Indiana and Ohio have suffered only slight deformation, but enough to provide reservoirs of enormous though unmeasured capacity. The Trenton limestone is an important source also of gas and oil in Kentucky, Tennessee, and elsewhere; and both bitumens occur in the Hudson River shale in moderate amount in Indiana, Ohio, and several other States. Both gas and oil are heavier in the Indiana and Ohio fields than in those of Pennsylvania.

Pre-Silurian and Eruptive.—Thus far the bitumens have been found in the Cambrian and older rocks in limited quantities only, the graphites, etc., sometimes contained in the rocks probably belonging, in part at least, to the series of fixed carbon compounds. The

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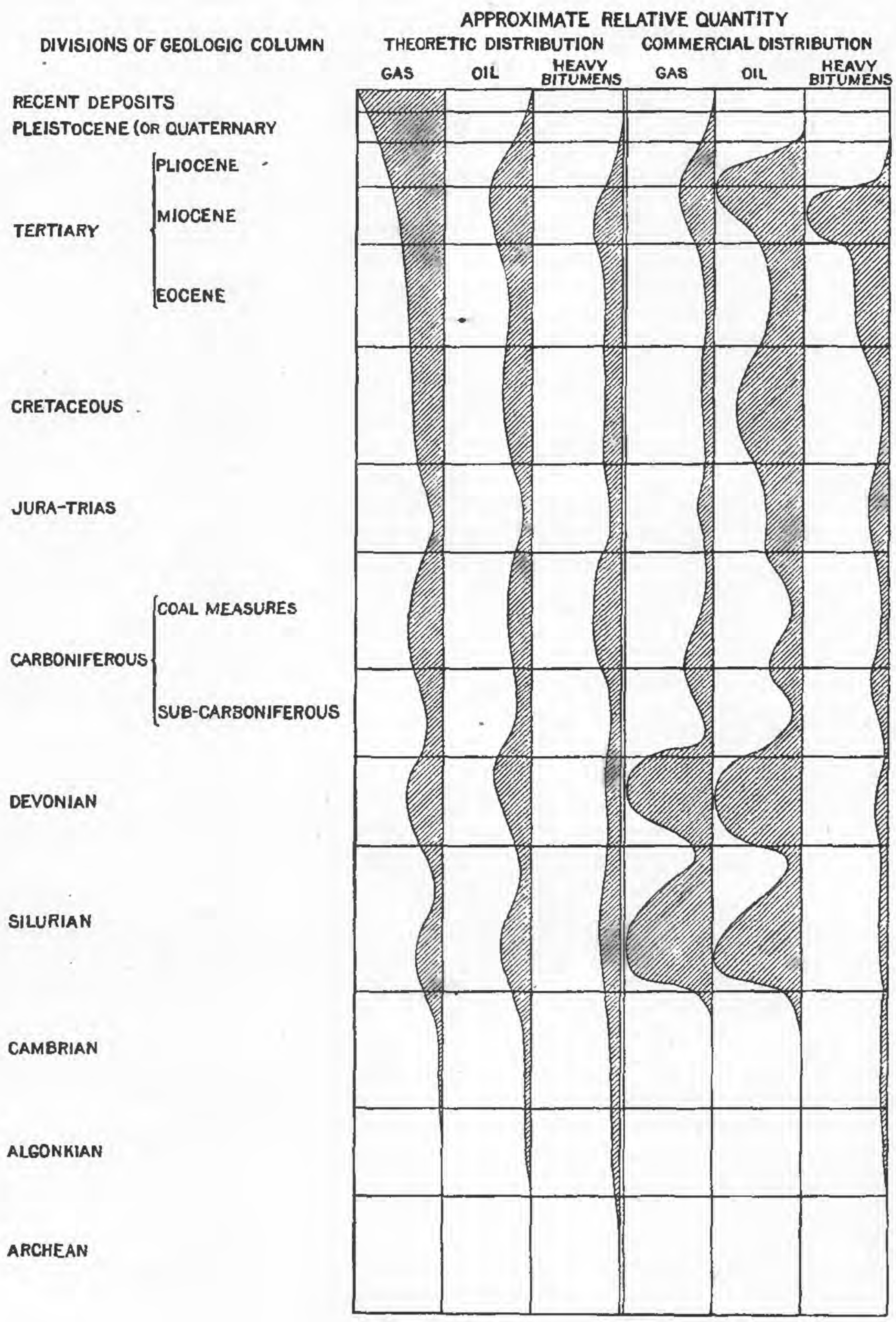
[1] Geology of Canada, 1863, p. 789.

[2] Ibid., pp. 524, 791.



GEOLOGIC DISTRIBUTION OF BITUMENS.

Algonkian shales of Michigan and Wisconsin are, however, locally saturated with hydrocarbons possessing all the characteristics of those found higher in the series. The eruptive rocks are of course generally destitute of the mechanically unstable carbon compounds, though this is not always the case—e. g., there are seams and pockets of solid bitumen in the Triassic traps of Connecticut and New Jersey;[1] and albertite is frequently found within veins sometimes regarded as eruptive[2] though more commonly (and justly) considered an evaporation residuum or sublimate.[3] The diamonds of the great Kimberley fields of South Africa, too, are found in basaltic necks or dikes penetrating carbonaceous shales, and are, according to Lewis, products of some process of segregation.[4]

Résumé.—Summarizing the recorded geologic and geographic distribution of the bitumens (which is but imperfectly exhibited in the preceding synopsis and the accompanying graphic representation forming Pl. LXII) it appears that these substances are found in greater or less quantity throughout nearly the whole of the geologic series and in nearly every country. The greater part of the commercially valuable bitumens are, however, concentrated in three widely separated parts of the geologic column, viz: (1) In the Tertiary in nearly all the known forms; (2) in the upper Devonian as petroleum and gas, the former probably predominating; and (3) in the Silurian as gas with associated petroleum. This concentration of the commercially valuable bitumens in certain formations and localities appears, however, to be in part due to local conditions, and thus fortuitous, and so it can not be regarded as representing a general law of either geologic or geographic distribution. As shown by Orton in Ohio and by Phinney in Indiana, the vast accumulation of gas and oil in the Trenton limestone is not so much due to the abundance of the hydrocarbons within this and associated formations as to local accidents of structure. The Silurian formations throughout the Mississippi Valley are fairly uniform in position and everywhere contain the hydrocarbons in greater or less volume, but it is only where they are flexed in such manner as to form inverted troughs or bowls in which the hydrocarbons are concentrated by hydrostatic pressure and confined by impervious overlying strata that either gas or oil is found in such quantity as to warrant extensive exploitation. The vast accumulation of oil and gas within the Pennsylvania fields also appears to be due to structural conditions, as long maintained by I. C. White; for although White's contention that the gas, oil, and water are arranged within the anticlines and domes in the order of their weight was at first strenuously opposed, it is fully sustained by recent developments of the drill. The occurrences of extensive accu-

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[1] Peckham, Rep. tenth Cen. U. S., 1884, vol. 10., p. 19.

[2] Peckham, ibid., p. 73.

[3] Dana, Manual of Min. and Pet., 1887, p. 350.

[4] Science, 1886, vol. 8, p. 345.

mulations of the various bitumens within the Tertiary can not, however, be considered as fortuitous, since the localities are many and widely separated; yet the local concentration and the local character of the bitumens appear to be affected by deformation of the strata. Even the dearth of commercially available bitumens in recent and Pleistocene deposits must be attributed, at least in part, to accidents of structure and texture, in consequence of which the lighter members escape so freely that, despite their considerable volume, they can not be utilized. The influence of conditions of structure must be constantly borne in mind in discussing the geologic distribution of the bitumens.

On seeking to deduce a general law of geologic distribution of the unstable carbon compounds, four generalizations appear. The first is that, other things equal, the volume of these substances is inversely proportional to geologic age, the proportionate volume diminishing progressively as the geologic column is descended. If allowance be made for the relative duration of the different epochs, for the degree of concentration of the bitumen, and for the possible freedom of escape due to structural and other conditions, etc., this generalization alone expresses fairly all that is now known concerning the distribution of the bitumens.

The second generalization is that, other things equal, the weight of the bitumen varies directly with geologic age, ranging from the marsh gas of recent deposits to the viscid oils, asphaltum, etc., of older formations. In this generalization much allowance must be made for structural accidents, possible freedom of escape, and degree of desiccation of the substances. Even then the relation is scarcely evident when the entire range of the phenomena is considered at the same time; but in regions of uniform geologic history the law is generally exemplified, and the bitumen found to increase in weight from the newest to the oldest formations.

The third generalization is that, other things equal, the weight of the bitumen varies directly with the deformation suffered by the strata, ranging from the marsh gas and associated light oils of the little disturbed recent and Pleistocene deposits, to the heavy oils, asphaltum, albertite, and perhaps the graphite and ozocerite of greatly disturbed and altered deposits. This generalization, like the first, also comprehends the greater part of the known facts; and the law which it expresses seems to be widely applicable.

The fourth generalization is that "the oil and gas derived from limestones contain larger proportions of sulphur and nitrogen than are found in the oil and gas of the shales,"[1] and are thus the more unstable and rank-odored.

The third generalization is so clearly exemplified in the Pennsyl-

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[1] Orton, Eighth Ann. Rept. U. S. Geol. Surv., 1889, p. 494.

vania-Ohio-Indiana field that it may safely be accepted as a guide to future exploration. The slightly disturbed formations of western Pennsylvania, gently corrugated into low anticlines and synclines by the weakened Appalachian uplift, generally contain petroleum with some heavier oils and considerable associated gas. In Ohio, where the disturbance of the rocks is less, gas is the predominant hydrocarbon, but considerable oil is associated. In Indiana, where the deformation reaches a minimum, only small quantities of petroleum are associated with the abundant gas. It is noteworthy, however, and apparently inconsistent with the first generalization, that both gas and oil are heavier in the little disturbed and older deposits than in the more strongly corrugated and newer part of this region.

These generalizations and others based upon the common processes of technology contribute to the solution of the problem of the origin of the bitumens.

SECTION IV.—THE NATURAL STORAGE OF THE LIGHTER BITUMENS.

The apparent inequality in geologic and geographic distribution of the bitumens is now known to be due mainly to circumstances affecting the local accumulation; and it was largely by the discovery of this fact that the gas and oil problem was solved. The conditions of accumulation of the lighter bitumens are related to or identical with those governing the accumulation of artesian water. These are well known; but for the purpose of elucidating the relation between rock structure and accumulation of oil and gas, they may be stated.

In the inverse order of their importance, the requisites for artesian flow of water are, (1) conditions of structure, (2) conditions of texture, and (3) conditions of supply. The most favorable structural condition is an arrangement of the strata in the form of a basin, as in the province of Artois in France, from which the flowing well takes its name. The rain water falling upon the rim of such a basin percolates through the strata to its center, and there rises through natural or artificial openings to a height depending upon the difference in altitude between the area of supply (or catchment area) and the head of the well; but the basin structure is *not* absolutely essential, and artesian flows are obtained from uniformly inclined strata (such as those constituting the Atlantic coastal plain) when the catchment area is elevated considerably above the well-head, or when the strata either diminish in permeability in the direction of inclination or extend far beyond the point of outlet, i. e., textural and other conditions may combine with structure to produce flow where structure alone is unfavorable. The most favorable textural condition is found when the porous stratum extends from the catchment area to the part of the basin, trough, or monocline tapped by the drill, and is overlain (excepting in the catchment area) by an impervious stratum. This condition, like the last, is not absolutely essential to artesian flow, since all rocks are more or less pervious, and if the difference in altitude between catchment area and well-head is sufficient a slight flow may be obtained almost anywhere; but it is essential to abundant flow, and indeed to the slightest flow, unless other conditions are exceptionally favorable. The most favorable condition of supply is found where a porous formation rises from beneath less porous strata and forms the surface over a broad area. It should be borne in mind that on nearly all parts of the land the annual aggregate volume of rainfall largely exceeds the aggregate volume of river flow; that a considerable part of the water not carried directly into the sea by the rivers finds its way thither more slowly by percolation through the rocks; and that in consequence the strata of the earth—at least below the reach of surface evaporation—are more or less completely saturated. Even in desert regions a part of the rain drank by the thirsty sands during each rare storm reappears in springs or may be reached by artesian borings to form oases at lower levels. In short, while the condition of supply is the essential and primary one, it is a fact that the supply is adequate in nearly all parts of the earth, and that artesian flow or its failure are usually determined by local conditions of structure and texture.

The essential conditions of accumulation of the lighter bitumens are like the foregoing in all respects save that the arrangement of the strata must be reversed and the basin or trough converted into a dome (quaquaversal) or an inverted trough (anticlinal), when the requisite structural condition is met. The requisite textural conditions for bitumen accumulation are identical with those for water accumulation, i.e., there is required a porous stratum through which the bitumens may freely pass and within which they may be stored up, and an overlying impervious stratum, or cover, by which their escape is prevented. The third condition, or condition of supply, is met (as will more clearly appear later) whenever the rocks are charged with organic tissue not yet completely decomposed; and since nearly all the sedimentary rocks of the earth, at least above the Cambrian and outside of mountain regions, contain such matter, the primary requisite for oil and gas accumulation is almost as universal as that for artesian water accumulation. So in every locality the solution of the bitumen problem depends mainly upon the local elements of structure and texture. It should be noted, however, that the conditions of accumulation of the heavier bitumens differ more or less from those governing the accumulation of the lighter members of the series; but they do not require consideration in this connection.

Every richly productive gas field, at least in eastern United States and Canada, is a dome or inverted trough formed by flexure of the strata; and in every such dome or inverted trough there is a porous stratum (sandstone in Pennsylvania, and coarse-grained magnesian limestone in Ohio and Indiana) overlain by impervious shales. These domes or arches vary in dimensions from a few square miles in some of the Pennsylvania areas to 2,600 square miles in the great Indiana field. The last mentioned field is not, indeed, a perfect dome, but its structural incompleteness only emphasizes the importance of the textural condition. It is the northern part of the great quaquaversal known in geologic literature as the "Cincinnati arch," whose apex is trenched nearly or quite to the gas-bearing stratum by the Ohio River near Cincinnati; but approaching this breach the Trenton formation, which toward the north is partly a porous dolomite, becomes a pure, fine-grained, and non-porous limestone. The great trough has one end open, but the texture of the rocks forms an impassable barrier against the escape of gas and oil, and their accumulation is secured by the combination of conditions.

Within each gas-charged dome there are found three or more substances arranged in the order of their weight; gas at the top, naphtha (if it exists in the field) and petroleum below, and finally water, which is generally salt and sometimes a strong and peculiar bittern. This order is invariable throughout each field, whatever its area, although in Indiana, at least, the oils are found most abundantly about the springing of the arch, while toward its crown gas immediately overlies brine; and the absolute altitude of the summit level of each substance is generally uniform whatever the depth beneath the surface. Thus the "dead line," or plane beneath which the bitumens are not found, is in Indiana 100 feet, in the Findlay (Ohio) gas field, 400 feet, and in the Lima (Ohio) oil field, 500 feet below tide. This relation to tide level is of course fortuitous; but its recognition in each field is important to the prospector. Now the volume of gas or oil accumulated in any field evidently depends on the area and height of the dome in which it is confined and upon the porosity and thickness of the rock in which it is contained, and thus the productiveness of a given field may be definitely predicted after the structure and texture of the rocks have been ascertained. It is of interest to note that the area of the Indiana field is seven or eight times that of the Pennsylvania-New York and Ohio fields combined; that the Indiana dome is the highest of all, and that in this State the gas-bearing stratum is as porous and as thick as in any other field of anything like commensurate magnitude. So it would appear that the great gas field of Indiana not only promises better for the future than any other thus far discovered, but, since the Cincinnati arch is by far the largest simple quaquaversal in the country if not in the world, and since textural conditions are here more favorable than in any other great dome known to the geologist, that this field is destined to ever head the list of the world's gas-producing areas.

In all productive bitumen fields the gas and oil are confined under greater or less pressure. When a gas well is closed, it is commonly found that the pressure at the well head gradually increases, through a period varying from a few seconds in the largest wells to several minutes or even hours in wells of feeble flow; and that afterward the pressure-gauge becomes stationary. This is the "confined pressure," "closed pressure," or "rock pressure" of the prospector, or more properly the *static pressure*. When a well is open and the gas escaping freely into the air, it is found that if the stem of a mercurial or steam gauge be introduced, a certain constant pressure is indicated upon the gauge. This is the "open pressure" or "flow pressure" of the gas expert or the *dynamic pressure* of the systematic student; and the capacity of the well may be determined from it. The static pressure varies in different fields. In Indiana it ranges from 300 to 350 pounds per square inch; in the Findlay field it is from 450 to 500 pounds; and in the Pennsylvania field it reaches from 500 to 900 pounds. The cause of this enormous pressure is readily seen in Indiana. The Cincinnati arch is substantially a dome about 50 miles across, rising in the center of a stratigraphic basin fully 500 miles in average diameter; throughout this basin the water falling on the surface is in part absorbed into the rocks and conveyed towards its center, where strong artesian flow of water would obtain were the difference in altitude greater; and the light hydrocarbons floating upon the surface of this ground water are driven into the dome and there subjected to hydrostatic pressure equal to the weight of a column of water whose height is the difference in altitude between the water surface within the dome and the land surface of the catchment area about the rim of the inclosing basin. Accordingly the static pressure is independent of the absolute altitude of the gas rock and of its depth beneath the surface, except in so far as these are involved in the relative altitudes of the gas rock and a catchment area perhaps scores or even hundreds of miles distant. Gas pressure and oil pressure may therefore be estimated in any given case as readily and reliably as artesian water pressure; but while the water pressure is measured approximately by the difference in altitude between catchment area and well-head, that of gas is measured approximately by the difference in altitude between catchment area and gas rock, and that of oil is measured by the same difference minus the weight of a column of oil equal to the depth of the well. It follows that the static pressure of gas (as indicated at the surface) is always greater than that of oil, particularly in deep wells. It follows also that the pressure, whether of gas or oil, is not only constant throughout each field, but diminishes slightly if at all on the tapping of the reservoir until the supply is exhausted; and hence that pressure is little indication of either abundance or permanence of supply.

So the concentration of light bitumens in the lower part of the geologic column (the Devonian in Pennsylvania and New York, and the Silurian in Ohio and Indiana) manifestly depends upon fortuitous and local conditions of rock structure and texture, and the apparant anomalies in the geologic distribution of the bitumens vanish; the primary generalization concerning the distribution of these minerals—i. e., that their volume is inversely proportional to geologic age—is thus strengthened; and at the same time the mysteries of the apparently adventitious accumulations of gas and petroleum in the Paleozoic rocks of the Mississippi Valley and of the enormous pressures to which they are subjected completely disappear.

SECTION V.—THE ORIGIN OF ROCK GAS AND RELATED BITUMENS.

In considering the genesis of rock gas it must be constantly borne in mind that it is but one of a series of bitumens of common or at least related origin; and moreover, that chemists and geologists are not in full accord as to the causes of diversity among the various members. Thus, it is evident from the boring records of subsequent pages that the gas and oil of the Indiana field are separated from each other and from the associated brine chiefly by gravity; it is equally evident, as pointed out by I. C. White and Orton, that the bitumens of the Pennsylvania and Ohio fields are similarly separated; and it is also evident that the maltha and asphaltum of Trinidad, California, Canada, and Galicia are, at least in part, residua left after evaporation of the gaseous elements. It is nevertheless true that certain bitumens do, while others do not, contain paraffin; that bitumens of certain localities are always gaseous, those of other localities always liquid, and those of still other localities always viscid or solid under the conditions of observation; that certain light bitumens do not form asphaltum upon desiccation; and that there are certain constant differences in the behavior of petroleum and artificially distilled coal oil under the processes of technology, e. g., limestone petroleum is much more refractory than shale petroleum: and these facts have led some students to doubt the close genetic relations of the several compounds. Most American geologists, however, regard the various bitumens found in the rocks of the earth as essentially of common origin.

Various hypotheses concerning the genesis of the lighter bitumens specifically, or of the bitumen family in general, have been framed. Those most prominently advocated and at the same time inherently probable fall into two classes commonly called "chemic" and "non-chemic," or more properly *inorganic* and *organic* (since chemic processes are contemplated in both, those of the one class being reactions and other changes among inorganic substances, and those of the second reactions and other changes among both inorganic and organic substances). They are as follows:

I. Hypotheses of inorganic origin:
    1. Berthelot's hypothesis of origin through contact of carbonated waters with the alkali metals.
    2. Mendelejeff's hypothesis of origin through contact of water with highly heated metallic iron and metallic carbides.

II. Hypotheses of organic origin:
    1. Bischoff's hypothesis of origin through primary decomposition (sometimes followed by dry distillation) of vegetal substances contained in sedimentary strata.[1]
    2. Newberry's hypothesis of origin through secondary decomposition or slow spontaneous distillation at low temperature of the organic matter (mainly vegetal) of shales, etc.
    3. Hunt's hypothesis of origin through primary decomposition of organic matter accumulated in limestones.
    4. Coquand's hypothesis of origin through primary decomposition of organic matter in deep-lying strata and accumulations in newer strata at the time of deposition through the action of springs.[2]
    5. Lartet's hypothesis of origin through distillation of organic matter in deep-lying strata accompanying metamorphism by pressure and the action of superheated waters, and of convection to the surface by springs.[3]
    6. Peckham's hypothesis that certain bitumens are of animal origin and indigenous in the rocks, and others of vegetal origin and the product of distillation under the influence of heat generated by orogenic movement.
    7. Orton's modification of Hunt's hypothesis, i. e., of origin through primary decomposition of animal and vegetal tissue contained in shales and limestones.[4]

In Bischoff's hypothesis, the various hydrocarbons are supposed to evolve either simultaneously or in the order of their weight, from the lighter to the heavier. In Newberry's hypothesis, carburetted hydrogen is supposed to appear on primary decomposition, while the oils are considered the product of longer continued or more intense bituminization.[5] In Hunt's hypothesis the bitumen is supposed to form originally as petroleum, which on coming to the surface gives

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[1] Elements of Chemical and Physical Geology (Works of the Cavendish Society), 1854, vol. 1, pp. 252, 274, 291-296.

[2] Bulletin Société géologique, 2d ser., 1867, vol. 24, pp. 506, 565.

[3] Expl. géol. de la Mer Morte, 1877, p. 315; and Bulletin Société géologique, 2d ser., 1867, vol. 24, pp. 30-31.

[4] U. S. Geol. Survey, 8th Ann. Rep., 1889, p. 498-505.

[5] Fourteenth Ann. Rept. Ohio State Board of Agriculture, p. 607.

off gas, leaving heavier residua behind. In Coquand's hypothesis, too, petroleum is considered the original form and supposed to have volatilized in porous strata, liberating gas and leaving heavy residua. In Lartet's hypothesis the bitumens are supposed to develop in the order of their weight, from gas to petroleum or maltha, with the progress of decomposition. Peckham, like Hunt and Coquand, considers the original form to be petroleum, hardening on desiccation—probably with the evolution of gas—to maltha and asphaltum (though he regards albertite as eruptive); and Orton in like manner holds that petroleum is the original form, and that it gives rise to marsh gas and suffers decomposition on exposure to destructive agencies.

It is not proposed to discuss these or other hypotheses at length. Students will find the subject elaborately treated, with references to the greater part of the literature, in volume 10, of the Reports of the Tenth Census, 1884; volume 6, of the Reports of the State Geological Survey of Ohio, 1888; in the Eighth Annual Report of the U. S. Geological Survey, 1889; and a bibliography of petroleum (including other hydrocarbons), arranged chronologically, may be found in the Annual Report of the Geological Survey of Pennsylvania for 1886. It will suffice to say that every American and nearly every foreign geologist has rejected the non-organic hypotheses of origin, and that the notable preponderance of bitumens in newer strata is the converse of the distribution demanded by the hypotheses. With respect to the organic hypotheses, the pendulum of opinion has swung first to this side and then to that, the amplitude of each oscillation depending upon the local conditions of the problem as attacked by different investigators; but in America, where the opportunities for investigation are unexampled, it has again settled in very nearly the position in which it was left by Bischoff. Hunt, Peckham, and Orton have indeed shown that the unstable hydrocarbons may be the product of animal as well as vegetal decomposition; Newberry has shown that the organic matter in the older rocks has generally undergone disorganization (or primary decomposition), and that the evolution of bitumen from such rocks accompanies a completion of previously arrested alteration (or secondary decomposition) which approaches in character the process called *distillation* in technology, though it may be questioned whether the primary and secondary processes of decomposition are essentially distinct; Coquand, Lartet, and Peckham have shown that the action of subterranean waters and orogenic movement bear upon the development of the bitumens; and White, Orton, and Phinney have elucidated the relation between the structure and texture of the rocks and the accumulation of gas and oil; but all geologists and most chemists of this country to-day coincide in Bischoff's opinion that the various bitumens are genetically connected with and closely allied to marsh gas, and that they are produced by natural decomposition of organic tissue. It is pertinent to add that all recent investigations strongly corroborate this view of the genesis of the lighter bitumens.

Since, however, the object of the present report is as much to give intelligent direction to future exploration as simply to record statistics of gas and oil, it seems desirable to set forth those generalizations and inferences concerning the origin and distribution of the hydrocarbons which have been developed in the progress of the investigation described herein, and which promise to be of practical utility to future explorers.

It has long been known that small quantities of petroleum and gas occur in nearly every formation in Indiana and Ohio, and indeed of the eastern slope of the Mississippi Valley, though they are not found at every locality; and their aggregate amount is enormous. Dr. Newberry estimated that the bituminous matter in the Huron shale of Ohio is equivalent to that contained in a coal bed 40 feet thick; and where it is not reduced or removed by erosion the Black Shale of Indiana may safely be estimated to contain bitumons equal to a coal seam 15 or 20 feet in thickness. Other formations, too, abound in both oil and gas. The Lower Helderberg and Niagara limestones may be recognized by their characteristic bituminous odor throughout the Mississippi Valley; the cavities of corals and other fossils in the Corniferous limestone at Jeffersonville and elsewhere are frequently filled with petroleum; the limestones occurring near the summit of the Hudson River formation are commonly more or less bituminous; all of the argillaceous formations of Indiana locally yield shale gas, and the intercalated limestone beds sometimes yield the same bitumen in commercially valuable quantities. Orton estimates that the petroleum contained in each square mile of the stratified rocks of Ohio at 75 million barrels, or nearly one-half of the total product up to date of the entire Pennsylvania-New York oil fields. While most of this bituminous matter is so widely and so sparsely distributed as to be of no practical value under existing commercial conditions, its presence is significant.

In addition to the bitumens already differentiated and lodged within the rocky strata there is a vast amount of partially decomposed organic matter in every formation of the geologic series. The external crust of the earth is a veritable charnel house on an immense scale; limestones, often hundreds of feet in thickness, are composed largely of comminuted remains of sponges, corals, mollusks and diatoms; the argillaceous beds, which are of even greater volume, are charged with the remains of sea-weeds, land plants, woody matter, microscopic spores, and other vegetal products; the bituminous shales associated with the coal seams contain immense quantities of woody and peaty matter; and everywhere throughout nearly the entire sedimentary series of the Mississippi Valley, and indeed of the world, the strata abound in remains of organisms not yet completely decomposed. Let it be noted, too, that the strata containing undecomposed organic tissue are everywhere identical with or adjacent to those containing the bitumens; and that not only in American gas fields but throughout the globe the productiveness of the rocks in hydrocarbons (including the hydrocarbon coals) is closely proportionate to the amount of contained organic matter.

This association of fossiliferous with bituminiferous rocks is too intimate to be fortuitous, and even by itself shows that the problem of the origin of rock gas and related bitumens finds its key in the daily operations of laboratory and manufactory and in natural processes exemplified in every reeking marsh in field or forest on the face of the globe.

According to Peckham, "The experience of technology has shown that if coal or pyroschists are distilled at the lowest possible temperature, particularly in the presence of steam, a black tarry distillate is obtained, along with a considerable quantity of marsh gas and very volatile liquids that can not be condensed except at low temperature. * * * It is impossible to conduct this primary * * * distillation without producing marsh gas, but the amount and density of the fluid produced will depend on the temperature at which the distillation is carried on and the rapidity of the process."[1] And in his studies of metamorphism, Daubrée "a pu transformer du bois, soumis à l'influence combinée de la pression et de l'eau sur chauffée, successivement en lignite, en houille et en anthracite, et il en a ainsi séparé des hydrogènes carbones, possédant jusqu'à l'odeur caractéristique du bitume."[2]

This appears to be precisely what takes place when, under somewhat different conditions of temperature and rate, marsh gas is generated in the muddy bottom of a pond. In the natural process, however, the transformation takes place with extreme slowness, and is by most students no longer called distillation but decomposition; but whether there is more complete decomposition of the organic matter and consequent diminution of the solid residue (itself susceptible of redistillation at slightly higher temperature or, probably, at a somewhat lower rate), or whether the solid residue combines with associated beds after the manner of the humus acids set free on more rapid decomposition in air, this residue disappears or becomes unrecognizable. The freedom with which marsh gas is evolved indicates that the disorganization of plant and animal remains imbedded within recent deposits progresses rapidly and produces only the lightest of the hydrocarbons, so long as the burial is shallow and

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[1] Rept. Tenth Census, 1884, vol. 10, p. 69.

[2] "Was able to transform wood, through the combined influence of pressure and superheated water, successively into lignite, into coal, and into anthracite, and thereby he separated from them hydrocarbons possessing the exact odor characteristic of bitumen.—Expl. géol. de la Mer Morte, 1877, p. 315; cf. Géologie Expérimentale, 1879, pp. 177, 178.

the strata are freely permeable to air and water; and this free evolution of marsh gas—usually without the heavier members of the series—indicates also that the lightest of the hydrocarbons is the first in order of development, and no doubt by far the larger part of the gases of decomposition (especially of the softer tissues) escape into the air, while shallow burial and ready permeability persist. Immense quantities of organic matter are, however, deeply buried before its transformation is effected; indeed, as already shown, the process is not complete even in the lower Paleozoic strata, though it may there be essentially secondary. Decomposition must be retarded by such burial, though it doubtless continues at a lessened rate so long as undecomposed matter exists and the sediments remain in any degree permeable to water and air and subject to molar or molecular changes due to increasing pressure or temperature. The experience of technology, the results of experiment, and observation upon the widely known phenomena of marsh gas, all indicate that rock gas and its allies are simple products of decomposition of organic matter contained in the rocky strata of the earth, and that their evolution is now in progress in all rocks containing partially decomposed organic remains at a rate depending on the amount of matter yet undecomposed and on depth of burial (together with certain other conditions), or, in general terms, upon geologic age. This inference coincides with the first generalization deduced from geologic distribution. It is probable, however, that the weight and certain other attributes of the hydrocarbons thus generated—e. g., the presence or absence of paraffins, benzines, etc.—are determined by other conditions.

In general the formation of marsh gas is not accompanied by the formation of the heavier hydrocarbons; but in the deeply buried forest bed of the Pleistocene drift, where considerable pressures obtain, and in mud volcanoes, where the pressure is not only considerable but where the temperature is locally raised by the internal movement, pretroleum occurs, i. e., the heavier appear to be the later formed members of the bitumen family. This inference is in harmony with the second generalization deduced from the geologic distribution of the substances.

In the rapid processes of technology and laboratory experimentation, as well as in the more active "mud volcanoes" of recent times, tarry or oleaginous distillates are evolved with the gas; i. e., when the processes of distillation are intensified, heavier bitumens are formed in connection with the lighter. Now, whether or not still heavier members of the series are formed where comparatively gentle "mud-lump" movement gives place to decided orogenic movement has not been ascertained by direct observation; but analogy would indicate that the mud-lump petroleum is itself a natural distillate, and that still heavier members of the series might be formed in similar manner if the natural processes were still further intensified or still longer continued. So the results of laboratory experimentation and common observation alike, and the logical inferences therefrom, all harmonize with the third generalization recorded above, i. e., that, other things equal, the weight of the bitumen varies directly with the amount of deformation the rocks have suffered. The limits of the operation of this law have not been defined, and it may extend to dehydrogenation, and even into the domain of crystallization, and thus to the formation of graphite as a furnace product and of the diamond as either a natural or artificial product. It is probable, however, that the heavier hydrocarbons (at least from maltha downward) explored or exploited up to the present date are mostly residua left after evaporation of the lighter members.

Thus far bitumens do not appear to have been formed from animal matter either in the laboratory or in natural sediments under conditions open to inspection; but the observations of Peckham upon the apparently animal oils of California, the inferences of Hunt and Orton from the nitrogenous character of the limestone oils, and the similarity in composition in animal and vegetal organisms, all indicate that both animal and vegetal tissues under certain conditions of disorganization yield hydrocarbons differing but little in composition. This inference is in line with the fourth generalization above noted.

In short the hypotheses suggested alike by the observations in Indiana, by the phenomena of the bitumen fields of the world, by common manufacturing processes, by the results of laboratory experimentation, and by observations upon a well known natural process, are as follows:

(1) Rock gas is a simple product of slow primary decomposition at low temperature of organic matter (animal and vegetal) contained in natural sediments;

(2) Petroleum is a simple product of primary decomposition of organic tissues imbedded in sediments when the process is long continued or accelerated by rise of temperature, increase of pressure, or orogenic movement;

(3) The heavier bitumens may be products of primary decomposition of organic matter contained in sedimentary strata when the process of decomposition is exceedingly long continued or greatly intensified by heat, pressure, or structural deformation; but most of them are doubtless residua left after evaporation of the lighter members of the series;

(4) In recent deposits, gas alone may be generated, but in older deposits gas and oil are commonly generated simultaneously in pro-

portions varying with the rate of the process and the extent to which it has been carried; or in brief—

(5) Rock gas, petroleum, and the heavier bitumens are simple products of natural processes of decomposition of the organic matter contained in sediments; and their weight and other attributes depend upon the conditions under which decomposition takes places.

SECTION VI.—THE FUTURE OF ROCK GAS AND ITS ALLIES.

The exploiter and consumer of rock gas daily inquires with a degree of anxiety depending upon the current state of the well or of the tank supplied from it, "Is natural gas yet forming?" To this question an affirmative answer may be confidently given. Moreover, it may be predicted that gas will continue to form until the organic matter disseminated throughout the formations of the world is completely decomposed, though the rate will ever decrease and the proportion of oil to gas generated as the ages go on will constantly but slowly increase. But this affirmative answer and prediction can scarcely be regarded as encouraging to the prospector of to-day. There is no reason to believe that rock gas is generated as rapidly within any hundred feet of Paleozoic strata as within an equal thickness of the overlying Pleistocene and recent deposits; and although the escape of the deeper gas is retarded by the blanket of newer deposits, there is not a shadow of reason for believing that gas is accumulating within any of the famous fields as rapidly as it is consumed. Rock gas is indeed forming daily throughout the entire Paleozoic basin whose bottom swells into the Cincinnati dome; throughout by far the greater part of this vast area it escapes into the air as rapidly as generated, yet so slowly that the escape is not perceived; it is only where natural reservoirs have been formed by accidents of structure and texture that the gas is stored in considerable volume; and it is unquestionable that, as soon as the supply within the Cincinnati dome, representing the accumulation of millions of years, is exhausted, the rate of natural flow will fall until it may become too small to be measured even if concentrated in a few hundred bores, and will certainly become insignificant under existing commercial relations. The same propositions are true of every other gas field obtaining its supply in Paleozoic formations, and they are equally true of oil fields. But encouragement is found in other directions.

The recent discovery that rock gas and petroleum are accumulated in large volume only within natural reservoirs gives guidance to prospecting. The geologist is now able to locate gas and oil reservoirs as readily as coal fields or artesian water areas; and the indication of the presence or absence of these minerals throughout the country has become one of his legitimate functions, the performance of which may justly be demanded by the layman. Moreover, it is probable that the days of reckless expenditure in prospecting and reckless waste of products when found are numbered, and that hereafter the bitumens will be intelligently utilized.

The use of rock gas has forced upon practical fuel consumers a conviction long held by students, i. e., that the gaseous is the most convenient and economical form of fuel as well as illuminant. Even if the natural supply of rock gas were exhausted to-morrow, manufacturers of glass, certain grades of iron, and other products would substitute an artificial gas for the natural product rather than return to coal. Enormous waste would thereby be prevented; the gas by which the air of whole counties in coke-burning regions is contaminated would be utilized, and the carbon of the dense smoke-clouds by which manufacturing cities are overshadowed would be turned to good account. Moreover, it is an easy step from the manufacture of coal gas to the distillation of bituminous shales and pyroschists, abounding in carbon available only in the gaseous form. Even had it no other use, rock gas is a boon to industry in that it has led to modification of manufacturing methods and reconstruction of manufacturing plants in such manner as to obtain better and more economical results from other fuel sources, in that it leads to the utilization of waste products, and in that it opens a way to the use of fuels not hitherto available.

At the present rate of consumption the known anthracite of America will be exhausted in a few decades, the known bituminous coal fields of the Carboniferous in a few centuries, and the vast bituminous coal beds of the Cretaceous in the Rocky Mountain region within a millenium or two; and since the rate of consumption is ever increasing, the entire available stock of fixed carbons in this and other explored countries must melt away within a few centuries. Some coal fields in this and other countries unquestionably remain to be discovered; magnificent possibilities lie within the little explored areas of South America, Africa, and Asia; but the surface and sediments of the earth have been examined so thoroughly as to prove that the final exhaustion of the coals can not be far off. To the geologist who regards each coal-forming period as an epoch, the immeasurably shorter period of coal consumption is but a fleeting episode in the history of the earth, an episode so brief as to require multiplication by millions in order to be made commensurable with the terms of geochrony. With the increase in population and the ever increasing control of natural forces by human intelligence, food sources multiply, while the sources of mineral fuel remain unrenewed; and were there no other fuel source than the fixed carbons of the coal seams and lignite beds, the prospect for the future would be gloomy indeed. But while the stock of fixed carbons is so limited that its exhaustion is becoming a serious menace, the stock of bitumens in the rocks of the earth is a hundred-fold greater, and practically unlimited. It is true that gas and oil are but sparsely disseminated through the strata; it is true that under existing commercial conditions they can be successfully exploited only where accumulated in exceptional volume; but, despite the extravagant waste of gas accompanying the process, oil was economically extracted before the great natural reservoirs were discovered, and with the increasing values following exhaustion of these reservoirs the limits to improvement in methods of extraction and to material extractable are indefinitely remote. The rocks are as inexhaustible a source of hydrocarbons as the soil of carbohydrates, and under suitable stimuli bountiful nature will probably give forth the one as lavishly as the other.

Rock gas and related bitumens are the fuels and illuminants of the future. Upon them, in conjunction with the foods extracted from the soil and the waters, we must depend for the energy by which the wheels of future progress will be kept in motion.

THE NATURAL GAS FIELD OF INDIANA.

By A. J. Phinney.

HISTORY OF THE INVESTIGATION.

The discovery of natural gas in Ohio in November, 1884, marked the beginning of a new era in the development of the manufacturing industries of Ohio and Indiana. As soon as the Findlay gas field gave evidence of permanence and abundance of supply the excitement spread, not only over Ohio, but over Indiana and other Western and Southern States. The early identification of the gas-bearing rock at Findlay as the Trenton limestone made this formation the Mecca of all explorers in Indiana. As the lower Paleozoic formations of Indiana were not as yet known to be sources of gas and petroleum, the early exploration of that State was necessarily experimental. The existence of the Trenton limestone, indeed, was only inferred and the experimental stage of its exploration was not passed until the drill had revealed that limestone in Indiana is a gas-bearing rock.

The great mass of bituminous shales of Pennsylvania and eastern Ohio had long been considered the source of the gas found there; but since all previous attempts to find gas and oil in considerable quantities in the lower geologic horizons had failed, geologists had tacitly concluded that it was useless to seek for either in the formations below the thick beds of shale in Ohio and Indiana. The facts developed in the Findlay field were a revelation to the geologist, as they demonstrated the existence of a source of light and heat where least expected.

Fortunately the first wells drilled in Indiana, after the discovery of gas at Findlay, were successful. The excitement immediately following this discovery of gas was intense. Companies were organized, and the drill was sent on its journey of exploration in almost every town and city throughout the State. Some of the prospectors were successful, but many were doomed to disappointment. Efforts were made again and again by some only to end in failure, while with others success attended every effort. The geologist was power-less to stay the reckless waste of money or to guide the attempts of prospectors, for he really knew but little more than the mass of people concerning the distribution of gas. The science of geology deals with facts and legitimate inferences therefrom, and the geologist was wise when his teachings were confined to the known, without attempting the rôle of the prophet; the unknown was to all alike a sealed book, and it was necessary for the drill to break the seal before its contents could be ascertained.

As a rule the position occupied by the geologist with respect to the explorations for natural gas has not been rightly understood. Not familiar with the principles recognized or the methods employed by the geologist, people have supposed him to possess occult methods of investigation and thus to be able to reveal the mysteries of the unknown. Because he has been unable to do this to their satisfaction, his failures have been attributed to the unreliability of geologic science rather than to the mistakes of the individuals; and unfortunately, individuals who ought never to have been ranked among geologists were those whose predictions were most freely made and quoted. The investigations for gas and oil afforded a fine field for the smatterer and he was found in every workshop or field and on every street corner; and without any foundation for his predictions, save the wish that was father to the thought, the existence of gas and oil was predicted at all points by these pretenders. The trained and experienced geologist is often accused of undue theorizing; but the accusation is true neither of the geologist nor of the science he represents, and even the most visionary among them is conservative as compared with the masses of the people. The scientist collects facts one by one and his theories are those at first suggested and afterward supported by the facts; but the untrained in science, who constitute the mass of the people, reverse this process.

It is easy then to understand why explorations in Indiana were, for a time, carried on without system and with such an enormous waste of money. Those most competent to offer suggestions of value were most disposed to profit by the experience of others and to withhold opinion until they were in possession of facts to sustain it. The ablest geologists were unable to render such assistance as they desired, until the philosophy of the field had been determined.

The careful students of the investigations have now attained a definite knowledge of the geological structure of the State and of the conditions that control the accumulation of gas and oil. Never before was such an opportunity presented to study the rock formations of the drift-covered area of Indiana, and this opportunity was all the better because of the limited knowledge of prospectors concerning the distribution of gas. The productive territory is now clearly defined and its limits approximately determined, and drilling outside of this area is in a great measure suspended. The outlay required to establish the limits of this area has been enormous; yet the harvest has been a rich one, for it has revealed the fact that Indiana possesses one of the largest natural gas fields in the world. Already the stimulus of this discovery is felt not only over the gas districts but throughout the State. Within the gas district the cities and towns have taken on a new life, manufacturing establishments are seeking locations, new industries are developed, and the bustle and stir consequent upon rapid increase of population are visible on every hand.

Instead of examining at his leisure the rock exposures of extended surfaces, the student was compelled to adopt a different method of investigation. The débris brought up by the sand pump, washed over by artesian flow, or blown into the air by escaping gas, was all that was given the geologist from which to solve the many geologic problems. In entering upon the study of the results of the borings he was confronted by a number of sources of error, some of which it was impossible for him to avoid. He was often dependent upon the observation of unskilled observers, and in many cases their observations were unreliable. The record of each boring was kept by local observers in all parts of the State, and of many wells the record of measurements given is so meager that all that the student can obtain is a rough estimate of the thicknesses of the different formations, or the depth beneath the surface at which the gas-bearing or water-bearing rock was struck.

Very few complete suites of drillings have been preserved, and records made from partial suites are scarcely satisfactory, especially as in many instances the depth from which they were taken is only approximately given. The altitudes of the different wells were determined by a reference to railway profiles, but the surveys of the different railways are so discrepant that it was often difficult to find reliable figures. This has been a cause of serious embarrassment in studying the topography of the Trenton limestone. It was also impossible to visit all the wells in Indiana, and where such was the case the altitude given is the estimate made by the local observers and is only approximate.

Absolute accuracy is not claimed for many of the data that are presented in the following pages, when so many sources of possible error exist. Every effort has been made to obtain reliable information, but with all the labor expended in the investigation, the results still fall short of that high degree of accuracy that the writer hoped to attain. Future investigations will no doubt result in some corrections in, as well as many additions to, the matter of this report.

All available records of borings have been incorporated into the following pages, the unsuccessful as well as the successful. The many failures to find gas have not all been total failures, for, from a scientific standpoint, a well kept record of a deep well and a full suite of drillings from it are invaluable. It is only where no record was preserved and where neither science nor the investor obtained any return that we may consider the money expended in drilling to have been spent in vain.

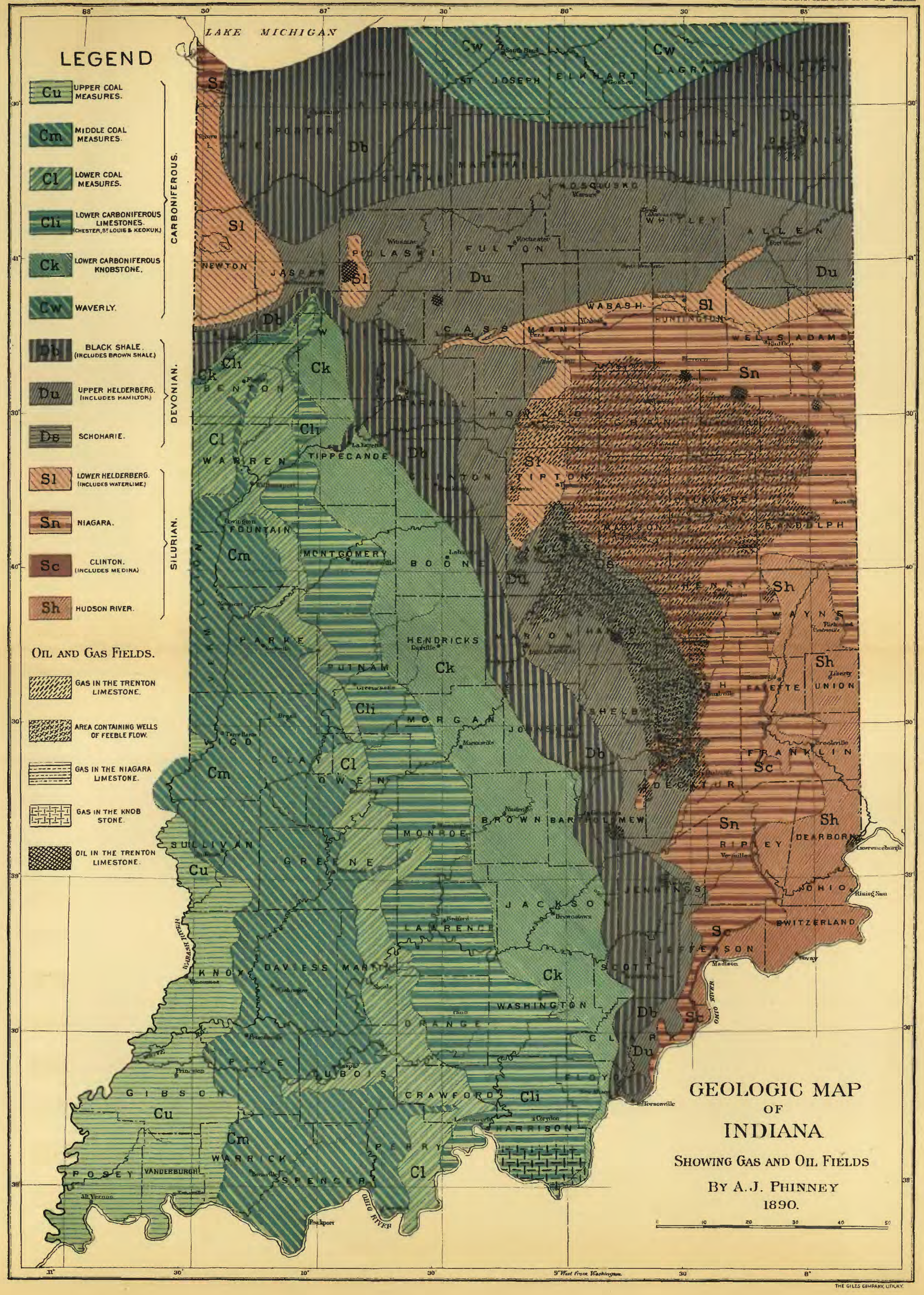
In the preparation of this report attention has been confined chiefly to the recent developments of the drill and to surface observations made in connection with the study of the well records, and in the description of the various formations of the State there will be found only such a review of published data as to their extent, character and general economic uses, as is essential to an understanding of the general geologic structure. It is believed that by excluding data already published, the report will be rendered more useful to those seeking information relating to the subjects covered by it.

THE GEOLOGIC MAP.

The boundaries of the different formations as represented upon the map forming Pl. LXIII, are regarded by the author as only approximately correct.

The limits of the different elements of the Carboniferous are essentially the same as given on the map prepared by Prof. John Collett, who has, however, kindly consented to make a few slight corrections for this edition. The boundaries of the Lower Silurian have been extended considerably to the northward and a few minor changes have been made in other directions.

The western border of the Upper Silurian has been considerably modified, while the large Silurian area in the northwestern corner of the State has been much reduced, the Devonian black shale being the first rock struck in the borings in that section. The Upper Silurian has been divided into (1) the Clinton, the limits of which are very indefinite; (2) the Niagara, and (3) the Lower Helderberg and Waterlime, the two latter being united under one color. The last named formations are the surface rocks at Kokomo and those found for a considerable distance in either direction from that city. The limits assigned to them may be too large or too small—probably the latter—for it is impossible to give exact limits where the drift is so thick and the exposures are so few. Prof. Orton reports these formations at Decatur and at Huntington. Profs. Owen and Collett both mention a small Devonian outcrop on Treaty Creek, southeast of Wabash, and if these references are correct it is probable that the Lower Helderberg and Waterlime may be found beneath the drift in the hills south of that city. The exposures in the vicinity of Wabash have been considered Niagara limestone, as the fossils are identical with those found at Marion where the exposure is un-


LEGEND
Cu UPPER COAL MEASURES.
Cm MIDDLE COAL MEASURES.
Cl LOWER COAL MEASURES.
Cli LOWER CARBONIFEROUS LIMESTONES. (CHESTER, ST LOUIS & KEOKUK.)
Ck LOWER CARBONIFEROUS KNOBSTONE.
Cw WAVERLY.
CARBONIFEROUS.
Db BLACK SHALE. (INCLUDES BROWN SHALE.)
Du UPPER HELDERBERG. (INCLUDES HAMILTON.)
Ds SCHOHARIE.
DEVONIAN.
Sl LOWER HELDERBERG. (INCLUDES WATERLIME.)
Sn NIAGARA.
Sc CLINTON. (INCLUDES MEDINA.)
Sh HUDSON RIVER.
SILURIAN.
OIL AND GAS FIELDS.
GAS IN THE TRENTON LIMESTONE.
AREA CONTAINING WELLS OF FEEBLE FLOW.
GAS IN THE NIAGARA LIMESTONE.
GAS IN THE KNOB STONE.
OIL IN THE TRENTON LIMESTONE.
LAKE MICHIGAN
OHIO RIVER
WABASH RIVER
GEOLOGIC MAP OF INDIANA
SHOWING GAS AND OIL FIELDS
BY A.J. PHINNEY
1890.
9° West from Washington.
THE GILES COMPANY, LITH. N.Y.

doubtedly Niagara. The Waterlime and Lower Helderberg are also exposed on both sides of the Wabash River both above and below Logansport. At Eel River dam, northeast of the city, the Corniferous is seen resting upon the brecciated beds of the Lower Helderberg. The fossils mentioned by Prof. Collett as identified by Mr. G. K. Greene, found at Monon and near Rensselaer, and also at Delphi, would indicate that the strata there belong to the Lower Helderberg. This inference is sustained by the description given in the Geological Reports of Illinois of certain exposures in Illinois having all the characteristics of the Waterlime; the rise of the strata to the northwest bringing these lower strata to the surface in Kankakee, Iroquois, and Cook Counties. It is freely confessed that the boundaries of these formations as thus far determined are indefinite, and that more detailed observation is needed before positive statements can be made concerning them.

The Upper Silurian area may be much more extensive than is indicated upon the map with patches of the Upper Helderberg at intervals overlying the older formations. The eastern, southern, and northern limits of the black shale are also approximately given, as the thickness of the drift is so great that it is impossible accurately to define its limits. Patches of the shale will no doubt be found both east and south of the boundaries here shown, since this formation undoubtedly once covered nearly the whole of the Lower Devonian rocks; its area has been reduced to the present limits by extensive erosion.

Additions to the Waverly and Knobstone have so far been made only in the northern part of the State, having been found only at South Bend, Elkhart, and Goshen. The thickness at these places is such as to suggest that there is quite an area of these rocks; that represented upon the map may be proved too large or too small by future investigations. While it is not claimed that the map is complete, it is believed that it represents all that is now known of the geologic structure of Indiana; that it will serve as a guide to the prospector and a sufficient basis for future geologic investigation; and that, accordingly, it will prove acceptable to all who are investigating the geology of Indiana either for scientific or economic purposes.

ACKNOWLEDGMENTS.

I take this opportunity to express my indebtedness to all who have aided in my researches. The list is too long to publish here. The secretary and president of each company have usually given all the information in their power, and local geologists, superintendents of schools, and other intelligent citizens have shown an interest in the work and have contributed materially to it. Most of the drillers have taken an active interest in the investigation and have rendered valuable assistance.

Though it is not possible to give to all the public recognition they deserve, I have kept a record of those who have kindly aided me in any way, and shall remember gratefully the courteous assistance so often received and hold myself in readiness to reciprocate should opportunity ever offer.

CHAPTER I.

GEOLOGIC STRUCTURE OF INDIANA.

SECTION I.—GENERAL STRUCTURE.

Some knowledge of the rock formations is essential to a proper understanding of the relations between natural gas and petroleum on the one hand, and the strata in which they occur on the other, and it is as necessary to understand the character of the cover of the reservoir from which the gas is obtained as the character of the reservoir itself. The geologic section of Indiana is exceedingly simple, comprising a series of sedimentary strata generally superimposed one upon the other without any great break in the series. Many of the formations are, it is true, but the vanishing edges of deposits that are thick, important, and capable of many subdivisions in the east. While it is impossible to identify some of the eastern subdivisions, owing to their absence, lack of exposures, or rarity of fossils, yet the formations can usually be correlated with those of Ohio, New York, and the Appalachian series.

The great mass of rocks found over that portion of the State within which drilling has been most active consists of limestones and calcareous shales, and it may be stated that, whatever their character or composition, all of them were of marine origin and were generally laid down in comparatively deep and quiet waters. The earlier and lower formations are coextensive with the State, but the higher and later are more restricted in area, owing partially to an elevation of portions of the slate a little above sea level soon after the deposition of each formation, and partially to subsequent erosion. No Archean rocks have ever been found within the limits of the State, either exposed at the surface or encountered by the drill, and the only igneous rocks met with so far are the ice-transported bowlders. The strata of the State have never been greatly disturbed, and, except in a few gentle swells and broad arches, the rocks lie to-day nearly as they were originally deposited. None of them have been metamorphosed, but all remain in essentially the same condition as when first laid down, though the great beds of calcareous mud filled with the remains of the life of their periods have been consolidated into limestone or, where the proportion of lime was small, into calcareous shale. Beds of sand have been cemented into sandstone and beds of clay have generally been converted into argillaceous shale. The change has usually been so slight that geologist and layman alike infer the original character of most of the deposits from their present condition.

In the southeastern portion of the State the rocks dip to the west and southwest. Each formation is exposed in a narrow belt that dips beneath the newer and higher formations to the west. A few of these belts of outcrop extend northward from the Ohio River to the south line of Michigan, while the Lower Silurian extends only about one-third across the State, and the Upper Silurian, Subcarboniferous, and Coal Measures extend only about two-thirds of the way. In the northern and northeastern portions of the State the strata dip to the north and northeast and the trend of the outcrop is nearly east and west. In the northern portion of the State are a few formations that are as yet unknown or absent from the southern portion; and, moreover, the formations found in both portions are so unlike in thickness and sometimes in other characteristics that it is impossible with our meager knowledge concerning them to correlate the different members. It is evident that somewhat different conditions prevailed in the two regions during the later part of the Silurian period. Over much of Indiana, rock exposures are rare and geologic investigation is in consequence difficult and sometimes unsatisfactory. This fact, together with the fact that certain formations are but the vanishing edges of great deposits in New York and the whole Appalachian region, increases the difficulty of correlating the Indiana formations with those of other portions of the country. This explanation is especially applicable to the minor subdivisions of the different formations. The more marked elements of the series, or great divisions, can be identified with almost absolute certainty. The accompanying general section is as accurate as it can be made at present.

SECTION II.—STRATIGRAPHY.

General section of the rocks of Indiana.—The well marked rock formations of Indiana are as follows:

	Feet thick.
Quaternary:	
Alluvium	0 to 50
Loess	0 to 30
Glacial drift	0 to 380
Carboniferous:	
Upper Coal Measures	50 to 195
Middle Coal Measures	600 to 888
Lower Coal Measures and Conglomerate	60 to 210
Chester	0 to 74
St. Louis	0 to 330
Keokuk	6 to 106
"Knobstone" Waverly	42 to 532

	Feet thick.
Devonian:	
Black shale	70 to 120
Brown shale	25 to 47
Hamilton { limestone, 27 feet shale, 20 feet }	47
Upper Helderberg	5 to 65
Schoharie	14 to 20
Upper Silurian:	
Lower Helderberg	25 to 230
Waterlime	65 to 150
Niagara { limestone, 50 to 440 feet shale, 2 to 40 feet }	52 to 480
Clinton { limestone, 30 feet shale, 16 feet }	46
Medina (?)	60
Lower Silurian:	
Hudson River	260 to 860
Utica	0 to 300
Galena and Trenton	486 to 525
St. Peter	150 to 224
Lower Magnesian	50

In a bore (made since the above was written) at Laporte, in the northwestern part of the State, the Trenton was reached at a depth of 1,380 feet, and undoubted Potsdam sandstone at 2,500 feet, showing a thickness for the Galena, Trenton, St. Peter, and Lower Magnesian limestones of 1,120 feet, 600 feet at least representing the two last named. The Potsdam was penetrated 323 feet without reaching its base.

Only those formations that are of especial interest on account of their relations to natural gas are described in detail in the following pages. It should be mentioned, too, that the upper portion of the above section is taken largely from the reports of Prof. Collett, while the portion below the Keokuk is based upon the well records described in a later chapter.

The Lower Magnesian Limestone.—The last 50 feet penetrated by the drill in the Bloomington well probably represents this formation. The rock here is described as gray in color and it contains "sulphur water" (probably a brine) in the last 8 feet. Drillings received from the bore at Greenwood, Johnson County, show essentially the same characteristics, the rock being a limestone with a considerable admixture of silica or quartz sand, some samples showing more quartz than others. It is doubtful whether any line can be drawn between this siliceous limestone and the Potsdam sandstone below, the latter probably being highly calcareous. The Greenwood amples are white, gray, or sometimes buff in color.

The St. Peter Sandstone.—The efforts of several prospectors to find gas or oil below the Trenton limestone have led to the addition of this formation to the previously known geologic series of Indiana. Although it is exposed on the surface in Illinois and Wisconsin its presence in Indiana has only been inferred hitherto. Its natural outcrops show where typically developed that it is composed of quartzose sand loosely cemented or sometimes altogether without cementation. In Indiana, though usually considered sandstone by the drillers by reason of the coarseness of its texture, it is largely calcareous, only a small residue of silica and crystals of quartz remaining after digestion in acid. The term sandstone usually given to it is hardly the proper one to use here, "siliceous limestone" better indicating its composition. This rock has at Portland a bluish cast and is a pure sandstone in its upper portion. At Union City it is described as a gray sandstone; at Muncie it varies in color from white to gray, or reddish, or buff. At Bloomington it is said to be white, gray, or yellow, and of variable hardness. At Indianapolis the upper 20 feet is simply a mass of loose sand, but below this the rock is calcareous and quite hard.

The depth from the surface at which this formation is struck varies in different portions of the State. It was reached at Portland at 1,600 feet; at Union City, 1,680 feet, 600 feet below sea level; at Muncie, 1,382 feet, 450 feet below sea level; at Rockville, in the western part of the State, at about 2,600 feet; and at Goshen, in the northern part, at 2,350 feet. Thin bands of shaly limestone are occasionally met with in this formation, as at Portland and Bloomington.

This formation is, as a rule, saturated with saline water popularly termed "Blue Lick water." This water is slightly laxative, owing to the presence of sulphate of magnesia, and it gives off the offensive odor of sulphuretted hydrogen gas. The water from this formation rises 1,100 feet at Muncie and 1,200 feet at Portland, and is usually found soon after the drill reaches the rock, though occasionally not until the formation has been penetrated 100 feet or more. The almost universal presence of salt water in this formation under such enormous pressure renders the probability of finding gas in it extremely doubtful, even when all other necessary conditions exist. The popular opinion, that gas might be found in this, and indeed in other low-lying formations if the drill was only sunk deep enough, has been proved erroneous.

The thickness of this formation has not been certainly determined because of the difficulty of drawing the line between this and the underlying formation. At Bloomington 227 feet of siliceous strata are reported above 50 feet of gray limestone, probably representing the Lower Magnesian. Between the Trenton limestone and the St. Peter, at both Connersville and Bloomington, there are beds of shale; at Connersville it is black and 25 feet thick; at Bloomington it is blue and 40 feet thick; it was also met at Edinburg, where it is 83 feet thick. Whether this shale belongs to the Trenton or St. Peter, or whether it ought to be separated, can not be determined at present.

The Trenton Limestone.—This important formation, the reservoir of the gas and oil in Indiana as well as in western Ohio, is also a recent addition to the geologic section of the State. Its existence in Indiana had long been inferred from its outcrops in Illinois, Wisconsin, Michigan, Kentucky, and Tennessee, but nothing could be said of its character here until the drill revealed it. It is remarkable that it should preserve its identity as a great limestone mass over such an extensive area, varying but little in its characters from New York to Tennessee and Minnesota. It is sometimes heavy bedded or massive in its upper part, as in middle Tennessee, where it is of a bluish dove color; sometimes shaly bands are present in other localities. The drill shows that this formation in Indiana has essentially the same characteristics as shown in the outcrops in other States, the different beds varying in color, hardness, and thickness, and from the drillings defying identification of its divisions. Its thickness in Indiana varies from 470 to 586 feet. At Bloomington, where it reaches a maximum thickness, the drillings show that some beds of calcareous shale are intercalated with the limestone. In the extreme southeastern portion of the State and westward along the Ohio River as far as Jeffersonville some shaly layers are usually met with in its upper portion, and where such is the case the color is darker than usual. Wherever the upper portion of the Trenton exhibits this shaly character the Utica shale is usually below its normal thickness and often somewhat lighter in color. In such cases it it difficult to determine whether the shaly layers belong to the Utica or the Trenton.

Prof. Orton claims[1] that "the Utica shale is lost in the Ohio Valley by the overlap of the Hudson River shales, which there come directly down upon the Trenton limestone." Now, this may be the case in Ohio on the crown of the Cincinnati arch, but there are facts that render such a condition in Indiana very doubtful.

It is difficult to determine the Trenton rock from the drillings alone, for in some localities the drillings from the Lower Helderberg and Corniferous limestones resemble it closely; moreover, as already mentioned, it is frequently dark and shaly in its upper portion and hard to distinguish from the Utica. All possible sources of error have, however, been carefully guarded against in the identifications of this formation.

At Lawrenceburg a hard limestone was struck at a depth of 261 feet from the surface. Between this and the limestone considered the Trenton is a dark and soft shaly limestone 36 feet thick. The first flow of gas was struck at a depth of 261 feet and the main flow at 325 feet, or 10 feet below the summit of what is considered Trenton. This lower limestone has the same characteristics as the Trenton at

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[1] Preliminary Report on Natural Gas and Petroleum, Columbus, Ohio, 1886, p. 118.

other localities. At Madison a bed of hard gray and white limestone was struck at a depth of 330 feet beneath the characteristic bluish green Hudson River shale; and between this limestone, which was 110 feet thick, and the rock regarded as Trenton was found a dark soft and shaly limestone or calcareous shale 90 feet thick. The rock beneath the 90-foot shale was found to be 474 feet thick and the base had not been reached when the drilling was suspended. It is of a grayish or white color in its upper portion, gradually becoming darker toward its base, where it is quite shaly.

Now, while it is a question what relation the 28-foot limestone at Lawrenceburg sustains to the 110-foot limestone at Madison, both, together with the associated shaly limestones, may be regarded as belonging to the Utica.

The thickness of the Trenton at Connersville, North Vernon, and Madison show little variation, while the thickness of the Hudson River and Utica at Connersville, Madison, and Richmond show great uniformity. It is probable that the change in the Utica and Hudson River in southern Indiana is but the beginning of the change whereby these formations lose the greater part of their shaly layers in their southern extension through Kentucky and Tennessee.

In the northwestern part of the State the Trenton is of a chocolate or brown color to a depth of 256 feet. Such an unusual color, where the Utica is absent or of a bluish green color, would suggest the possibility that the Utica had there changed to a limestone. The presence, however, of the same chocolate brown limestone at South Bend, where the Utica is well developed, would indicate that the Utica had disappeared farther west rather than changed to a limestone. It is probable that the extreme upper part of the Trenton, corresponding to the Galena limestone, is the rock that acts as the reservoir for the gas in Indiana and Ohio, and that the Trenton proper represents the base of the great limestone mass as in Illinois and Wisconsin.

The upper part of the Trenton is a dolomite; and it contains a number of comparatively thin sheets or strata of porous rock of great lateral extension, the gas and oil being found in a higher portion of the upper stratum, while the remainder of it and all porous strata below contain salt water. The usual colors of the formation are gray, buff, white, or brown. The porous stratum is usually limited to the upper 50 feet, and it varies from 1 to 30 feet in thickness and is usually capped by a hard non-magnesian limestone from 1 to 15 feet in thickness, occasionally 50 feet thick. The rock immediately below the gas-bearing portion is usually very hard and non-porous, and sometimes of a chalky white color. Outside of the gas area to the southeast and south the porous rock is absent or is confined to narrow strips or spots, and in this section no salt water is likely to be found until the drill is sunk deep into the Trenton or perhaps not until the St. Peter is reached. The significance of this fact will be dwelt upon in the discussion of the Cincinnati Arch as the reservoir of gas.

The Trenton limestone in this State contains very little siliceous material, and by reason of their granular texture the drillings are sometimes referred to as Trenton sand.

Much reliance is often placed upon the character of the drillings as indications of gas or oil, but such characters are of very little practical value. As a rule the harder the rock the finer the drillings, and the prediction may safely be made, that, where the drillings are fine when the drill is working where the porous rock ought to be, the prospects are unfavorable even if all the other conditions are present. Where gas is found in considerable volume it usually blows all the drillings out of the well and pieces from the size of a pin-head to that of a hickorynut can be procured. Such specimens show the true character of the porous portion.

The Utica Shale.—This formation does not come to the surface anywhere in the State, but we have become quite familiar with its composition, since it is represented by abundant drillings from a large number of wells. As a rule it is so persistent and constant in its characters that it is easily recognized when its true horizon is reached. Its color is usually dark brown or black. At Zionsville it is light colored and shades gradually into the bluish green shales of the Hudson River above it. At Jeffersonville the Utica, as defined by petrographic characters, is only 127 feet thick, yet the combined thickness of the Hudson River and Utica is such as to indicate the presence of both in their normal thickness. Hence it is apparent that the upper portion of the Utica has lost its dark color, and thus that there is a gradual transition between the Utica and Hudson River. This view is supported by the fact that in nearly all the wells in the State the transition from the overlying bluish green shales to the black Utica is gradual. Sometimes there is an alternation of the beds for 50 or 100 feet, but occasionally the change is abrupt. At Seymour, north of Jeffersonville, this formation has an exceptionally light color; at Brownstown the Utica shales are reported as blue, and at Lawrenceburg and Madison the formation departs somewhat from its normal composition and color, as already described on a previous page.

This formation is well developed with its usual color at Vernon, Rushville, and Connersville, and northward from these points it exhibits a wonderful persistence in all its characteristics quite to the south line of Michigan. In the northwestern part of the State the whole mass of Lower Silurian shales, Hudson River and Utica combined, become much reduced in thickness; at Richmond it is 900 feet thick, and at Logansport 424 feet, of which 280 feet belong to the Utica. At Royal Centre 330 feet is reported, and at Monon, still farther westward, 285 feet, while at Valparaiso the whole mass is reduced to 160 feet of bluish green shale. It appears from the Logansport section that the attenuation is principally in the Hudson River, as the Utica there retains its normal thickness. The absence of this formation in its usual color at Valparaiso and at points in Illinois and Wisconsin, where the Hudson River is exposed in outcrop, shows that it has entirely disappeared or undergone complete change in color in the interval between Logansport and Valparaiso. It is heavily charged with bituminous matters and usually gives an odor of petroleum. It is also quite calcareous, a character by which it may be distinguished from the Devonian black shale.

Mr. C. D. Walcott has suggested that the Utica shale is the equivalent of the Galena limestone, but after following this formation carefully from the Ohio River to Michigan and Illinois, no changes have been observed in the base of the Utica indicating such transition except at the points previously mentioned, the transition from the Utica to the Trenton being almost everywhere else abrupt.

The Hudson River.—This is the lowest formation exposed in natural outcrops in Indiana. It is the surface rock over a belt about 20 miles wide, skirting the Ohio line in the extreme southeastern section of the State and extending thence southward into Kentucky and eastward into Ohio. Within Indiana it is composed of limestones alternating with beds of clay or marl, becoming shale below, and when exposed in the deepest valleys a homogeneous bluish green shale. The entire formation is usually considered shale in many of the well records, and the upper 100 feet is sufficiently hard to be considered a limestone, though usually softer than the Niagara limestone above it.

Over most of the gas area this more calcareous portion is sharply defined by the softer shales constituting the body of the formation below and by the well marked Niagara shale above. West and southwest of its natural outcrops the entire formation becomes more calcareous. At Jeffersonville the upper calcareous member is 350 feet thick and at Rushville 420 feet thick. To the north the formation retains the characters exhibited in the extreme southeastern portion of the State although (as already noted) it thins materially, the thinning affecting the shaly member more than the overlying limestones. At South Bend there are 85 feet of the upper limestone member and 135 feet of the shales; while at Connersville a complete section gives 150 feet of the limestones and 300 feet of the shales. The limestones are everywhere bluish, while the shales are bluish green. Fossils are quite common in the upper portion. *Zygospira modesta* was found at Selma, Delaware County, and fragments of characteristic brachiopods and corals were observed at many other localities. The limestones are somewhat porous, and slightly brackish water is often met with. The transition from the harder into the softer portion is gradual, thin bands of limestone appearing occasionally in the shales, and shaly partings always occurring between the limestone bands.

Moderate flows of gas are frequently met with in or beneath the limestone intercalated within the shales, but the flow has in all cases proved limited. The most persistent flow yet recorded where the volume was large was found at Fort Recovery, Ohio, where two wells yielded a large supply for over a year. Both have now failed. At Shideler, Delaware County, and at Camden, Jay County, pockets of shale gas were struck in this formation that blew the 1,800-pound drill quite out of the well, and hurled it through and over the top of the derrick. The flow, however, was exhausted within a few days. The total amount of gas contained in this formation must be enormous, but it is scattered over a vast area and in small pockets and is nowhere accumulated in sufficient quantities to warrant boring in search of it.

While the shales of the Hudson River and Utica are without value as gas-bearing rocks, they perform an important and essential function in the economy of natural gas by serving as an impermeable cover to the reservoir within which the hydrocarbons of Indiana are collected.

This is the lowest formation of the Indiana series which can be identified by means of fossils. In these, in its general structure and in its composition, it resembles the Hudson River formation where typically developed in New York, and by the same characters it may quite certainly be correlated with the same formation as developed in Illinois, Wisconsin, and Iowa.

The Clinton and Medina.—These formations crop out at intervals both north and west of the area of the Hudson River. They are so inconstant in lithological characters that it is frequently difficult to identify them from the drillings alone, and where such is the case it has been deemed better to consider them absent than to assign a constant thickness to formations that are probably wanting in many localities. While of great thickness in the Appalachian region and of considerable thickness in New York, they attenuate westward and disappear altogether in Illinois and Iowa. At Eaton, Delaware County, the Clinton is buff-colored and 10 feet thick; at Daleville, in the same county, it is probably represented by a thin bed of reddish, coarse-grained rock; at Valparaiso it is a white and steel-gray limestone 55 feet thick; at South Bend it is a reddish limestone 35 feet thick, and at many other points a reddish or steel-gray limestone of moderate thickness is reported at this horizon.

At Muncie the bluish subcrystalline limestone that underlies the Niagara shale could not be distinguished from the limestones constituting the upper portion of the Hudson River series, and the same is true at Winchester, Randolph County. At both these localities especial pains were taken to determine the character of the rock occupying this horizon.

Samples of drillings received from Albion, Noble County, exhibit the following series at this horizon:

	Feet.
1. Very hard reddish limestone	30
2. Reddish shale	16
3. Hard steel-gray siliceous limestone	59
Total	105

The upper two members of this series belong to the Clinton and the third to the Medina. The large quantity of iron present in No. 1, a common characteristic of this formation where best developed, and its relations to the base of the Niagara justify its assignment to this horizon. If the Medina is represented in Indiana at all, No. 3 should be assigned to that horizon, as the order of the series is the same as in Ohio, where both formations are quite well developed. A similar series is reported at Larwill, Whitley County. The Medina is probably confined to the southeastern portion of the State.

The Niagara.—The different members of this formation constitute the surface rocks over a narrow belt skirting the Hudson River on the west and over a broader tract in the eastern-central part, and extending westward nearly one-half way across the State. Its trend clearly indicates the form and direction of the Cincinnati arch in Indiana.

As developed in this State this formation comprises the following elements, viz:

1. Cedarville or Guelph limestone.
2. The Niagara limestone proper.
3. The Niagara shale.

The Niagara shale, the base of the formation, is very persistent and easily identified, and affords a datum plane from which to determine superjacent and subjacent formations. It is of a bluish green color, and where best developed is quite free from calcareous matter. In the central and northwestern portion of the State it is exceptionally calcareous and much reduced in thickness, and still farther to the northwest it disappears entirely, either being absent or passing into the limestone of the dominant member. Within the gas area the drillings usually show a fine tenacious clay, easily distinguished when once recognized, and so decidedly unlike anything else penetrated by the drill that samples are almost invariably preserved. It is 40 feet thick at Muncie, 45 feet at Rushville, 35 feet at Kokomo, where it is quite calcareous, 40 feet at Peru, where it is also calcareous, and only 2 feet at Logansport. If it occurs at all at South Bend it has there become a limestone. So far it has been found of no economic value.

The Cedarville limestone and the Niagara proper can not always be separated, owing to the great variation of each in color and texture and to the limited exposures on the surface. It is not always possible to discriminate drillings from these members. Usually, however, the upper beds are white, bluish or buff, while the lower beds are nearly always blue. The materials vary from subcrystalline buff limestone to bluish cryptocrystalline or bluish green shaly limestone, sometimes passing into calcareous shale. The combined thickness of the limestones of these two elements ranges from 50 to 440 feet. This inequality is partly due to erosion, but chiefly to the thickening of the Upper Silurian to the northward. This formation is unbrokenly continuous with the Niagara of Illinois and Wisconsin, but in those States it admits of different divisions. In the southeastern portion of Indiana the uppermost stratum of the Niagara consists of shale, sometimes 20 feet thick, and in some localities full of well preserved fossils, as at Waldron and vicinity. The aggregate thickness along the Ohio River barely exceeds 100 feet. In the northern part of the State this limestone frequently contains salt water. At Muncie and Selma pockets of a red ferruginous clay that gave the drillers much trouble were found in the Cedarville beds.

Thus far this formation has yielded no gas except at Vernon, Jennings County, where a strong but diminishing flow was found in some shaly layers at a depth of 145 feet from the surface.

The Lower Helderberg and Waterlime.—These closely related formations of the Silurian are described together because of the difficulty of separating them in the well records or from the drillings, and because sufficient study has not been given them to allow their limits to be determined. They are usually associated in their natural outcrops and contrast strongly in lithological characters, but under cover to the northward they thicken and apparently blend, though the lower portion is usually darker in color, corresponding more nearly to its color as observed in the outcrops.

The Waterlime is finely exposed at Kokomo, Howard County, and is quite extensively quarried for building material. It is here an evenly bedded limestone, the layers are thinnest at the top, occasionally quite shaly but gradually thicker toward the bottom of the quarries. It is of a gray or light brown color, sometimes quite black and locally rich in bituminous matter. The presence of numerous thin films of bituminous matter parallel with the bedding planes gives this rock a peculiar banded appearance different from any other formation in Indiana. A fine specimen of *Eurypterus remipes* was observed in the quarry about 2 miles south of Kokomo, and two other specimens, probably different species of *Eurypterus*, were found in a quarry 3 miles southwest of that city. These fossils establish the identity of this formation with the Waterlime of New York and Ohio. The massive limestone constituting the upper portion exposed in the quarry 2 miles south of Kokomo belongs to the Lower Helderberg.

The Waterlime and Lower Helderberg are both finely exposed at Logansport and also both above and below that city along the Wabash River. About an equal thickness of each formation is exposed in the outcrop. Prof. Orton informs me that he succeeded in finding *Leperdita alta* at a quarry about 2 miles west of Logansport. Both these formations are also exposed along Pipe Creek southeast of Logansport. About 40 feet is exposed in the quarries at Kokomo, and the bores show a total thickness of about 75 feet, making a thickness of 70 feet for the Waterlime. At Logansport and vicinity about 75 feet is exposed and the bores show as belonging to these formations 138 feet of limestone, at least 100 feet of which must be considered as Waterlime. Northwest of Logansport near Monon, Francisville, and Rensselaer, the Lower Helderberg is the surface rock over quite an extensive area.

Prof. Collett reports the following characteristic fossils from the above localities, viz: *Pentamerus galeatus*, *P. nysius*, and *P. littoni*. Prof. Orton also reports these formations at Decatur, Adams County; Huntington, Huntington County; and Delphi, Carroll County.

At Goshen brownish limestone 380 feet thick, considered as belonging to these formations, was met in the bores. The rock is here extremely hard, but tests show the presence of gypsum throughout a band about 100 feet thick near the middle of the series. They appear to be about 235 feet thick at South Bend, and throughout 150 feet of thickness gypsum occurs in abundance. Gypsum is also found in the drillings at Albion, Noble County, and no doubt would have been found at many localities in northern Indiana if the drillings could have been examined.

The rapid increase in thickness of the Silurian limestones commonly reported north of the Wabash River is due to the existence of these formations. They doubtless extend over much of the northern part of the State beneath the drift and other more recent formations, but have so far not been met with between Indianapolis and the Ohio River.

The Lower Helderberg is, wherever exposed, a cherty limestone and often irregular and uneven in its bedding and sometimes brecciated, generally of a buff, sometimes of a gray color.

The Schoharie (?).—The sandstones exposed at Pendleton, Madison County, and northward in Hamilton County, are referred to this member of the New York series with some doubt. Prof. Hall assigns these sandstones to this horison on paleontological grounds. The fossils, however, viz, *Cyathophyllum rugosum*, *Conocardium trigonale*, *C. nasutum*, *Tentaculites scalariformis*, and several species of favositoid corals, appear more nearly related to the fauna of the Corniferous. The sandstone in Ohio, occupying a similar relation to the Corniferous, has been referred to the Oriskany by Newberry and others, but Prof. Orton claims that the sandstones of Monclova and Sylvania, formerly referred to the Oriskany, belong to the Lower Helderberg. It is quite probable that the sandstones found at different localities do not all belong to the same horizon; e. g., the upper member of the Upper Helderberg at Logansport has been assigned to this horizon, which is obviously erroneous.

The formation is a pure bluish white sandstone, largely used as building material and in the manufacture of glass. It is soft when first quarried, but hardens upon exposure. Its outcrops, so far as at present determined, are confined to Madison and Hamilton Counties, and it is met with in the bores in Hancock, Marion, Johnson, and Hendricks Counties. A strong flow of gas was found in it at Plainfield, Hendricks County, but the flow was not persistent; but elsewhere it has afforded neither gas nor oil.

The Upper Helderberg.—The rocks composing the coral reef at the Falls of the Ohio are commonly referred to the Upper Helderberg. This formation crops out at intervals from the Ohio River northward as far as Logansport, but north of the Wabash River it is concealed by the drift and more recent formations.

The Upper Helderberg has not yet been found valuable as a source of gas or oil, although it contains considerable petroleum in its interstices and in the cavities of its fossils found so abundantly at the Falls of the Ohio River. It is frequently confused with the Trenton in the northern part of the State, where it is overlain by black and greenish blue shales, a succession which exactly duplicates that of the bluish shales of the Hudson River and Utica that overlie the Trenton. This confusion illustrates the fallibility of prognostication from drillings alone.

The Upper Helderberg formation—commonly referred to in Indiana as the Corniferous—exhibits considerable variation in color, composition and texture in different localities and in its different members. The following section taken from the outcrops near Logansport shows well the different elements and the relations to the formations underlying it :

Section at Logansport.

		Feet.
Upper Helderberg.	1. Yellow siliceous limestone	13
	2. Blue limestone (firestone)	7
	3. Corniferous limestone	8
Lower Helderberg.	4. Brecciated cliff limestone	15
	5. Delphi limestone	15
	6. Waterline	50
Total		108

The thickness of the Upper Helderberg increases northward, from 30 to 65 feet usually being assigned to this formation in the bores, though it is exceedingly difficult to separate it by the drillings from the underlying Lower Helderberg; and commonly it is impossible to determine whether the overlying Hamilton is present or not. This formation is, wherever exposed, full of the characteristic fossils, viz: *Favosites hemisphœricus, F. limitaris, F. arbor, F. tuberosus, Cyathophyllum rugosum, Zaphrentis foliata, Acervularia davidsoni, Stromatopora substriatella* and *Paracyclas elliptica* var. *occidentalis.*

The Hamilton Limestone and Shale.—Samples of the drillings from the well at Goshen show a 20-foot bed of brown calcareous shale overlying the gray limestone that is considered Upper Helderberg. There is above the shale a bed of dark gray limestone 27 feet thick, and this is followed in turn by the brown shale described in a later paragraph.

This 27-foot bed of dark gray limestone is quite different from that of the Upper Helderberg, and shales or shaly limestones are so far unknown in the latter. If we are right in assigning the 27-foot limestone to the Hamilton it follows that the underlying calcareous shales also belong to the Hamilton. It is noteworthy that, although much reduced in thickness, the sequence here is the same as that of the Thunder Bay region in Michigan, where, according to Prof. Rominger, an "artesian boring" started in undoubted Hamilton limestone and passed through, first 400 feet of limestone, and next a shale bed 80 feet thick containing a great variety of characteristic Hamilton fossils, proving positively a thickness of 480 feet for the Hamilton series at that locality.[1]

The presence of these beds in Indiana and their agreement with the section of northern Michigan warrants their assignment to the Hamilton.

The aggregate thickness of the Siluro-Devonian limestones varies greatly in different parts of the State, not by reason of unconformity, but because of the absence of certain formations over portions of the State and the local thickening or thinning characteristic of all the deposits in Indiana; also because of post-Paleozoic erosion. As a rule the thickness increases rapidly northward from the gas area.

The thickness at various points is shown in the following table:

	Feet.		Feet.
1. Jeffersonville	150	13. Logansport	438
2. Seymour	225	14. Wabash	425
3. Rushville	102	15. Rochester	535
4. Greenfield	150	16. Larwill	522
5. Greensburg	70	17. Royal Centre	486
6. Cambridge City	2	18. Monon	530
7. Winchester	70	19. Valparaiso	610
8. Union City	227	20. Warsaw	652
9. Muncie	225	21. South Bend	805
10. Anderson	206	22. Goshen	885
11. Noblesville	286	23. Albion	900
12. Kokomo	250	24. Butler	1,064

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[1] Geology of Michigan, vol. 3, pl. I, p. 63.

The Brown Shale.—The Hamilton is overlain in northern Indiana by a thick bed of brown shale which occupies the horizon of Prof. N. H. Winchell's Olentangy shale. It is questionable whether this bed should be separated from the widely distributed black shale overlying it, but since the beds are readily distinguishable from the drillings and commonly from the records, tentative separation at least appears warranted. Moreover, Prof. Orton speaks of a bed of bluish shale formed in northwestern Ohio which he regards as the equivalent of the Olentangy shale of Winchell and which occupies a similar position with reference to the black shale as the formation under consideration, and is therefore more nearly related to the subjacent limestone than to the black shale above it. This brown shale is usually quite calcareous. Its thickness has been well ascertained only at two points, viz, at Goshen where it is 47 feet thick, and at South Bend, where it is 25 feet thick. Careful examination of the drillings would no doubt show its presence at other localities.

The Black Shale.—This formation has been refered to the Genesee on paleontological grounds, but it is questionable whether this reference can be maintained. In the Appalachian region the Genesee shales are overlain by several thousand feet of shales and sandstones belonging to the Portage, Chemung, and Catskill formations, and the whole series from the Genesee to the summit of the Catskill is conformable throughout. Passing to the westward these enormously thick deposits become thinner and less clearly differentiated, until in central Ohio they are inseparable and together constitute the Ohio shale of Prof. Orton. Still farther westward they continue to thin until they disappear entirely on the eastern flank of the Cincinnati arch, though they doubtless completely surround its margin. Now in Indiana there is no unconformity above the black shale, but there must have been had the surface been above the sea during the vast period represented by the deposition of the Chemung, Portage, and Catskill formations in the Appalachian region. Although so greatly attenuated and practically indivisible, the Indiana series is as completely conformable as that of New York or Pennsylvania. On the whole it appears evident that the black shale of Indiana and contiguous States should be regarded rather as the representative of the entire Genesee-Catskill series of the East than of the basal part of that series; indeed, it is more probable that the brown shale represents the Genesee of New York and the black shale the three superjacent formations than it is that the black shale should represent the Genesee and the greater formations be without equivalents in Indiana.

This black shale is throughout heavily charged with bituminous matter and is the source of the gas found in Harrison and adjacent counties along the Ohio River. Elsewhere in Indiana its gas supply is neither large nor persistent, and its structure is unfavorable to the accumulation of gas in considerable quantities.

The formation varies considerably in color, thickness, and texture, as shown in the following sections.

The subdivisions reported at Brownstown are as follows:

	Feet.
1. Black shale	108
2. Green shale	15
3. Drab shale	20
Total	143

At Seymour the following are shown:

	Feet.
1. Blue shale	4
2. Black shale	21
3. Yellowish shale	2
4. Brown shale	53
5. Blue shale	10
6. Black shale	25
Total	115

At Columbus where the upper portion has been removed by erosion the sequence is:

	Feet.
1. Black shale	13
2. Blue shale	13
3. Black shale	16
Total	42

At Rockville, Parke County, 102 feet of black shale was reported; at South Bend 70 feet of black shale overlie the 25 feet of brown shale; and at Goshen 93 feet of black shale and 47 feet of brown shale are represented in the drillings.

The Waverly and Knobstone.—Only the lower strata of the well developed and characteristic Waverly formation of Michigan extend into northern Indiana. It is there a bluish green shale, quite calcareous and resembling the lower strata of the Hudson River. It varies in thickness, being 143 feet at South Bend, 215 feet at Elkhart, and 200 feet at Goshen.

In the southern portion of the State there is a body of shales alternating with sandstones and with occasional thin bands of limestone which is perhaps equivalent to the Waverly. It has here developed a distinct character in weathering which suggests its local name, *Knobstone.*

Over a portion of the State this formation affords a cover for the black shale; but neither the textural conditions of the Waverly nor the structural condition of the two formations are such as to warrant belief that considerable quantities of gas will be found in it in Indiana. A few wells in southern Harrison County have, however, yielded a fair supply of gas.

The Keokuk, St. Louis, and Chester.—These formations together constitute the surface over a considerable area in the southwestern portion of the State, their outcrops extending from the Ohio River in a direction a little west of north to near Rensselaer, Jasper County, nearly two-thirds of the entire length of the State. Their outcrops vary in width from 55 miles along the Ohio to a narrow strip or even to a series of isolated outcrops in the north, with an aggregate thickness, where fully developed, of about 500 feet. The Keokuk and St. Louis are usually composed of limestones with occasional thin beds of shale, while the Chester consists of alternating beds of sandstones and limestones. So far they have proved of little if any value as sources of gas or oil, but the deficiency in this direction is fully compensated for in their excellent qualities for building stones. The St. Louis is almost as well known for its oolitic limestones as the Trenton limestone is for its gas and oil.

The Coal Measures.—This series of rocks occupies a large area in the southwestern portion of the State; but owing to the great depth of the Trenton limestone from the surface within its area, comparatively few bores have been put down, and consequently little new information has been gathered concerning it. The few test bores have occasionally penetrated beds of coal and occasionally strata yielding light flows of gas, but the results so far are such as to offer no encouragement to the driller.

The best record is that of Princeton, Gibson County, where two wells found gas in small quantity, but neither was considered of sufficient importance to be utilized. Gas was found at a depth of 625 feet from the surface. The series probably contains a large amount of gas in the aggregate, but it is too widely diffused to be commercially available.

The Drift.—Under this head are grouped all the superficial beds of sand, clay, gravel, bowlders, etc., that overlie the regularly bedded rock formations of the State. Much of the material is foreign and evidently derived from the vast area of crystalline rocks beyond the Great Lakes and over the Canadian hills, though a considerable proportion seems to be the product of the breaking up and intermingling of portions of formations found in Indiana and Michigan. The shales have been reduced to clay, the sandstones to fine sand, and both clay and sand thoroughly mixed with other material derived from the rocks to the north, except where they have been reassorted and the sand, clay, and gravel deposited in alternating layers. The whole mass gives evidence in its structure and composition of the combined action of ice and water during a long period of time; but the elucidation of its history, though interesting and important, is scarcely pertinent to a discussion of rock gas and petroleum and their sources. Pockets of gas are indeed occasionally met with in the drift; but they invariably prove a delusion and a snare to all who consider them indications of hydrocarbons in the rocks beneath. The gas found in the drift is unquestionably derived in a majority of cases from vegetable material buried beneath or incorporated within it. It seems almost needless to warn the prospector that the supply is certain to be exceedingly limited.

Some consideration of the drift as a thick formation occupying the surface of the greater part of the State is, however, imperative, since the topography of the adjacent rock surface can be developed only by ascertaining the thickness of this deposit at as many points as possible. It is also desirable to place upon record all of the facts concerning this complex formation that can be obtained as an aid to the elucidation and explanation of the many problems connected with its study. With this end in view the following sections were collected and recorded:

At Michigan City.	Feet.
1. Sand	25
2. Gravel	5
3. Blue clay and bowlders	167
4. Blue bowlder clay	53
Total	250

At South Bend.	Feet.
1. Sand	25
2. Gravel	20
3. Clay	30
4. Sand	25
5. Gravel	37
Total	137

At Larwell, Whitley County.	Feet.
1. Clay	90
2. Gravel	50
3. Quicksand	75
4. Coarse gravel	30
5. Quicksand	40
6. Hard clay	5
7. Coarse sand	10
8. Quicksand	45
9. Cemented gravel	20
Total	365

This town is situated upon the interlobate glacial moraine described by Prof. Chamberlin, and as it occurs near the highest point between Warsaw and Columbia it probably gives a fair idea of the thickness of the drift deposit in this section of the State. Albion and Kendallville, where an extraordinary thickness of the drift was revealed, are also situated on this interlobate moraine. The moraine of the second Glacial Epoch has been mapped in great detail by Prof. Chamberlin, but since it is not represented upon the accompanying plates its course may be briefly indicated in the eastern part of the State. It enters Indiana from Ohio about the southeastern corner of Randolph County and passes thence almost directly west to near Losantville, where it turns abruptly to the south, and with a direction a little west of south it extends through the western part of

Wayne and Fayette Counties, passing near Hagerstown, Cambridge City, and Dublin. The records show that this morainic ridge corresponds roughly with an elevation of the Trenton limestone beneath and having a similar direction.

In the wells quoted in the following table only the total thickness of the drift is noted. The figures illustrate fairly the thickness of this formation throughout the central, eastern, and northern portions of Indiana:

Town.	County.	Thickness.	Town.	County.	Thickness.
		Feet.			*Feet.*
Seymour	Jackson	75	Anderson, No. 1	Madison	129
Brownstown	...do	42	Anderson, No. 2	...do	114
Franklin	Johnson	170	Alexandria	...do	26
Edinburg	...do	115	Summitville	...do	98
Greenwood	...do	210	Elwood	...do	108
Shelbyville	Shelby	48	Noblesville, No. 1	Hamilton	140
Morristown	...do	140	Arcadia	...do	130
St. Paul	Decatur	90	Lebanon	Boone	210
Greensburg, city well	...do	10	Zionsville	...do	160
Connersville, No. 1	Fayette	85	Frankfort	Clinton	280
Brookville	Franklin	157	Tipton	Tipton	139
Liberty	Union	70	Kempton, No. 1	...do	306
Rushville	Rush	48	Kempton, No 2	...dc	243
Carthage	...do	50	Sharpsville	...do	70
Greenfield	Hancock	215	Fairmount	Grant	35
New Palestine	...do	285	Jonesboro	...do	162
Indianapolis	Marion	90	Upland	...do	185
Brightwood	...do	199	Hartford City	Blackford	125
Bridgeport	...do	160	Portland	Jay	58
Cumberland	...do	248	North Manchester	Wabash	274
New Castle, No. 1	Henry	380	La Fontaine	...do	300
New Castle, No. 2	...do	240	Wabash, No. 1	...do	36
New Castle, No. 5	...do	500	Wabash, No. 2	...do	180
Knightstown, No. 1	...do	65	Xenia	Miami	58
Spiceland	...do	150	Peru, No. 1	...do	38
Cadiz	...do	327	Peru, No. 2	...do	318
Springport	...do	156	Monticello	White	205
Sulphur Springs	...do	232	Valparaiso	Porter	125
Mt. Summit	...do	232	Hebron	...do	108
Dublin	Wayne	300	Crown Point	Lake	176
Cambridge City, No. 2	...do	160	Laporte	Laporte	295
Centreville	...do	175	Michigan City	...do	250
Hagerstown	...do	100	South Bend	St. Joseph	157
Fountain City	...do	185	Goshen	Elkhart	162
Washington	...do	212	Elkhart	...do	105
Dalton	...do	275	Rochester	Fulton	245
Walnut Level	...do	280	Plymouth	Marshall	242
Winchester	Randolph	147	Larwill	Whitley	365
Union City	...do	98	Columbia City	...do	224
Farmland	...do	55	Albion	Noble	375
Losantville	...do	173	Kendallville	...do	400
Muncie	Delaware	0 to 85	Auburn	De Kalb	282
Yorktown	...do	68	Butler	...do	387
Selma	...do	90	Garrett	...do	318
Cowan	...do	145	Waterloo	...do	365
Oakville	...do	147			

Topography of the Rock Surface.—Study of the topography of the rock surface beneath the drift in the northern portion of the State reveals the existence of a gentle swell apparently independent of the rock structure. To illustrate the position and character of this swell the following table is introduced, the altitudes being respectively that of the well head and of the upper surface of the rock beneath:

Locality.	Altitude of well.	Altitude of rock.
	Feet.	*Feet.*
Peru	655	660
Wabash	760	760
North Manchester	780	506
Columbia City	826	602
Larwill	950	585
Auburn	872	552
Butler	865	487
Logansport	611	611
Monticello	672	467
Royal Centre	730	621
Rochester	790	506
Warsaw	815	567
Albion	927	552

Royal Centre is located on the low swell discussed later.

On examining the foregoing list in connection with the map (Pl. LXII) it will be seen that there is an elevated tract in the region of the interlobate moraine as mapped by Chamberlin. This elevation is due possibly to a gentle swell in the strata as well as to a greater thickness of the drift. The surface rocks along the Wabash River are also higher than to the northward.

The relations between the rock surface and drift surface south of the Wabash Valley are indicated in the following table:

Locality.	Altitude of well.	Altitude of rock.
	Feet.	*Feet.*
Huntington	726	724
Warren	710	671
Marion	830	830
Xenia	803	745
Mier	815	815
Wabash No. 2	785	605
La Fontaine	928	628

Whenever rocks are exposed south of the Wabash Valley (except in the beds of rivers) they occur at a higher level than within and north of the valley. Part of the general irregularity of the rock surface is due to the unequal erosion it has suffered.

There are certain variations in the thickness of the drift indicating that the preglacial system of drainage was, in portions of Indiana, materially different from the present system. Thus, a well drilled 2½ miles north of Peru found 381 feet of drift; this, after allowing for differences in altitude, would show a great depression, probably the ancient valley of the Wabash River. It is quite safe to conclude that wherever streams in northern Indiana flow upon rocky bottoms, they are not following their old channels, and sufficient investigations would doubtless show that the old channels, are usually quite independent. Borings thus far made indicate that the old channel of the Wabash River lay considerably north of its present channel, especially at Peru and Logansport. By reason of the variable thickness of the drift and the lack of sufficient drilling, it is impossible accurately to map the boundaries of the rock formations of the State, and those shown upon the geologic map (Pl. LXIII) will be somewhat modified as investigation proceeds. Especially will this prove true in the northern and central parts of the State, where the Waverly and the black shale form the surface beneath the drift.

SECTION III.—ATTITUDE OF THE STRATA.

The Cincinnati Arch.—The discovery of the Findlay arch (now called Lima axis) and the elucidation of its relations to the petroleum and gas of that region by Prof. Orton gave reliable guidance to further exploitation in that State. This same discovery, however, proved immediately injurious, though remotely advantageous in Indiana, for this anticline of western Ohio was at once inferred to extend southwestward into and even through Indiana. Believing that this arch was one of a series of anticlinal axes so well developed in the Appalachians, numerous other northeast and southwest lines were projected parallel with this Lima axis, all of which were supposed to contain gas. This view was for a time apparently supported by the discovery of many swells in the Trenton limestone having essentially the same direction as the Lima axis. Nearly every town in Indiana claimed to be located either on the southwestern prolongation of the Lima axis or on one of the arches parallel to it, and numberless wells were sunk at an enormous cost in hope of striking it. Compensation for this outlay was obtained only when the actual gas field was accurately outlined by means of these preliminary borings.

There is little indication of extensive upheaval of the strata of southwestern Ohio and southeastern Indiana in the topography of the surface. The Silurian rocks there outcropping have been degraded to such an extent that the surface has more the appearance of a basin than of a ridge or dome in form; for the summital formations have yielded less readily to erosion than the basal strata and now form a rim surrounding the Lower Silurian rocks, this rim being one of the most prominent topographic features of the region. In some cases this topographic configuration has misled geologists. Prof. E. T. Cox says of this phenomena:[1]

> An examination of the hydrography of the district occupied by the Lower Silurian rocks should at once convince the most skeptical that instead of the Cincinnati anticlinal, it would be more proper to say Cincinnati synclinal; and instead of dome, basin.

Many geologists, too, have held that the phenomena of the Cincinnati arch represent the general erosion of the strata elevated above the sea at the close of the Paleozoic age in conformity with the general continental elevation occurring at that time, rather than a localized uplift. All observers have, however, noted that the formations skirting this area of Lower Silurian rocks in Ohio and Indiana dip to the east and southeast on the one side and west and southwest on the other side.

Dr. J. S. Newberry[2] has given a very lucid exposition of the phenomena of the Cincinnati arch and of the history recorded therein, and Prof. Orton[3] has more recently made important contributions to our knowledge of the subject. The probability that the Cincinnati arch extends into Indiana was first pointed out by the author[4] of this report several years ago; but until recent borings for gas and petroleum revealed the structure of the strata of Indiana over a large area, the northwestern extension of the arch was not generally recognized.

During an early period of the investigation in this State the facts obtained were sufficient to demonstrate the existence of an arch in Indiana; but it was supposed to be a fold subordinate to the main body. More extended research has, with the facts obtained by Prof. Orton in Ohio, enabled us to demonstrate that the anticline entering Indiana from Ohio represents the main body of the arch. It appears, however, that within this State the arch becomes broad and somewhat indefinite, and is perhaps divided into a series of folds throughout the gas area, with an occasional spur from the main body.

In view of the fact that the accumulation of large quantities of gas in Indiana is largely dependent upon the existence of the main body of the Cincinnati arch, it seems desirable that its structure should be given in some detail, especially as the literature of the subject is not accessible to most of those interested in the distribution of gas and petroleum.

Geologists have long been cognizant of the line of gentle upheaval passing from near the middle of the south line of Tennessee, through

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[1] Geologic Report of Indiana, 1878, p. 6.

[2] Geol. Survey of Ohio, vol. 1, 1873, p. 93.

[3] Preliminary Report upon Petroleum and Gas, 1887, p. 124 et seq.

[4] Geologic Report of Indiana, 1882, p. 188.

Nashville and Cincinnati to Lake Erie, about midway between Toledo and Sandusky. This low and broad anticline nowhere presents the topographic features of a mountain range or even a series of hills; but consists rather of a broad and broken tract, over most of which the Silurian formations constitute the surface rocks and are flanked on both sides by broad areas of newer formations. It nowhere presents the characteristics of a sharp ridge, but is simply a belt of lower Paleozoic rocks from 50 to 125 miles wide, from which the formations skirting it dip gently to the east and west respectively from the central line of the tract. South and east of Nashville the Trenton limestone is the surface rock over a large area, around which the more obdurate rocks of the Hudson River form an elevated border or rim, giving the central area the form of a basin. The area of the Hudson River is also surrounded by a high terrane of harder Devonian and Subcarboniferous rocks from 350 to 500 feet in height.

"Could the reader be elevated 2,000 or 3,000 feet above Murfreesboro, he would see below and around him the great oval basin; further off the highland rim rising up in bold terrace-like walls all around the basin, and then extending off in every direction in great plains."[1]

In southern Kentucky the anticline appears lower than usual, and must have lain beneath the surface of at least the later Paleozoic seas, since it is bridged by the Carboniferous formation. In the neighborhood of the Kentucky River the Trenton again comes to the surface and extends northeastward to Point Pleasant, Ohio, the most northerly natural outcrop of the Trenton on the line of the anticline (if Prof. Orton's identifications of the strata at that point are valid), and here as in central Tennessee the arch is topographically a basin rather than a dome. North of Cincinnati the eastern fork of the axis, formerly regarded as the main body because of its extension in the same direction, diminishes in height and contracts in width and practically disappears at the south shore of Lake Erie and is unknown beyond.

It was shown by Dr. Newberry that the arch or anticline is the result of an important orogenic deformation of the Paleozoic period not contemporaneous with the development of the Appalachian folds or the post-Paleozoic elevation, but beginning about the close of the Lower Silurian age and continuing well into if not through the Carboniferous age. During the progress of the investigations recorded in this report many facts have been developed which show that the uplift resulting in the Cincinnati arch began soon after the deposition of the Trenton limestone and before much of the great mass of soft shale was deposited upon it. Certain facts bearing upon the history of the formation of the arch indicate that about the close of the Lower Silurian age there was an island in what is now southern

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[1] Safford's Geology of Tennessee, p. 81.

Ohio and northern Kentucky, which was the cuminating point of the northern half of the arch, and a similar island representing the apex of the southern portion of the arch or anticline in what is now central Tennessee.

It is also probable that this anticline was a line of unequal disturbances or deformation that culminated only with the general continental elevation of the whole interior basin. In southern Ohio and northern Kentucky, on the eastern slopes of the arch, the Lower Helderberg and Corniferous limestones are concealed by an overlap of the black shale and are generally absent over the crest of the dome, showing that the shore line lay far away during the period of their deposition. This elevation of the island in southern Indiana must have thrown the shore line of the Lower Helderberg period far to the west, as this formation is, so far as known, absent from this section of the State. This stage of high level was evidently followed by a subsidence of the island, during which the Corniferous limestone was deposited as a great coral reef over a much larger area. There followed another period of high level that probably affected the arch throughout its whole extent in Indiana, restricting the Hamilton formation to the extreme northern and the southwestern portions of the State. This was followed by the final and probably the greatest subsidence preceding its final elevation above the sea, for the black shale reaches high up on the arch, its area being nearly coextensive with that of the Corniferous limestone, perhaps even greater, as its area is more probably much restricted, owing to extensive degradation. It is evident, however, that this ancient island rose but little above sea level, for the missing formations are not represented by strongly marked unconformities.

In general terms it may be said that the deformation of which the Cincinnati arch was the expression began about the close of the Trenton period and progressed with repeated oscillations through the later Silurian, Devonian, and Carboniferous periods, and that it terminated before the Appalachian elevation and deformation began.

One who travels over the surface of Indiana and Ohio seldom forms any conception of the magnitude of the Cincinnati arch, the dominating structural feature of Indiana, as it is truncated by erosion, and as the basset edges of successive formations are commonly buried beneath superficial detritus. Structurally it is a great ridge approaching the dimensions of the most conspicuous mountain system of the globe. A traveler journeying from the Blue Ridge westward leaves the Trenton limestone in the Cumberland Valley, and passes successively over newer formations until he approaches the Ohio in the vicinity of Wheeling or Pittsburgh, where fully two miles in vertical thickness of later Paleozoic strata lie beneath his feet and above the Trenton. Continuing westward he descends in the geologic scale over the outcropping edges of successively older strata until he again reaches the Trenton in the vicinity of Cincinnati; and were he to continue his journey westward he would again rise in the geologic column, passing successively over newer strata, viz, Upper Silurian, Devonian, and Carboniferous, to the summit of the Coal Measures in Illinois, where he would again find a thickness of more than a mile of strata overlying the Trenton. The crest of the ridge about Cincinnati must rise about a mile and a half above the bottoms of the synclinal troughs on either side, and from one-fourth to one-half a mile above the broad basin about its northern extremity.

It must be borne in mind that the Cincinnati arch is largely confined to the Trenton limestone and underlying formations.

The principal axis of the elevation after reaching the Ohio River between Cincinnati and Point Pleasant, Ohio, turns gradually to the northwest, and enters Indiana between Lawrenceburg and Liberty, its highest point probably entering Franklin County, whence it extends in a northwesterly direction across the State into Illinois. A portion of the main uplift seems to continue northward from Cincinnati at a much lower level, its eastern slope being the more abrupt, and all becoming gradually lower and less distinctly marked until it becomes lost in the Lima axis. This Lima axis seems to be an offshoot from or possibly a crosscut arch to the main body. Its southwestern extremity seems to be near Rushville, Rush County, from which point it extends in a northeasterly direction through Cambridge City and Dublin, Hagerstown, Losantsville, and Fountain City, probably passing into Ohio south of Union City at a much lower level. The main body of the arch enters Indiana with an altitude for the upper surface of the Trenton of about 175 feet above sea level; it becomes reduced to 150 feet at Brookville and to 120 feet at Connersville, but the northwesterly dip is broken by the crosscut axis just mentioned, since the Trenton rises to 176 feet above tide at Cambridge City, and 186 feet at Hagerstown. North of these points the dip of the Trenton is again to the northwest until it is 338 feet below sea level at Monticello, White County. Northwest of Monticello it begins to rise, being 210 feet below tide at Francesville. In Indiana the Cincinnati arch is not a simple ridge or broad dome, but is complicated by spurs or offshoots, one of which has a westerly direction, Noblesville being situated upon it. It is also probable that the elevation of the Trenton shown at Wabash is due to a spur having a northerly direction. Logansport appears to be situated near a low spur that probably extends northward to Royal Centre. Delphi and Kentland are both probably located on local swells subordinate to and connected with the main body.

The Lima axis, popularly called the Findlay arch, after entering Ohio as already indicated, extends northeasterly in a broken line to Findlay, where it takes a northerly course to Lake Erie. The data so far developed seem to indicate that this axis is only one, though the most marked one, of the spurs or subordinate anticlines characteristic of the dome in Indiana.

The configuration of the Cincinnati arch in Indiana and Ohio, as indicated by the borings, is illustrated in the profiles representing the surface of the Trenton limestone, forming Pls. LXV and LXVI. The altitude of the upper surface of the Trenton at each locality is indicated by the figures in the following table in addition to the graphic representation in the sections.

It will be observed that to the east, west, and north alike this petroliferous formation sinks to such a depth beneath overlying formations that it would be impracticable to reach it with the drill, even if it were known to be gas and oil bearing. It has been estimated that the Paleozoic formations are 6 miles in thickness in Pennsylvania; and, although they diminish in thickness westward, they are in eastern Ohio and central Illinois thicker than the deepest well that it has thus far been found practicable to put down.

A careful examination of Pl. LXV shows well some of the facts previously stated. The arch is distinctly shown at Wabash in Fig. 1. The true character of the Findlay arch is not shown in Fig. 2, as the apex should be truncated and the western slope broken or terraced. Fig. 1 also illustrates the broken character of the Lima axis. Figs. 1 and 3 show the abrupt descent to the east from the high tract in Ohio. Fig. 4 shows the rapid rise in the Trenton where the section crosses the northeast and southwest crosscut arch. Fig. 5 shows well the northerly dip of the Trenton limestone. It is impossible to exhibit all the minor variations in the upper surface of the Trenton in profile sections drawn to scale. The surface is everywhere gently undulating, but most markedly so over the dome of the arch. The profile sections on Pl. LXVI illustrate the character of the main body of the arch in Indiana. The local swell at Columbia City is quite marked, but not so distinct as the one at Royal Centre, which shows a rise of 119 feet between that point and Logansport.

The Topography of the Trenton in Indiana.—From the large number of wells sunk in different portions of the State the general topographic configuration of the surface of the Trenton can readily be conceived. As may be inferred from the preceding statements, its upper surface rises into a broad elongated dome trending northwest and southeast across the State, from near its southeastern portion to its northwestern, with several subordinate ridges setting off from it and perhaps a few subordinate domes or ridges that hardly merit the term anticline distributed about its apex. The principal dome inclines at first gently, then on its flanks more rapidly, and about its base once more gently to the northeast and southwest, and in still gentler slopes to the northwest. This general configuration is rep-

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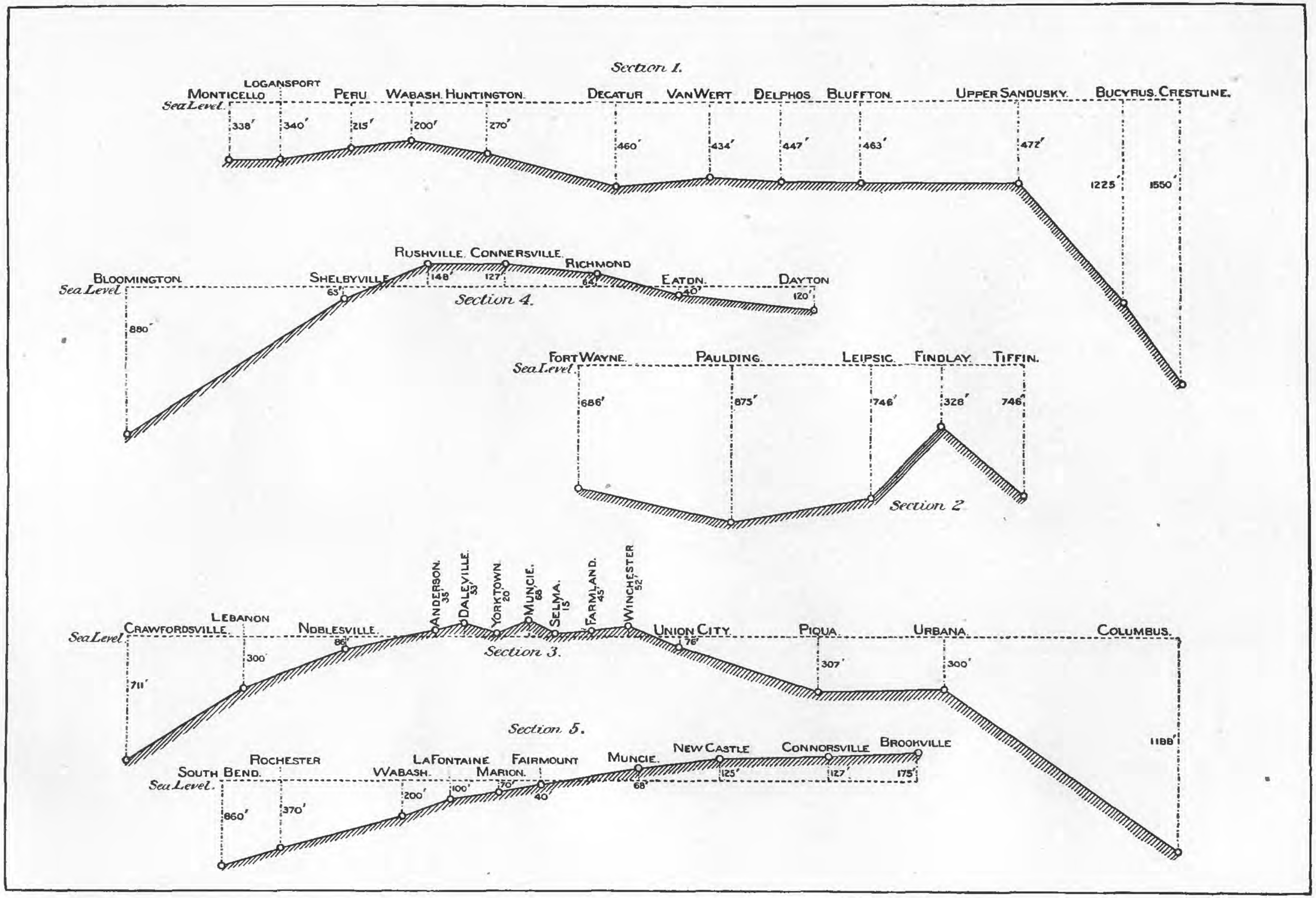


SECTIONS SHOWING ALTITUDE OF THE SURFACE OF THE TRENTON LIMESTONE.

resented in the profiles of Pls. LXV and LXVI; but it may be observed that there are not as yet a sufficient number of drillings to warrant detailed representation of the Trenton surface in all parts of the State.

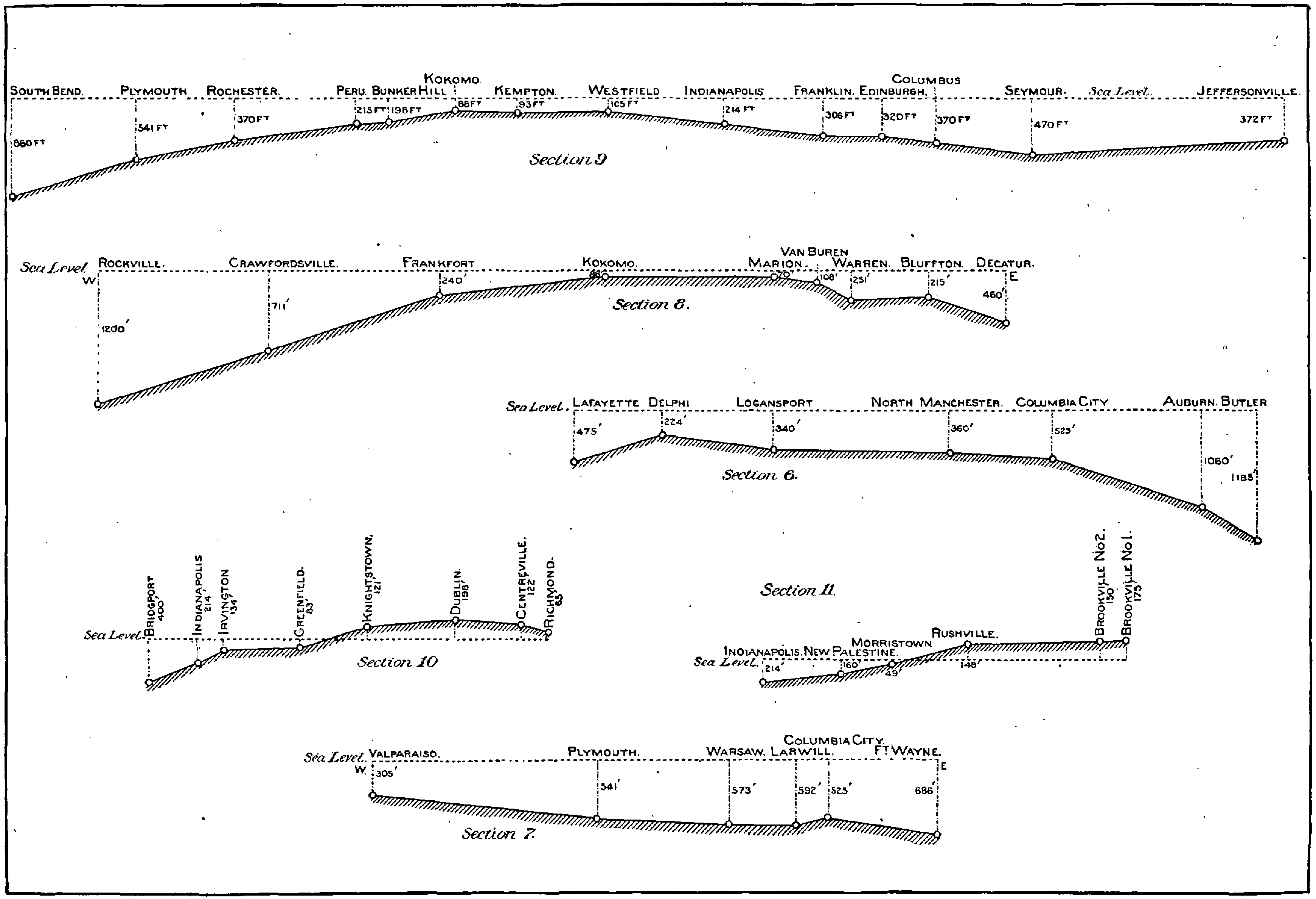
The graphic representation of the upper surface of the Trenton, as illustrated on Pls. LXIV, LXV, and LXVI, is supplemented by the following alphabetic list of altitudes. It will be observed that figures represent the altitude of the *surface of the Trenton limestone with respect to sea level.* The surface altitudes of the same localities are indicated elsewhere.

List of towns and cities in Indiana where the altitude of the Trenton limestone relative to sea level has been determined.

Town or city.	Sea level.		Town or city.	Sea level.	
	Below.	Above.		Below.	Above.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Auburn	1,060		Elwood	82	
Amboy	90		Edinburg	320	
Anderson, No. 1		36	Elizabethtown	265	
Anderson, No. 2		31	Fort Wayne, No. 1	660	
Anderson, No. 5		35	Fort Wayne, No. 2	686	
Alexandria	30		Francesville	210	
Albany		20	Frankton	60	
Arcadia	93		Frankfort	240	
Albion	963		Franklin	306	
Bunker Hill	196		Farmland		45
Broad Ripple	105		Fairmount	41	
Brightwood	147		Fortville	80	
Bridgeport	400		Greenfield, No. 1	83	
Bluffton	215		Greenfield, No. 4	100	
Butler	1,185		Galveston	1,223	
Brookville, No. 1		175	Goshen	1,030	
Brookville, No. 2		150	Greensburg city well		68
Brownstown	703		Greensburg, No. 1		55
Cambridge City, No. 1		176	Glenwood		142
Cambridge City, No. 2		182	Garrett	1,120	
Columbia City	525		Hartford City, No. 1	52	
Columbus	370		Huntington	271	
Crawfordsville	711		Hobbs Station	119	
Connersville, No. 1		127	Hagerstown		167
Connersville, No. 2		112	Indianapolis	214	
Connersville, No. 3		122	Irvington	134	
Connersville, No. 4		103	Jonesboro	68	
Connersville, No. 5		116	Jeffersonville	372	
Centreville		122	Kokomo, No. 1	87	
Chesterfield		36	Kokomo, No. 2	88	
Crown Point	183		Kokomo, No. 3	75	
Circleville	150		Kokomo, No. 4	86	
Dublin		198	Kempton, No. 1	93	
Daleville		58	Kirklin	168	
Decatur	460		Kendallville	946	
Dunkirk	30		Knightstown, No. 1		112
Delphi	272		Knightstown, No. 2		121
Eaton		5	Knightstown, No. 3		121

List of towns and cities in Indiana where the altitude of the Trenton limestone relative to sea level has been determined—Continued.

Town or city.	Sea level.	
	Below.	Above.
	Feet.	*Feet.*
Liberty		74
Lawrenceburgh		152
Lawrence	126	
Logansport, No. 1	340	
Logansport, No. 2	334	
Larwill	592	
Lebanon	300	
La Fontain	100	
La Fayette (about)	475	
Muncie, No. 1, Artificial Gas Company wells		65
Muncie, No. 2, Artificial Gas Company wells		47
Muncie, No. 3, Artificial Gas Company wells		65
Muncie, No. 1, Natural Gas Company wells		60
Muncie, No. 2, Natural Gas Company wells		44
Muncie, No. 3, Natural Gas Company wells		68
Muncie, No. 5, Natural Gas Company wells		58
Muncie, Tuthill's well		37
Muncie, Boyce well, No. 1		58
Marion, No. 1	60	
Marion, No. 2	80	
Marion, No. 5	70	
Madison	33	
Martinsville	778	
Morristown	49	
Montpelier	107	
Monticello	338	
Monon	206	
Middletown		36
New Castle, No. 1		125
New Castle, No. 2		118
New Castle, No. 3		125
Noblesville	85	
North Manchester	360	
Pendleton		19
Plymouth	541	
Plainfield	457	
New Palestine	160	
Peru, No. 1	215	
Portland, No. 2	63	
Portland, No. 3	61	
Portland, No. 4	68	
Portland, No. 5	67	
Rushville, No. 1		136
Rushville, No. 2		144
Rushville, No. 3		148
Richmond City Company's wells		64
Richmond, No. 4		131
Richmond, No. 5		120
Richmond, No. 6		125
Ridgeville		2
Rochester	370	
Royal Centre	195	
Red Key	32	
Shelbyville		65
Selma		15
Spiceland		85
St. Paul		24
Sheridan (about)	82	
Seymour, No. 1	470	
Seymour, No. 2	500	
South Bend, Oliver well	860	
South Bend, Studebaker well	850	
Summitville	30	
Salem (about)	1,024	
Sharpsville		
Springport		61
Mt. Summit		91
Tipton	129	
Thorntown	444	
Union City, No. 1	76	
Union City, No. 4	83	
Vernon	120?	
Winchester, No. 1		24
Winchester, No. 2		53
Winchester, No. 3		70
Warren	251	
Wabash, No. 1	200	
Wabash, No. 2	146	
Walton	232	
Westfield	105	
Xenia	100	
Valparaiso	305	
Van Buren	108	
Yorktown		20
Zionsville	228	
Rockville	1,200	
Bloomington	880	
Warsaw	575	
Losantville		146
Fountain City		
Waterloo		



SECTIONS SHOWING ALTITUDE OF THE SURFACE OF THE TRENTON LIMESTONE.

In constructing the accompanying topographic map of the Trenton limestone forming Pl. LXIV, the four divisions were designed to show clearly not only the greater variations in altitude of the surface of the limestone but also the position and configuration of the Cincinnati arch in Indiana. The boundaries of these divisions can be considered only approximately correct, since in many cases the intervals between the borings are wide and no data could be obtained at intermediate points. The representation is, however, believed to be fairly trustworthy and it is certainly as accurate as it can be made from the data at hand.

The Hypothetic Wabash Arch.—The concealment of the rocky strata of northern Indiana and their exposures at intervals along the Wabash Valley in rather uncommon condition has led to speculation concerning their attitude and structure. In one case, at least, inferences which appear to be unfounded have been placed upon record. These are best stated in the words of their authors.

Mr. S. S. Gorby,[1] who gave this supposed line of disturbance some study, says:

> There is certainly absolute evidence of an upheaval extending from the northern part of Indiana, near the Ohio line, northwesterly by Chicago to the regions of Lake Superior. That the position of the rocks at Chicago, Momence, Kentland, Delphi, Wabash, and Huntington and other points is due to the same cause, I have no doubt whatever.

He adds:[2]

> The general line or axis of upheaval was from the northwest to the southeast, but the principal exposures in Indiana from which the phenomena may be studied are those which have been revealed by the denudations of the Wabash River; and the general direction of this river, until it reaches Delphi, in Carroll County, is westerly. The same evidences of upheaval are observed in Illinois, and may be seen to some extent at Momence, in Kankakee County, and also in the vicinity of Chicago. The line or axis may be followed northwesterly from Chicago until the volcanic regions of Lake Superior are reached. It is highly probable, as was suggested to me by Prof. S. A. Miller, the learned paleontologist of Cincinnati, Ohio, that this line or axis of upheaval is a projection of ancient disturbances, which originated in the volcanic regions of Lake Superior. * * * The inference, then, is that the disturbances occurred at the close of the Upper Silurian formation and before the beginning of the deposition of the Devonian rocks. In fact, it seems probable that the upheaval occurred while great masses of the Upper Silurian deposit were yet in a plastic condition, which is evidenced by frequent and large impressions termed *cone in cone*, caused probably by an upward pressure of the substrata.

He designates[3] the "upheaval" the "Wabash arch," and points out that "The gas and oil fields of western Ohio are in the area influenced by the disturbances which tilted and distorted the strata along the Wabash River," and encourages exploitation of the disturbed area in Indiana.[4]

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[1] 15th Ann. Rep. Geol. and Nat. Hist. of Indiana, 1886, p. 240.
[2] Ibid., pp. 228, 229.
[3] Ibid., p. 228.
[4] Ibid., p. 241.

Mr. Maurice Thompson, State geologist, says:[1]

> One feature of this report must be found of singular interest to those who have been studying the geology of Indiana. I speak of that part of the report treating of what Prof. Gorby has named the *Wabash arch.* A few years ago, while engaged in making some preliminary railroad surveys, I noted at a number of points in northern Indiana evidences of a line of disturbance affecting the rock strata across the State in a direction generally east and west. * * * My opinion was that I should find these disturbances in the form of a practically continuous anticlinal extending into Ohio. It would be along the apex of this anticlinal, or upon swells of its offshoots, so to say, that borers would be most likely to reach gas or oil.

He, too, encourges[2] exploitation of the "disturbed area" for gas.

Great care has been taken to procure all data that would throw any light on the structure of the State through which this supposed line of upheaval passes, but so far not a single observation indicates the existence of any such upheaval, arch, or anticlinal; indeed, the evidence all points in the opposite direction.

In the description of the altitude of the surface rock along the Wabash Valley we have shown in every instance that the surface rocks, where not eroded, rise higher on the south side of the valley than to the north of it. The same relation is observed when the surface of the Trenton is studied in the borings adjacent to the valley. Thus in an interval of 4 miles, between well No. 2 and well No. 1 in the valley at Wabash, the Trenton dips northward 54 feet. At Bunker Hill the Trenton is 196 feet below tide, while at Peru it is 215 feet below, showing a northerly inclination of 19 feet. And these are only representative cases. Any number of sectional lines may be drawn crossing the Wabash Valley and the law is always the same, i. e., the Trenton is always found higher on the south side of the valley, and the dip is uniformly northward except at Royal Centre. The reason for this discrepancy has already been given.

The apparent dislocation of the rocks at Wabash and Peru, about which so much has been said and upon which the "Wabash arch" is predicated, appears to be superficial or confined to a limited thickness of the strata. At Wabash a ridge of hard limestone trending north and south is exposed on each side of the valley and the strata composing it stand at a high angle, dipping irregularly and in various directions, and the bedding is unequal or wedge-shaped at these points. But where regular, as at several localities in the vicinity, the stratification is seen to be nearly horizontal, even within a few rods of the rocky ridge. Some of the beds after standing at a high angle gradually turn and become horizontal within a few rods. In short, the ridge would appear to have been simply a rocky prominence or reef in the Niagara sea about which thinly bedded, horizontally laid strata were deposited, gradually encroaching upon it and finally covering it completely. This overlapping of horizontally laid strata upon rocks of the same formation indicates that if any upheaval ever

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[1] Ibid., p. 6.

[2] Ibid., p. 320.

did occur it was during and not after the Upper Silurian age. Neither at Wabash nor Peru is there any exposure where even-bedded strata shows any disturbance other than the slight dips in conformity with the undulations of the strata throughout Indiana and adjacent States. This undulation is nicely shown in the vicinity of Logansport. Delphi, too, is situated on a gentle swell in the Trenton, already mentioned as probably a spur or offshoot of the Cincinnati arch. All apparently local areas of disturbance in the Wabash Valley are probably portions of and subordinate to the Cincinnati arch. It is not reasonable to suppose that any upheaval as extensive as the Wabash arch has been indicated to be would have affected the surface rocks without also producing some disturbance in the Trenton limestone beneath; but it can not be stated too emphatically that thus far no evidence has been found of any break in the inclination of the Trenton to the northward from the arch shown in Pl. LXIV.

It appears probable that the phenomena which have given rise to the hypothesis of the Wabash arch are to be attributed to the building up of coral reefs and rocky prominences over portions corresponding to the dome and offshoots of the Cincinnati arch or to inequalities in the sea bottom, such as are found in other States. It is not at all probable that the coral reefs were everywhere continuous or even of equal thickness, and in the deeper waters adjacent we should find the finer material deposited as even or regularly bedded strata, such as may be now observed throughout the Wabash Valley adjacent to the supposed points of greatest upheaval.

In view of the supposed bearing of this hypothetic arch upon the gas supply of northern Indiana, it seems well to emphasize the fact that the supposed axis of upheaval is at its nearest point 10 miles distant from the most northerly point where gas has been found in paying quantities; and also that no gas or oil of consequence has as yet been found north of it except at Auburn, which is located over a local and independent swell in the Trenton. It is, of course, possible that gas may yet be found northwest of Monticello, where the Trenton lies at a higher level than in the vicinity of that city; but if so its occurrence should be attributed to that high level of the Trenton as a part of the great Cincinnati arch rather than to the existence of the supposed "Wabash arch."

CHAPTER II.

CONDITIONS OF GAS ACCUMULATION.

SECTION I.—CONDITION OF ROCK STRUCTURE.

Although the Trenton limestone is the principal reservoir of gas and oil in Ohio and Indiana, as incidentally mentioned in the preceding pages, the formation is not everywhere and in all portions of its mass a reservoir for gas or petroleum, as it is only locally and under certain conditions that it becomes gas-bearing.

The requisites for gas yield in any rock are: (1) a carbonaceous stratum within which the hydrocarbons are generated; (2) a porous rock overlying it or adjacent to it; (3) an impervious cover to prevent its escape; (4) the presence of the necessary structural relief to enable a separation of the gas, oil, and salt water to take place; (5) the absence of extensive deformation and fracture of the strata that would afford avenues of escape; and (6) absence of outcrop whereby the products might escape. The failure of any one of these necessary structural or textural conditions would render the accumulation of large quantities of the hydrocarbons impossible.

The Trenton limestone meets the second of these requisites over only a portion of Ohio and Indiana, for over all that portion of the Cincinnati arch that lies south of Mercer County, Ohio, and south and west of the gas area and on the flanks of the arch as shown on Pl. LXIII, the Trenton is not generally a porous rock.

The Utica shale is over most of Indiana and Ohio a perfect cover, especially where the Trenton is otherwise properly conditioned, and it is only where the latter fails in its requisites that the Utica also fails to meet the requirements. The Cincinnati arch meets the other necessary requirements, and fortunately all these requisites of all the elements are present over a large area of Indiana.

In considering the behavior of gas, oil, and water under various structural conditions their relations to gravity must be kept in view. Rocky strata are of high specific gravity, but usually porous or vesicular, or sometimes cavernous at intervals, at moderate depths, and within their interstices liquids and gases may accumulate. These substances, however, arrange themselves in the order of their specific gravities. The water being heaviest seeks the lowest point; the petroleum takes its position above the water, while the gas, being lightest of all, seeks the highest point attainable. As the hydrocarbons are generated within the rocks, they are generally displaced by the heavier water with which the rocks are permeated and are forced to the surface, whence they escape into the air. If, however, all the necessary structural features are present, the hydrocarbons are retained and accumulate in the inverted basins beneath the crowns of the arches in the order named above.

As the area and structure of the Cincinnati arch have been determined approximately from the borings, it remains to consider its relation to the accumulation of gas and oil, in accordance with the foregoing principles.

As a preliminary to the discussion it may be well to state in positive terms that all reference to the sea level is a matter of convenience. Sea level has no relation to the height the water in any rock will rise, as that is determined by the altitude of the rock containing it and the elevation of the source or catchment basin. In Indiana the salt water rises, where given free flow in wells drilled just outside the gas area, about 600 feet above sea level. The sea-level line is used as a datum line for convenience, as all our railroad profiles and altitudes are referred to sea level.

Within the area of the Lima axis in Ohio the gas is generally found between 300 and 400 feet below sea level, varying only with the altitude of different portions of the arch. This axis is, however, sharp and comparatively high, and its continuity with the higher portion to the south is so broken that there is no natural vent for the gas. The broken ridge or isolated arch acts as a trap in which the gas accumulates, the pressure of the salt water on all sides preventing its escape after having once risen into the arch.

In Indiana the conditions are somewhat different. The arch is broad and gently sloping, and so far as now known it is practically unbroken, so that all portions of the arch and territory adjacent to it lower than 100 feet below sea level undoubtedly have free communication with the crest. Thus the gas generated over northern Indiana and in the deep basin south and west of the Cincinnati arch would accumulate under the cover of the impermeable Hudson River shales, in the crest of the arch, or the highest porous portion of the Trenton, where it has been forced and is now retained under a pressure determined by artesian pressure of the salt water surrounding the field.

The depth of the Trenton limestone below sea level does not directly affect the accumulation of gas and oil; it is only necessary that there should be the necessary structural relief in the way of an arch to act as a trap. The relative height of the arch is the important factor.

It is evident that a large volume of gas might be stored in low and broad arches in which the necessary relief is not sufficient to permit the complete separation of the gas and salt water. Where such is the case, even though the total amount of gas might be large, the yield of any individual well must be small. In a sharper arch, where complete separation takes place, a single well might yield abundantly until the reservoir was exhausted. So, in comparison with the Ohio field, that of Indiana seems to promise a longer continued flow and in the aggregate a much greater volume of gas.

As shown by the profiles of Pls. LXV and LXVI the eastern fork of the Cincinnati arch or Lima axis is much depressed, relatively, while the main body in Indiana has a higher level. Over its highest portion adjacent to the Ohio line and south of the gas area the Trenton is of limited porosity, consequently the arch is practically closed in that direction and the great body of the arch northwestward forms a reservoir or trap for the gas, not only from the area of the arch itself but from a considerable area adjacent. This fact is important, as it results in a single field of great volume and pressure into which all the gas finds its way as fast as generated.

Where favorable structural and textural conditions exist in areas moderately removed from and independent of the Cincinnati axis, gas will of course be found, no matter what the depth below sea level; but it is probable that the arches and swells in the strata flanking the great one have in general only served to enrich the latter. The only notable exception to the above so far developed is the arch at Auburn, De Kalb County, and as the salt water and gas are there in close proximity it is not probable that the arch is of great extent or elevation.

Between its outcrops in New York and Pennsylvania on the east; Kentucky and Tennessee on the south; Iowa and Wisconsin on the west, and Michigan and Canada on the north, the Trenton limestone forms a great basin in the center of which the Cincinnati arch rises. Throughout the greater part of its extent this limestone is a reservoir of water which accumulates about the rim of the basin and flows downward toward its center, becoming brine in its progress by taking into solution the saline matters already in the rock. It then rises into the central dome until an equilibrium is established. The flow of water into the center of deepest depression of the basin is interrupted on the east by the Lima axis, which is located between deeper portions of the basin on the northwest and east. The salt water would doubtless fill every crevice and pore in that anticlinal if it were not already occupied by gas and oil. In Indiana the arch is higher and the salt water forced into it in obedience to hydrostatic laws rises to a higher level, driving the gas and oil before it until the resistance from the compressed gas within is equal to the weight of the column of water without or the hydrostatic pressure of the column of water on the opposite side of the basin. The height to which the salt water rises depends upon the elevation of its source, the porosity of the rock, and the altitude of the arch. The Utica shales are everywhere in Indiana impervious to gas and water, and hence the horizon of the salt water in any arch is largely dependent upon the altitude of the reservoir, as the water horizon must rise or fall with the elevation or depression of the Trenton. In Indiana the salt-water horizon is, on the west, northwest, and north of the gas area, about 100 feet below sea level, though a few feet of variation must be allowed for the local swells outside of the main field, where it may be found a little lower. If the rock is not uniformly porous the salt-water horizon may be expected to vary considerably, even within short distances. If it were not for the presence of the gas and oil in the highest part of the porous portion of the dome the salt water would completely fill it; hence it follows that the salt-water horizon, or the 100-foot dead-line, is determined largely by the quantity of gas in the reservoir, and it has no relation whatever to the sea level. The salt-water horizon of every gas field varies with the altitude of the reservoir and the volume of gas and oil in it, and as the gas and oil are exhausted the water will rise and ultimately fill the whole arch.

SECTION II.—CONDITIONS OF ROCK TEXTURE.

While the structural conditions and altitude of the Trenton limestone are the main factors in determining its gas supply, there is a third factor of equal importance, viz., its texture.

It has already been stated that the Trenton limestone is not throughout its whole extent or thickness a gas-producing rock, the productive portion being confined to the upper 50 feet within which the porous gas-bearing stratum varies from 1 to 20 feet in thickness. The porous stratum is usually overlain by a hard non-porous cap rock varying in thickness from 1 to 15 feet. In this porous stratum, which is dolomitic so far as known, the Trenton yields gas abundantly. But it is only where such conditions exist, combined with favorable structural conditions, that the potency of this factor is evident.

The relation between rock texture and flow is proved by the behavior of wells; for the flow, feeble at first, gradually increases as the drill sinks into the porous stratum and culminates when the base of the porous stratum is reached. It is only in rare instances where the gas comes with a gush, as though a cavity or open space had been found. There is no foundation for the popular belief that the gas of the Trenton is accumulated in caverns or open fissures formed by fracture of the strata during upheavals, for the drillers have failed to find caverns, fissures, or other vacant spaces of any considerable dimensions in the Trenton. There can be no reasonable doubt that the gas is simply accumulated under pressure within the minute pores and interstices of the coarse-grained dolomite.

It should be noted that the porosity of the dolomitic portion of the Trenton limestone is not due wholly to coarseness of grain, for chips and larger masses thrown out of the wells by the force of the gas show that even when the rock is hard and compact, small cavities are scattered throughout it in such a manner as to suggest that a part of its substance had been removed by solution. Sometimes one side of a chip is quite solid while the other is porous; and some specimens are perforated in various directions by irregular canals the size of a pin, while the intervening rock is hard and compact. Air may be blown freely through some chips of this porous rock, which in some cases is so open-textured as to absorb one-tenth or even one-eighth its weight of water. It is unquestionable that the abundance of gas in the dolomitic portion of the Trenton limestone is dependent upon the porosity of this portion of the rock. It is also obvious that the accumulation of gas is not influenced by the chemical composition of the rock except so far as its texture is determined thereby, but simply to the mechanical condition which permits the storage of a considerable volume of gas within each cubic foot.

It would be interesting and perhaps economically important to ascertain the cause of the porosity of the upper portion of the Trenton. Prof. Orton, who has sought to answer this question, suggests that the formation was a moderately pure carbonate throughout, but that in its upper portion there has been a chemical change resulting in the substitution of magnesia for a part of the lime; and it is quite possible that this explanation is the correct one. It should be pointed out, however, that in the Indiana specimens at least, the texture indicates that in any alteration which may have taken place the porosity is the result of loss of substance and not of substitution, as the rock is commonly hard and uniform in texture and moderately compact between the irregularly ramified cavities and pores interspersed through it. In drilling through the Trenton limestone in portions of the State, water veins are struck at intervals in porous rock, and the question naturally arises whether the porosity of the different strata is due to the same cause. A study of porous Niagara limestone showed spaces 1 to 3 inches wide and about as deep, scattered irregularly through it, and an analogous condition undoubtedly exists in places in the Trenton limestone.

The porosity of the rock favors permeation by water and oil as well as gas, and around the main body of the gas field the water rises to nearly equal altitudes on all sides. Over northern and central Indiana the Trenton is porous on both sides of the arch but in the southeastern part of the State the rock is close or only feebly porous in spots or narrow strips; especially is this true over most of the Cincinnati arch where it is more than 110 feet above sea level. Throughout this area the rock is hard and close-textured, and as a rule neither gas nor salt water is found in the Trenton. This lack of porosity over the higher portion of the Cincinnati arch in Indiana effectually seals it and prevents the escape of the gas in this direction. So the main body of the arch may be regarded as a long trough or tube having its southern end closed and its northern end immersed in the salt water which is forced up into and around it by the hydrostatic pressure of the water. This pressure is enormous. At Lawrence the water rose 700 feet in the well; at Huntington, 750 feet; at Frankfort it overflowed while the drill was working; at Edinburg it rose 1,500 feet; at Logansport, 950 feet, and at Peru, 800 feet; and in almost all cases 600 feet above sea level.

It has already been pointed out that the volume of gas in the reservoir and its back pressure upon the brine are the factors that determine the salt water horizon around the gas area at about 100 feet below sea level. It is evident that as the gas is withdrawn the water will rise and completely fill the reservoir. The influence of texture upon gas yield is evident from a study of the well records. South and east of Henry County—with the exception of the western portion of Rush and Decatur and eastern Shelby Counties—the Trenton lacks porosity but yields a little gas, enough to encourage drilling, thus leading to a great expenditure of money. Over the gas area the Trenton is not equally porous and the porous rock varies in thickness. Patches of hard, compact rock, often narrow or irregularly shaped, are frequently met with over all the higher portions of the field and are not uncommon in the gas area. As a rule the Trenton is most porous where near the salt water horizon or in the center of the field.

We have called attention to the uneven surface of the Trenton limestone over the gas area, and while this character has no appreciable effect upon the gas flow, the beneficial results of a combination of these structural characteristics with the proper textural condition is fully seen over a narrow belt just outside the main body of the field, where every local swell is an advantage as affording a reservoir or trap for the gas, while the intervening depressions contain salt water. The slope of the arch is so gradual that many of these swells in the Trenton may be found, and it is here that careful exploitation is needed. No single well, however large the flow, can be considered evidence of a large volume of gas in the vicinity, as the local reservoir may be small. No single failure should be considered positive evidence of the absence of gas, but explorations should be carefully conducted and the records of different wells compared until the character of each local swell in the Trenton is clearly made out and its relation to the great arch determined. This applies of course only to the area immediately adjacent to the main body. It has cost the people of this State thousands of dollars to dispel the widespread and popular delusion that gas and oil are as likely to be found in one locality as in another, and to diminish the wide-spread faith in odors of petroleum as indications of the presence of gas in paying quantities. The expenditure has, however, not been wholly lost, as the drilling incited by these popular but unfounded ideas has enabled the gas area of Indiana to be determined. Moreover, the laws governing the distribution and accumulation of gas and petroleum have been concurrently ascertained and the subject is no longer enveloped in obscurity. The geologist can now, after a thorough mastery of the facts already developed, give intelligent and valuable direction to the prospector in his work.

The conclusions respecting the gas field of Indiana set forth in the foregoing and subsequent pages and in Pl. II have been reached only after a careful study of all available data obtained since the drilling first began in Indiana. Records of most of the borings have been scanned and the drillings of many carefully examined, and the conclusions here presented seem legitimate and the only ones that can be drawn from the facts. It is, of course, possible that other gas fields may yet be revealed, but if so the probabilities are that the fields will be limited in area and also in yield. It may be safely said that anywhere outside of the limits laid down on the accompanying map there are many chances of failure to one of success; indeed, thus far the proportion has been a hundred failures to one indifferent success. Judicious expenditure in prospecting should always be encouraged, but where there is so little prospect of obtaining return, investment without judgment is to be deprecated. Certainly the people of Indiana are no longer justified in sinking wells outside of the gas area, in the vicinity of repeated failures. It can hardly be expected that, even in the known field, every well will prove productive, though thus far there have been very few failures and wells may be sunk almost anywhere with reasonable assurance of success. It should be borne in mind that the natural gas in Indiana is being consumed much more rapidly than it is generated; that the vast reservoir in which it has been accumulating for ages is giving evidence of exhaustion, and that with this diminution of the supply the certainty of successful ventures also diminishes.

In the foregoing conclusions reference has been made only to the gas field in the Trenton limestone, for the reason that those of other formations are of limited extent and value. The pockets of gas in the Hudson River, Utica, and other formations have so far with one exception proved short-lived and of no value.

Considerable importance is often attached to surface indications as a guide to the prospector, but all such are without foundation, as the elevations or depressions of the drift surface can not possibly have any relation to the gas-bearing rock beneath it.

The accumulation of gas in large quantities is not an accident, but the result of certain fixed and well defined laws conjoined with the necessary structural and textural conditions. It must be borne in mind that throughout the whole gas area the porous strata below the gas-bearing and oil-bearing stratum contain salt water, and no portion, however high above sea level, is safe from the encroachments of salt water. It should also be remembered that around the lower borders of the field the upper porous stratum dips so gradually that its upper portion may contain gas and its lower portion salt water, as shown in a number of wells at various localities.

CHAPTER III.

GAS PRESSURE AND MEASUREMENT.

SECTION I.—DEFINITIONS.

When a gas well is closed it is found that the pressure of the confined gas within it gradually increases through a period varying from a few seconds in the largest wells to several minutes in wells of medium flow or even hours in wells of feeble flow, and that afterward the gauge becomes stationary. This is technically known as the "rock pressure," "confined pressure," or "closed pressure" of the well, but may more properly be called the *static pressure.*

When the gas from a well is allowed to escape freely into the air it is found that if the stem of a mercurial or steam gauge is held in the line of flow that a certain constant pressure will be indicated by the gauge. This is the "open pressure" or "flow pressure" of the well, and varies with the volume of gas and the size of the pipe through which it is allowed to escape. The capacity of a well may be determined from the flow pressure.

When gas is piped to a considerable distance from the well-head, there is a diminution in flow pressure, and an increase in the time required for reaching the full static pressure when the flow is interrupted. The defect of available pressure produced by these causes is known technically as the *retained pressure.* Actually there is always a reduction of pressure in the well itself, varying inversely with the capacity and the size of the casing-pipe, directly with the depth, and both directly and inversely with many other conditions, so that the available pressure at the well-head is less than at the well-bottom. Moreover, the frictional retardation suffered by the gas commonly culminates in the pores and canals by which the substance is conveyed from its reservoir into the bore, so that the available pressure in the well is less than that in the reservoir. In practice, however, these causes of reduced pressure are ignored, and the term is extended only to the reduction of available pressure produced by appliances between the well and the point of utilization. The retained pressure ranges from nearly zero to the maximum static pressure.

SECTION II.—THE STATIC PRESSURE.

Most of the wells in the productive field of Indiana show when confined a static pressure of 300 to 350 pounds per square inch, the average being about 320 pounds. This is the approximate measure of the pressure to which the gas within its natural reservoir is subjected by the hydrostatic pressure of the salt water which is below, but in immediate contiguity with, the gas. It has already been pointed out that the Cincinnati arch is a low dome of the Trenton limestone in the center of a basin several hundred miles in diameter and that surface waters flow down the strata (becoming a brine from the solution of saline matters met with in the rocks) toward the center, and rise within this central dome or arch, which they would doubtless completely fill were it not for the back pressure of the contained gas. The pressure of the salt water is enormous at the localities where it has been struck. In the following table the water pressure has been computed at 63 pounds per cubic foot.

It should also be noted that drilling was usually suspended when salt water was encountered and before the bore had penetrated the porous stratum to a sufficient depth to permit free flowage, and to this fact the discrepancies in height reached by the water are doubtless chiefly due. In many cases the height to which the water rose is only approximately correct, as no accurate measurements were taken, often only estimates.

Locality.	Depth at which water was struck.	Height water rose in the well.	Pressure per square inch.
	Feet.	*Feet.*	*Pounds.*
Logansport	968	968	423
Lawrence	1,015	700	306
Larwill	1,566	1,366	598
Huntington	1,037	950	420
South Bend	1,670	1,470	665
Goshen		2,000	876
Greenwood (St. Peter ss.)	1,865	1,700	745
Monon	880	850	374
Monticello	1,050	500	220
North Manchester	1,180	990	435
Frankfort	1,200	600	265
Brownstown (St. Peter ss.)	1,891	1,600	701
Do	565	540	238
Peru	900	800	350
Plainfield	1,500	1,200	525
New Palestine	1,003	660	290
Madison	950	250	110
Muncie (St. Peter ss.)	1,390	1,100	482
Portland (St. Peter ss.)	1,500	1,200	525
Plymouth	1,368	900	395
Warsaw	1,437	1,000	438

Examples like those introduced in the table might be multiplied indefinitely, and in every instance in which the drill penetrated the porous rock to a sufficient depth to admit of free flowage it would be seen that the pressure of the salt water increases with the depth at which the porous Trenton or other water-bearing rock is found. In nearly every case the pressure of the brine when encountered is considerably greater than the rock pressure of the gas in the Indiana field. This is because in the wells tabulated the brine was struck far below the gas level. The pressure of the brine in all the wells around the margin of the main field is but little less than the rock pressure of the gas in neighboring wells. The gas pressure is then primarily *determined by the hydrostatic pressure of the water in the lower portions of the reservior.* Where gas is found in formations where the structural conditions are different and it is not associated with water, as in the Hudson River shale, the confined pressure seldom exceeds 25 pounds, and is usually much less. A strong well at Vernon, Jennings County, from the Niagara, though discharging nearly 1,000,000 cubic feet per day for a time, gave only a static pressure of 2½ pounds. All such are distinguished as "low pressure" wells.

The enormous pressure to which the gas is subjected in the great reservoir increases its capacity many times, for under a confined pressure of 320 pounds per square inch the gas is reduced to one twentieth of the volume it has when escaping from the well. According to Prof. Phillips, of Western University (Allegheny, Pennsylvania), marsh gas, which constitutes the main bulk of natural gas, would be reduced to a liquid by a pressure of 2,700 pounds per square inch at a temperature of 12° F., or under a pressure of 1 atmosphere at 263° below zero. Such pressure or temperature does not exist in the Indiana natural gas reservoir, and the gas is stored away as a highly compressed gas but not as a liquid.

When a well is closed it becomes a part of the reservoir, and the length of time required to fill it with gas of the same density as that in the rock is the time required for the well to reach its maximum static pressure. In some cases the gas may escape from the porous rock penetrated by the bore more rapidly than it is supplied from adjacent parts of the reservoir, and in such cases considerable time is required for the establishment of an equilibrium between the well and the great body of the reservoir. It is probable, indeed, that if the porosity of the Trenton dolomite were greater and the gas pressure more rapidly equalized among the various wells that the range of pressure would diminish throughout the whole gas field and everywhere approach its maximum of 350 pounds.

The time required to reach maximum pressure varies with the capacity of the well (or in other words the freedom with which the gas enters the well from the surrounding rock), the depth of the gas-bearing strata beneath the surface, the size of the bore or of the pipe used in packing, the depth at which the packer is placed in the bore, etc. When closed, wells of great capacity reach their maximum pressure in a few seconds, medium sized wells in a few minutes, while it requires hours for the smaller wells to reach the same pressure; but at any locality all the wells, whether large or small, eventually reach the same pressure. A well of 14,000,000 cubic feet per day shows no greater static pressure than one of 250,000 cubic feet, though the first may reach its maximum in as many seconds as the other may require in minutes.

In the early days of gas utilization, efforts were frequently made to determine the capacity of wells from the time required to reach their static pressure. In view of the foregoing facts it must be evident that any such measurements are at best unsatisfactory. It is true that a rough estimate of the capacity of a well can be made by comparing the period within which it reaches its maximum pressure with the like period of a well of known capacity; but the estimate is at the best only a rough comparison and in most cases but little better than a guess, as shown alike by analysis of the method and by the measured records of the different wells.

The rate of increase in pressure when the well is closed is determined by several factors, some of which can be calculated while others are indeterminate in any case. Thus the capacity of a well is affected by the size of the packing tube, especially where it is not of sufficient caliber to permit free flowage. It has been found that the capacity of a well has been reduced from 7,981,500 cubic feet, as measured in the 5⅝ casing, to 6,712,000 feet when packed with a 3-inch pipe, the reduction in size of discharge pipe causing a retained pressure in the well. Again, more time is required to fill a large bore well than a small one, but on the other hand the friction to be overcome in the process is relatively diminished. So, too, a deep well requires a longer time in filling than a shallow one, and with free flow the difference in friction might not be sufficient to produce appreciable difference in flow. Moreover, there is a certain tract of porous rock surrounding each bore which serves as the medium connecting the body of the reservoir with the bore. This tract must in most cases be of considerable extent. It is everywhere ramified by a multiplicity of minute tubes and canals with other passages of various sizes and forms, each one of which is governed by the same laws regarding pressure, volume, friction, etc., as the bore itself. Many of these are doubtless so minute that while the gas may penetrate them freely under high pressure it will not do so under a somewhat diminished pressure, so that during a free flow only a part of those passages serve to connect the reservoir with the well. As a rule, the greater the capacity of the well, or the smaller the discharge pipe, the quicker will it reach a given pressure; and in the utilization of gas a well that reaches its maximum pressure quickly is considered more valuable than one that requires a longer time. This view is, of course, correct, but it affords no means of determining the number of cubic feet per day that the well will furnish.

The following table exhibits the time required to reach certain pressures in a few representative wells:

No.	Locality.	Time required to reach given pressure.				Capacity.
		100 pounds.	200 pounds.	300 pounds.	Maximum.	
1	Shideler	15 seconds	75 seconds	4 minutes	(325 pounds) 7 minutes.	1,225,000
2	Muncie Highlands well	10 seconds	35 seconds	2¾ minutes	....	1,380,000
3	Big Schrader, Kokomo	....	....	40 seconds	(320 pounds) 1 minute.	4,642,000
4	Hartford No. 3	....	....	....	(350 pounds) 3½ minutes.	1,854,000
5	Hartford No. 1	....	....	....	(350 pounds) 38½ minutes.	850,000
6	Quarry Mills	(175 pounds) 1 minute.	1½ minutes	(240 pounds) 5 minutes.	(290 pounds)	590,000
7	Walnut Ridge	....	....	8 minutes	(325 pounds)	500,000
8	Ogden	....	....	6 minutes	(315 pounds)	500,000
9	W. H. Cottingham well	....	....	....	(320 pounds) 1 minute.	....

All these wells have 2-inch tubing except No. 3 and No. 9, which have 3 and 4 inch tubing, respectively. Wells that have been torpedoed require a longer time to reach the maximum, even where all other conditions are equal.

Observations show that over the higher portions of the Cincinnati arch, where the Trenton is only slightly porous, the static pressure of the wells becomes gradually less the further they lie from the main body of the field. Thus, it is 200 pounds at Greensburgh, 40 pounds at Seymour, and 50, 27, and 18 pounds, respectively, in wells near Connersville. This loss of pressure in wells far from the salt water is undoubtedly due to the friction of the gas in its passage through the feebly porous rock. It seems to be a universal fact that where the Trenton is only slightly porous the gas has a comparatively low pressure unless some productive area is close at hand.

It should be borne in mind in making tests for confined pressure that where a large draft is made upon a limited area through many wells, if any well is closed it will not give the maximum pressure of the field because of the influence of the other wells surrounding it. The loss of pressure from this cause depends upon the porosity of the rock as well as the proximity of the other wells.

SECTION III.—THE OPEN PRESSURE.

The open pressure is the measure of the force with which gas escapes from a well. It is usually expressed in pounds, and ascertained by means of a steam or mercurial gauge the stem of which is inserted just within the well or packing tube.

It is necessary to exercise care in determining the open pressure. The best method is to use a reliable steam gauge with a curved stem 8 or 10 inches in length, in order that it may be easily held in the center of the tube, with the dial, face upwards, well outside of the stream of escaping gas; and it is also necessary that the stem shall be a thin-walled, slender tube, beveled to a sharp edge at its extremity. The stem should be held flush with the orifice of the well or packing tube, or not to exceed one inch within it.

Prof. Robinson, of the State University of Ohio, has devised a method by which the velocity and flowage can be determined from the open pressure thus measured. This method, which is an application of the principle of Pitot's tube, is stated at considerable length and the formulæ employed and tables computed therefrom are incorporated in a recent report of the geological survey of Ohio.[1] Prof. Robinson discusses the subject in an exhaustive manner, and his tables will doubtless serve as a standard for determining the capacity of gas wells henceforth. The essential tables, with the accompanying explanations and directions for use, transcribed from the original publication, are appended.

While Prof. Robinson's method is unquestionably correct in principle, considerable errors are liable to result from its practical application unless great care is exercised in measuring the pressure. When the orifice of escape is small and the tube attached to the gauge is large, free escape of the gas is prevented, and the area of the escape pipe is reduced by the area of the tube walls and the flow pressure is thereby increased. Again, tests are sometimes made by inserting the end of the gauge stem or tube into the opening of a stopcock and calculating the flow from the area of the pipe. Of course even approximate accuracy can not be claimed for the results of tests so made. Much depends, too, upon the position in which the gauge is held; for if the position is such that the needle will fall from the peg by its own weight, gravity and the flow pressure combined will render the reading too high, especially for low pressures. If the position is such that the gravity causes the needle to rest on the peg, the reading will be too low, as gravity will be opposed to the force of the current. Again, the tube or stem of the gauge is ordinarily inserted in the center of the orifice through which the gas escapes where the velocity reaches a maximum materially in excess of the mean; and so the determination of flowage is excessive, and the computed capacity is in excess of the actual capacity. The importance of the last-named source of error varies with the form of orifice from which the gas escapes and into which the stem of the gauge is inserted, and doubtless with pressure and other conditions.

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[1] Vol. 6, pp. 548-594.

In certain experiments conducted by Prof. Robinson in 1873 with a simple circular orifice in the flat wall of a tank 1 and 2 inches in diameter, beveled on the outer side, and under a head of from 2 to 4 inches of water, the following velocities were obtained in different parts of the orifice:[1]

Part of orifice.	Velocity per second.
	Feet.
Center	122
One-fifth way from center to side	122
Two-fifths way from center to side	121
Three-fifths way from center to side	118
Four-fifths way from center to side	114
At side	95

Since the conditions of Prof. Robinson's experiments were materially different from those encountered in the practical measurement of gas wells, it was deemed wise to make a new series of measurements. Accordingly, Mr. William Moore, of Kokomo, made for this report at my request some tests to determine the variation in the velocity at different points between the center and the sides of the 3-inch escape pipe of the Fairfield well. The gauge was firmly clasped to the escape pipe, thus avoiding any vibration of the needle and by means of a dial attachment the distances were accurately proportioned. The results of the test are as follows:

Part of escape pipe.	Flow pressure.	Velocity per second.	Capacity.
	Pounds.	*Feet.*	
Center	10¾	1,293	5,482,944
One-fifth distance from center to side	10½	1,282	5,436,288
Two-fifths distance from center to side	9½	1,226	5,198,860
Three-fifths distance from center to side	8	1,139	4,829,943
Four-fifths distance from center to side	6½	1,048	4,444,076
Side of escape pipe	5¼	914	3,875,827

The most serious source of error, however, is found in the use of unreliable gauges. The open pressure of even a vigorous well is small, only 1 pound in a 2-inch pipe for a capacity of 812,000 cubic feet. Indeed, ordinary steam gauges are not to be relied upon for making strictly accurate tests of gas wells, for although they may be fairly accurate for high pressures they are not sufficiently sensitive to low pressures.

Most of the sources of error to which Prof. Robinson's method is subject in its practical application tend to produce excessive results, and this tendency coincides with a natural but deplorable disposition on the part of drillers, well owners, and the press to exaggerate the

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[1] Geol. Surv. Ohio, 1888, vol. 6, pp. 551-553.

capacity of wells. The excitement following the success of the great Karg well at Findlay, Ohio, created a disposition to magnify the actual capacity of neighboring wells, and the total capacity of the Findlay field thus came to be greatly exaggerated. Then, as gas was found in other localities, the discoverers felt called upon to claim capacity approaching that of the Findlay field, in order that they might successfully compete with that town in obtaining the much-coveted boom. Local newspapers seized the opportunity to make much out of little, and the drilling of every new well was a signal for a louder flourish of trumpets. The author has personal knowledge of instances in which a capacity of 12,000,000 cubic feet per day was claimed for a well in the local press and the figures republished by scientific journals in other cities, when the actual capacity would not exceed 750,000 cubic feet. Indeed, most of the gas towns in the State claim from two to three times the actual capacity of their wells; nearly every large town claims the largest gas well, the greatest length of service pipe, the greatest aggregate volume of gas, and the most extensive utilization of gas in manufacturing.

It is no wonder that laymen have no definite ideas concerning the capacity of gas wells when newspapers and scientific journals, and even scientific men, indulge in exaggerated or indefinite statements or confine themselves to glittering generalities. A well is frequently spoken of even by so-called experts as a "300-pound gasser" or a "500-pound gasser," the implication being that this is a measure of its capacity or value, when in fact it only means that this is its static pressure regardless of its capacity. Little can be inferred as to the capacity of a well from its brightness when burning, for a well with a daily capacity of 350,000 cubic feet will burn more brightly from a 2-inch pipe than one with a capacity of 1,000,000 cubic feet.

The common exaggeration of the capacity of gas wells is in a measure fostered by speculators who desire to profit by the booms that they expect to create; and the charlatan who incites to misrepresentation distrusts those who confine their statements to actual facts, often considering them as enemies to the prosperity of the town. This is not only unjustifiable but foolish, for in general, mendacity is as potent in one town as in another, and exaggeration is roughly proportional to actual flowage, and so the distribution of prosperity is regulated in the end by the actual and not the false condition.

SECTION IV.—RETAINED PRESSURE.

As already stated, the retained pressure is the reduction of available pressure caused by insufficient capacity in the escape pipe to allow the gas to escape as fast as it enters the well. The accumulation of gas causes a rise in pressure up to a certain point, when it becomes stationary for the conditions of flowage present. Retained pressure may be caused by friction within the bore and packing tube, but more especially by the friction in its passage through main distributing pipes, etc. The smaller the mains and the greater the distance, the greater the friction. This friction in the mains prevents the free escape of the gas from the well, the effect being the same as that of reducing the size of the opening by turning a stop-cock. The Portland natural gas main from Camden to Portland shows a retained pressure of 200 pounds at Camden when the end at Portland is left open, all of this being due to the friction in the mains.

The Indianapolis Natural Gas Company's main, when in use to full capacity, shows a loss of 118 pounds for 21 miles of main. The Trust Company's line showed on January 16, 1889, a pressure of 190 pounds at the head of the 12-inch main and 75 pounds at Indianapolis, the distance being 17 miles—a loss of pressure of a little less than 7 pounds per mile.

This loss of pressure is an important factor in piping gas long distances, because of the rapid diminution of the volume which a main of a certain size will convey with the increase of the distance from the wells. While gas will find its way through a main, however long it may be, there is a practical limit to the distance to which it may be piped from wells of a given pressure. When the retained pressure at the well approximates the maximum rock pressure and the gauge at the delivery end of the main shows but a few pounds, the main is carrying gas to its full capacity or the limit is reached as to distance; and as the pressure of the gas at the wells is increased, the volume discharged by the well decreases.

A series of measurements was made with the object of determining the influence of retained pressure upon capacity. Its results are shown in the accompanying table :

Retained pressure.	Chesterfield well. 3-inch pipe.		Fay well. 3-inch pipe,		Muncie well. 2-inch pipe.	
	Open pressure.	Capacity.	Open pressure.	Capacity.	Open pressure.	Capacity.
Pounds.	*Pounds.*		*Pounds.*		*Pounds.*	
0	7	4,553,000	6	4,244,000	7½	2,088,000
25	5	3,925,800	6	4,264,000	6¾	1,991,500
50	3½	3,221,560	5	3,925,800	6½	1,959,400
75	3	3,095,000	4½	3,737,400	5½	1,824,800
100	2	2,623,724	3¾	3,440,000	4¾	1,702,950
125	2½	1,316,060	3	3,099,100	2¾	1,321,700
150	....	....	1	1,816,050	1½	991,370
175	....	....	½	1,316,000	½	584,880

When the Chesterfield well was tested the day was exceedingly cold, and the results are hardly satisfactory. The Fay well, however, shows a more gradual diminution in flowage with the increase of pressure. Another important fact is noteworthy, viz, the former discharges the same volume of gas under 125 pounds retained pressure that the other does under 175 pounds.

It will be seen from the above tests that a vigorous well, having a capacity of 4,000,000 or 5,000,000 cubic feet per day, can carry from 25 to 100 pounds retained pressure without material reduction of flow; but if the retained pressure is increased further the volume of gas discharged decreases rapidly. This is important in those cases where gas is piped long distances, or in which low-pressure lines are supplied by high-pressure lines. It is sometimes considered necessary to keep a considerable retained pressure in the well in order to give force to the flow, but it must be borne in mind that there is a reduction in flowage with every pound of retained pressure. In long pipe lines the friction in the pipes produces a retained pressure, and reduces the volume of gas that can be delivered in a given time; not because the pipe will not carry the gas, but by reason of the inability of the gas to escape from the well into the mains. Where the retained pressure is high, the greater the number of strong wells connected with the mains the larger the volume that can be discharged by the main, though each well will discharge but a small volume. Again, the greater the capacity of the well, the larger the volume of gas it can discharge under a given pressure. Hence, small wells have no practical value for piping long distances.

SECTION V.—MEASUREMENT OF GAS WELLS.

For gas wells producing less than 1,000,000 cubic feet per day the anemometer is excellently adapted. The discharges per second and per day are obtained by multiplying the velocity recorded by the anemometer by the area of pipe section in feet, and by area of pipe-section × 86,400.

Where accessible a mercurial gauge with a curved tube attached is the most reliable instrument for testing wells where the open pressure in any size pipe or the open casing does not exceed 5 pounds.

Where the flow is feeble (less than 1 pound) and an anemometer is not available, an easily improvised water gauge may be substituted. The apparatus requires for construction and use three pieces of glass tubing, each about a foot long, one bent or curved near the end to a right angle, two pieces of rubber tubing of the same size, one three inches and the other two or three feet long, a little water, and a graduated rule for measuring. The tubing is connected, the long end of the bent tube to the short rubber tube and the others alternating. The apparatus is partially filled with water, the short arm of the bent tube being held in the orifice from which the gas is escaping and the third glass tube is held upright and a little higher than the middle arm which is suspended by the rubber tubing, the longer section of the rubber tubing assuming a **U** shape. The water is allowed to escape from the third glass until its surface may be seen in both that and the middle glass tube, it will then be found that the water stands higher in the further tube and the difference as ascertained by the rule is the measure of the flow pressure in inches from which the capacity may be determined by reference to the accompanying table.

To measure the flow of a vigorous well by Robinson's method, attach an open tube of convenient length, straight or bent, to a steam gauge. Hold the open end in the current of gas at the well head and note the average pressure which the gauge shows in pounds and fractions of a pound ($p_1 - p_2$, first column of table). Add to this observed pressure 14·6 (pressure of air) and divide the sum by 14·6$\frac{p_1}{p_2}$ (second column of table). Find the resulting number or that nearest to it in the third column (m). increasing or decreasing proportionately to the difference between the number obtained by division and the number found in the second column. Multiply the number thus found (m) by 3,103, and the result will be the velocity of the gas current in feet per second. To find the volume per second, multiply the velocity in feet by the area of the pipe in terms of square feet. To find the volume per day, multiply the result thus obtained by 86,400, the number of seconds in a day of 24 hours. The result will be the volume of gas at a temperature of 32° F., and at an air pressure of 14·6 pounds per square inch.

Table to facilitate calculation of velocity and temperature of flowing gas, in which $p_1 - p_2$ is the observed pressure by gauge on Pitot's tube, and m the value of a coefficient.

$p_1 - p_2$ or observed gauge pressure.	$\frac{p_1}{p_2}$	m	$p_1 - p_2$ or observed gauge pressure.	$\frac{p_1}{p_2}$	m
0·5	1·034	·100	8	1·548	·368
0·75	1·051	·120	9	1·616	·387
1·0	1·068	·138	10	1·685	·403
1·5	1·103	·170	12	1·822	·436
2·0	1·137	·195	14	1·959	·461
2·5	1·171	·216	16	2·096	·488
3·0	1·205	·236	18	2·223	·512
3·5	1·240	·254	20	2·370	·533
4·0	1·274	·270	25	2·712	·578
4·5	1·308	·284	30	3·054	·617
5·0	1·342	·299	35	3·397	·653
5·5	1·377	·312	40	3·740	·683
6·0	1·411	·324	45	4·082	·709
6·5	1·445	·335	50	4·425	·734
7·0	1·479	·346	55	4·767	·757
7·5	1·514	·357	60	5·110	·778

In Prof. Robinson's tables the fixed multiplier, 3,103, is based upon a specific gravity of the gas of 0·6, approximately determined by direct measurement. Prof. Howard has calculated the specific gravity from the composition of the gas as determined and construed by him and finds it to be 0·57. If this determination should be adopted, the fixed multiplier would become 3,184. The question in regard to the exact specific gravity of the gas is still an open one.

To faciliate employment of the foregoing table, the following table showing areas in feet of the cross-sections of casing pipes of the dimensions commonly used is introduced:

1-inch pipe = ·00545
2-inch pipe = ·02182
2½-inch pipe = ·034
3-inch pipe = ·04908
4-inch pipe = ·08726
5⅝-inch pipe = ·1725

An example will make the mode of using the table clear. The pressure noted in the casing of a gas well is 6·3 pounds. 6·3 + 14·6 = 20·9. 20·9 ÷ 14·6 = 1·431. The number nearest this in the second column is 1·445. The difference is 0·014, which is seven-seventeenths of the difference between 1·445 and the next lower number in the table. In the third column, *m*, the number corresponding to 1·445 is 0·335. The difference between it and the next lower number is 0·011. $\frac{7}{17} \times 0{\cdot}011 = 0{\cdot}005$. Subtract this from 0·335 and the remainder is 0·330. Multiply 0·330 by 3,103; the product is 1,024, which is the velocity of the escaping gas in feet per second. The gas is escaping from the casing which is 5⅝ inches in diameter, or, in terms of square feet, 0·1725. The daily yield of the well is therefore 1,024 × 0·1725 × 86,400 = 15,261,696 cubic feet, at a temperature of 32° F. and a specific gravity of the gas of 0·6.

To render his method more readily available, Prof. Robinson has computed the following table:

Cubic feet of gas, reckoned at 32° F., discharged by well per day of 24 hours of continuous flow, by Pitot tube measurement; the specfiic gravity of the gas being here taken at 0·6 (air=1), and the temperature of the flowing gas at well mouth being taken at 32° F.

Observed pressure by water gauge.	Observed pressure by pressure gauge.	Diameter of orifice or of well mouth where observed, in inches.					
		$d_2=1$ in.	d=1½.	d=2.	d=2½.	d=3.	d=3½.
Inches.	*Lbs. per sq. in.*						
·1	·0036	12,390	27,880	49,556	77,440	111,510	151,780
·2	·0073	17,560	39,510	70,260	109,750	158,040	215,110
·3	·0109	21,480	48,330	85,940	134,250	193,320	263,130
·5	·0182	27,720	62,370	110,880	173,250	249,480	339,570
·7	·0254	32,820	73,840	131,260	205,100	295,380	402,000
1·0	·0364	39,210	88,230	156,830	245,100	352,890	480,400
1·5	·0545	48,030	108,070	192,120	300,200	432,270	588,400
2·0	·0727	55,340	124,520	221,360	345,900	498,060	677,960
3·0	·109	67,910	152,800	271,630	424,500	611,190	832,020
4·0	·145	78,410	176,420	313,660	490,100	705,690	960,600
5·0	·182	87,670	197,260	350,670	548,400	789,030	1,074,860
7·0	·254	103,500	232,880	414,000	646,900	931,500	1,267,900
10·0	·3636	123,000	276,750	492,000	768,800	1,107,000	1,506,750
13·75	·50	146,220	328,990	584,880	913,880	1,316,000	1,791,200
20·62	·75	175,350	394,540	701,400	1,096,000	1,578,150	2,148,169
27·5	1·0	201,800	454,010	807,200	1,261,200	1,816,050	2,471,900
41·25	1·5	247,840	557,650	991,370	1,549,000	2,231,000	3,036,000
55·0	2·0	285,130	641,540	1,140,500	1,782,000	2,566,200	3,493,000
	2·5	316,500	712,130	1,266,000	1,978,000	2,848,500	3,877,000
	3·0	344,350	774,780	1,377,400	2,152,000	3,099,100	4,218,000
	3·5	370,000	832,500	1,480,000	2,313,000	3,330,000	4,532,500
	4·0	393,000	884,250	1,572.000	2,456,000	3,537,000	4,814,200
	4·5	415,270	934,350	1,661,100	2,595,000	3,737,400	5,087,000
	5·0	436,200	981,450	1,744,800	2,726,000	3,925,800	5,343,000
	5·5	456,200	1,026,500	1,824,800,	2,851,300	4,105,900	5,589,000
	6·0	473,750	1,065,900	1,895,000	2,961,000	4,264,000	5,803,000
	6·5	489,840	1,102,100	1,959,400	3,062,000	4,409,000	6,001,000
	7·0	505,920	1,188,300	2.023,700	3,162,000	4,553,300	6,198,000
	7·5	522,010	1,174,500	2,088,000	3,263,000	4,698,000	6,395,000
	8·0	538,500	1,211,600	2,154,000	3,366,000	4,846,000	6,597,000
	9·0	565,970	1,273,200	2,263,000	3,537,000	5,093,000	6,932,000
	10·0	589,270	1,325,900	2,357,100	3,683,000	5,303,000	7,219,000
	12·0	633,340	1,425,000	2,533,300	3,958,000	5,700,000	7,758,000
	14·0	675,000	1,518,800	2,700,000	4,219,000	6,075,000	8,269,000
	16·0	713,550	1,605,500	2,854,200	4,459,700	6,422,000	8,741,000
	18·0	748,650	1,684,500	2,994,600	4,679,000	6,738,000	9,151,000
	20·0	779,350	1,753,500	3,117,400	4,871,000	7,014,000	9,546,000
	25·0	845,150	1,901,600	3,381,000	5,282,000	7,606,000	10,353,000
	30·0	902,180	2,029.950	3,609,000	5,639,000	8,120,000	11,054,000
	35·0	954,820	2,148,300	3,819,000	5,968,000	8,593,000	11,697,000
	40·0	998,680	2,247.000	3,995,000	6,242,000	8,988,000	12,284,000
	45·0	1,036,700	2,332,600	4,147,000	6,479,000	9,330.000	12,700,000
	50·0	1,072,000	2,412,000	4,288,000	6,700,000	9,648,000	13,132,000
	55·0	1,106,880	2,495,000	4,428,000	6,918,000	9,962,000	13,539,000
	60·0	1,137,600	2,559,600	4,550.000	7,110,000	10,238,000	13,935,000

Cubic feet of gas, reckoned at 32° F., discharged by well per day, etc.—Continued.

Observed pressure by water gauge.	Observed pressure by pressure gauge.	Diameter of orifice or of well mouth where observed, in inches.				
		d = 4.	d = 4½.	d = 5.	d = 5½.	d = 6 in.
Inches.	*Lbs. per sq. in.*					
·1	·0036	198,220	250,890	309,750	392,000	446,040
·2	·0073	281,040	355,590	439,000	555,910	631,160
·3	·0109	343,760	434,970	537,000	679,630	773,280
·5	·0182	443,520	561,330	693,000	877,080	997,920
·7	·0254	525,050	664,610	820,400	1,038,500	1,181,520
1·0	·0364	627,310	794,030	980,400	1,240,700	1,411,600
1·5	·0545	768,480	972,600	1,200,800	1,517,900	1,729,100
2·0	·0727	885,440	1,120,600	1,383,600	1,751,000	1,992,200
3·0	·109	1,086,510	1,375,200	1,698,000	2,148,800	2,444,800
4·0	·145	1,254,620	1,587,800	1,960,400	2,480,900	2,822,800
5·0	·182	1,402,670	1,775,310	2,193,600	2,733,900	3,156,100
7·0	·254	1,656,000	2,095,900	2,587,600	3,274,800	3,726,000
10·0	·3636	1,963,000	2,490,800	3,075,000	3,890,900	4,428,000
13·75	·50	2,339,500	2,760,900	3,655,500	4,626,500	5,864,000
20.62	·75	2,805,600	3,550,900	4,384,000	5,548,200	6,312,600
27·5	1·0	3,288,500	4,086,100	5,044,600	6,384,600	7,264,200
41·25	1·5	3,965,000	5,019,000	6,196,000	7,842,000	8,922,000
55·0	2·0	4,562,000	5,774,000	7,128,000	8,921,000	10,265,000
	2·5	5,064,000	6,409,000	7,913,000	10,014,000	11,394,000
	3·0	5,510,000	6,973,000	8,609,000	10,895,000	12,397,000
	3·5	5,920,000	7,493,000	9,250,000	11,707,000	13,320,000
	4·0	6,288.000	7,958,000	9,825,000	12,435,000	14,148,000
	4·5	6,644,000	8,409,000	10,382,000	13,139,000	14,950,000
	5·0	6,979,000	8,833,000	10,905,000	13,802,000	15,703,000
	5·5	7,299,000	9,238,000	11,405,000	14,435,000	16,423,000
	6·0	7,580,000	9,593,000	11,844,000	14,990,000	17,055,000
	6·5	7,837,000	9,919,000	12,246,000	15,499,000	17,634.000
	7·0	8,095,000	10,245,000	12,648,000	16,008,000	18.213,000
	7·5	8,353,000	10,571,000	13,050,000	16,517,000	18,792,000
	8·0	8,616,000	10,905,000	13,462,000	17,038,000	19,386,000
	9·0	9,054,000	11,459,000	14,147,000	17,905,000	20,371,000
	10·0	9,428,000	11,933,000	14,372,000	18,645,000	21,214,000
	12·0	10,133,000	12,825,000	15,833,000	20,040,000	22,800,000
	14 0	10,800,000	13,669,000	16,875,000	21,357,000	24,300,000
	16·0	11,415,000	14,449,000	17,839,000	22,577,000	25,688,000
	18·0	11,978,000	15,160,000	18,716,000	23,977,000	26,951,000
	20.0	12,470,000	15,782,000	19,484,000	24,659,000	28,057,000
	25·0	13,522,000	17,114,000	21,129,000	26,741,000	30,425,000
	30·0	14,435,000	18,269,000	22,555,000	28,894,000	32,478,000
	35·0	15,277,000	19,335,000	23,870,000	30,211,000	34,373,000
	40·0	15,979,000	20,223,000	24,967,000	31,599,000	35,952,000
	45·0	16,587,000	20,993.000	25,918,000	32,802,000	37,321,000
	50·0	17,152,000	21,708,000	26,800,000	33,919,000	38,592,000
	55·0	17,710,000	22,554,000	27,672,000	35,023,000	39,848,000
	60·0	18,101,000	23,036,000	28,440,000	36,000,000	40,953,000

The above tables and brief statement of Robinson's method of computing the discharge of gas wells are taken mainly from Prof. Edward Orton's monograph, "The Trenton Limestone as a Source of Petroleum and Inflammable Gas," published in the Eighth Annual Report of the U. S. Geological Survey, 1889, pages 600–603.

CHAPTER IV.

THE GAS FIELD AND THE BORINGS WITHIN IT.

SECTION I.—THE AREA YIELDING GAS AND OIL.

In the description of the topography of the Trenton limestone it was shown that the gas-bearing rock is one continuous stratum of porous dolomite or magnesian limestone occurring near the summit of the Trenton limestone, and within that portion of its area uplifted by the Cincinnati arch. So there is properly but a single important gas field in Indiana. The irregularity of its boundaries are due to local swells and intervening depressions near the salt water horizon, or to irregular variations in the porosity of the dolomite in the higher portion of the field. The local reservoirs adjacent to the field may properly be considered a part of it.

It will be seen from the map of the gas area on Pl. LXIII that the principal field is somewhat irregular in its boundaries and quite large in comparison with the few isolated tracts in other portions of the State. This principal field varies in productiveness in different localities; thus far the narrow southern prolongation has not proved rich, for although nearly all wells drilled find gas the flow is generally feeble. Southeast of a line connecting Knightstown and Winchester the rock is also compact and has so far, with the exception of a small area just east of Knightstown and at Hagerstown, proved unproductive. Feeble flows are found, it is true, all over the southeastern portion of Indiana; but with the exception of a small area at Brookville and Lawrenceburg none of the bores can be considered as paying wells. The wells in Rush, Shelby, and Decatur Counties are all weak producers, although if the flow proves persistent enough they may be found of considerable value. It is quite probable that the small area at Hagerstown is connected with the main body through the southern part of Henry County; it may prove, however, to be an independent field.

The absence of gas in large quantities from the highest portion of the arch and its western slope in southern Indiana is due to lack of porosity in the rock. The porous stratum is not of equal thickness over the whole gas area, nor is the rock everywhere of equal porosity; but as a rule toward the southern and eastern borders the porous stratum gradually becomes thinner, and finally becomes reduced to narrow strips or patches with intervening compact rock. The capacity of the wells vary with the thickness and porosity of the gas-bearing stratum, a thickness of 1 or 2 feet yielding wells of feeble flow, while from 2 to 6 feet gives fairly vigorous wells of from 1,000,000 to 2,500,000 cubic feet per day, the larger wells being found only where the porous rock is thickest.

It has already been indicated that under the theory of accumulation, developed during this investigation, and independently by I. C. White and Orton, the petroleum should be found in the same porous stratum as the gas, and in close proximity to but below it, and above the brine; and geographically about the flanks of the dome into which the gas is forced by the hydrostatic pressure of the brine. So far as revealed by the drill, this hydrocarbon has been found in these places; and thus far no extensive accumulations of petroleum have been found except around the margins of the field or in the local depressions within its margins and apparently in local pools or reservoirs. The slopes of the Cincinnati arch are so gentle that the petroleum seems to be widely diffused throughout the horizon between the gas and salt water, but the conditions do not seem to be favorable for its accumulation in large quantities. The only paying pools of oil found so far are at Montpelier and Portland; but in neither of these cases does the production exceed 75 barrels per day, and usually it is much less. The small pools of oil on the flank of the arch at Francesville and Royal Center suggest the existence of gas in the vicinity, but thus far very little has been found after repeated drilling.

As already stated, gas is not usually found in the main field in the Trenton where its upper surface is more than 100 feet below sea level, though some very productive local fields are found where the rock is 10 or 15 feet lower. This fact of distribution was stated in 1887.[1] This limit has been shown to be correct, though it must be borne in mind that the dead line for gas is now rising as the reservoir is being drawn upon, and will continue to change in the future, though the change will be slow. The horizon of the salt water is now about 130 feet below sea level.

The gas field at Auburn, De Kalb County, is a separate field, and its dead line or salt water horizon is determined by the structural conditions existing there and the local altitude of the Trenton formation.

The great extent and moderate height of the Cincinnati arch in Indiana has provided one of the most extensive reservoirs for gas that has yet been found in any country. The area of productive territory is not less than 2,500 square miles. This estimate is of course only approximate, but is more likely to prove too small than too large. The area by counties is shown in the accompanying table, those counties in which only feeble flows are found being omitted.

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[1] American Manufacturer and Iron World, September 2, p. 19.

It is quite likely, too, that some larger wells have been overlooked. The aggregate capacity of the wells must only be considered approximately correct. It is of course possible that the estimate given of some wells may be too small and of others too large, though every effort has been made to obtain reliable information, and any error in the result has crept in despite conscientious efforts to obtain at least an approximation to the truth.

Area of Indiana gas field.

Counties.	Square miles.	Producing wells.	Aggregate daily flow.
			Cubic feet.
Blackford	180	8	21,700,000
Jay	150	16	22,000,000
Delaware	350	55	97,000,000
Randolph	80	9	6,000,000
Wayne	3	5	2,000,000
Madison	445	40	114,000,000
Grant	325	22	80,825,000
Howard	160	28	80,000,000
Tipton	120	13	38,000,000
Hamilton	200	82	200,000,000
Hancock	200	9	15,000,000
Marion	70	26	40,000,000
Miami	20	13	24,000,000
Wabash	10	5	6,000,000
Henry	90	22	20,000,000
Rush	40	4	1,500,000
Shelby	20	8	3,000,000
Decatur	40	25	5,000,000
Franklin	2	4	500,000
Dearborn	2	2	1,500,000
De Kalb	....	3	2,000,000
Total	2,507	399	779,525,000

SECTION II.—RECORDS OF BORINGS WITHIN THE MAIN FIELD.

General remarks.—The borings recorded in the following pages are arranged by counties, and generally in historical order within each county.

While in many cases the progress of the drill was watched by the author in person, the records were more frequently furnished by others. In such cases the records, accompanied by drillings wherever possible, were obtained by correspondence or by visiting the localities at a convenient time. Accordingly, many of the records given in the following pages are variously arranged, for it has been deemed best to reproduce those records obtained from other parties in as nearly as might be the original form.

Blackford County.—With the possible exception of a small area in the extreme northeastern corner where the Trenton will probably be found below the salt-water horizon, the whole of this county lies within the gas field. The first well drilled in the county was located at Hartford, near the Fort Wayne and Muncie railroad depot.

Section of Hartford well.

	Feet.
1. Drift	125
2. Limestone	200
3. Shale	622
4. Trenton limestone	35
Total	982
Altitude of well about	895

The flow of gas was not large at first, but sufficient to demonstrate that Hartford is in the gas area. Its capacity, as measured by Prof. Orton in a 2-inch pipe, was 850,000 cubic feet per day. The well was recently drilled deeper and the flow increased to 2,787,000 cubic feet per day, as measured by Mr. Charles Cooley, the open pressure being 15 pounds in a 2-inch pipe.

As this well was not deemed of sufficient capacity to supply the town, a second was drilled half a mile southwest of the first, and south of the town. The Trenton was reached at a depth of 935 feet beneath the surface. Gas was struck near the summit of the limestone, and the flow continued to increase for about 15 feet and until it was ample for the needs of the city. The open pressure in the 5⅝-inch casing pipe was 1½ pounds, indicating a daily capacity of 7,982,000 cubic feet. When packed with a 3-inch pipe and tested by Mr. Charles Cooley, of Hartford, the flow pressure was 18 pounds, indicating a capacity of 6,712,000 cubic feet per day, the reduction in capacity after packing being attributable to the small size of the tubing, the effect of which is shown in the previous chapter. This is one of the great wells of the State, and being drilled at an early period of the investigations, did much to establish confidence in the field.

A third well, drilled by another company, was located somewhat north of the town. Gas was reached at a depth of 980 feet from the surface, and after packing with a 2-inch pipe, the well gave an open pressure of 6 pounds, equivalent to a daily capacity of 1,854,000 cubic feet. Although smaller than No. 2, this well deserves to be considered a fairly vigorous producer, as may be seen by comparing its output with that of other wells in the Indiana field.

A fourth well drilled at Hartford by Mr. Cooley, and reported by him, gave an open pressure of 1 pound in a 5⅝-inch casing, showing a capacity of 6,383,000 cubic feet per day.

Mr. Cooley kindly made for this report a series of tests designed to ascertain the time occupied in reaching the maximum pressure in the first and third of these wells. No. 1 reached a static pressure of 300 pounds in 2 minutes and 20 seconds, and 350 pounds (its maximum) in 38 minutes and 30 seconds (this test was made before the flow of the well was increased). No. 3 reached its maximum pressure in 3 minutes and 30 seconds. The static pressure reported by Mr. Cooley from these wells is greater than at any other point in the field; but it should be noted that the Trenton is reached at a greater depth from the surface than usual.

Natural gas is now used as a fuel in most of the dwellings and factories in Hartford, and the people have such faith in the newly discovered fuel that, with the view to fully utilizing it, they have already induced capitalists to invest in various manufacturing enterprises in their city.

A well drilled at Montpelier (reported by Dr. C. Q. Sholl) affords the following section:

	Feet.
1. Drift	16½
2. Gray limestone	23
3. Gravel 14 feet and red clay 16 feet, in the crevice	30
4. Gray limestone	180
5. Shale (Niagara)	38
6. Bluish limestone	65
7. Bluish shale	35
8. Brownish limestone	35
9. Bluish shale	35
10. Gray limestone	8
11. Bluish green shale	160
12. Brown shale	50
13. Bluish shale	18
14. Black shale	280
15. Trenton limestone	11½
Total	975
Altitude of well	857

At first this well yielded both gas and oil. The gas flow was estimated at 1,000,000 cubic feet per day, but soon diminished, while the oil increased, though the yield was never sufficient to render it profitable as an oil well.

A second well was put down soon after in the hope of obtaining a better flow, but instead of drilling nearer to the gas territory the well was located to the northwest of the first, or away from the gas field. As might have been expected, this well was a poor gasser but yielded quite a flow of oil (probably 40 or 50 barrels per day) for a time. At first there was gas enough to cause the oil to flow, but after packing the oil required pumping. At present prices of petroleum this would be unprofitable. The oil is similar to that of the Ohio field, being dark, heavy, and foul-odored (owing to the presence of sulphureted hydrogen). The Trenton was reached in this well at a depth of 974 feet.

A third well yields about 30 barrels of oil per day from the same horizon at which oil was found in wells Nos. 1 and 2. Other wells are being drilled in this vicinity. The gas from these wells is now utilized in mills and residences.

Millgrove, southeast of Hartford, is said to have obtained a vigorous well, but no data have been obtained concerning it.

Jay County.—Portland, the county seat, was one of the first towns in the State to begin explorations for gas. The first well was a failure, though the drill was sunk through the Trenton and into the St. Peter, where, at a depth of about 1,500 feet from the surface, salt water was struck and rose 1,200 feet in the well. A second venture was more successful, a flow of gas probably exceeding 150,000 cubic feet per day being found in the Trenton. Stimulated by this success the gas company put down a number of additional bores with results varying from total failures to a well having a daily capacity of about 2,000,000 cubic feet. Although the gas company at Portland has been energetic and persistent, the aggregate flow obtained would probably not exceed 4,000,000 cubic feet per day—too small a quantity to bring returns commensurate with the cost of the bores. Owing to the trouble from salt water and the difficulty of obtaining strong flows, the Natural Gas Company ceased drilling wells in the vicinity of the town, and proceeded to construct a pipe line from Camden, from which point they now bring in the greater portion of the supply required for the city.

In March, 1888, the Portland Natural Gas and Oil Company drilled a well about 1 mile west of Portland on the farm of James Penn. A small flow of gas was secured at a depth of 16 or 18 feet in the Trenton rock. A small quantity of oil was also encountered, which increased as the drilling proceeded until, at a depth of 25 feet in the Trenton, it rose to within 200 feet of the surface, the depth to the Trenton at this point being 975 feet. The oil rose slowly for some days and finally flowed over the top of the casing; it then subsided, but rose again and continued to ebb and flow for some months. It was then pumped and yielded about 25 barrels per day so long as worked.

A second well drilled in this vicinity yielded a much greater flow, the output being about 75 or 80 barrels per day.

The following section, as well as other data, was furnished by Mr. Elwood Haynes, to whom I am indebted for most of the facts concerning the wells at Portland and Camden.

Section at Portland.—Well No. 1.

	Feet.
1. Drift	58
2. Niagara limestone	192
3. Shales	740
4. Trenton limestone	500
5. St. Peter	20
Total	1,510

The irregularity of the surface of the Trenton limestone here is indicated in the following table:

Well.	Altitude.	Depth to the Trenton.
	Feet.	*Feet.*
1	919	990
2	920	983
3	919	981
4	919	986
5	817	834

Several wells were drilled at Portland of which no records were obtained.

At Red Key a boring reached the Trenton at a depth of 900 feet, and after drilling a few feet further obtained a fine flow of gas, the estimated daily capacity being between 1,500,000 and 2,000,000 cubic feet. A little salt water was also encountered.

At Dunkirk the first well reached the Trenton at a depth of 925 feet, and the drilling was continued 28 feet further, when a flow (about 5,000,000 cubic feet per day) was obtained. A second well, put down by a rival company, did not prove such a vigorous producer, its capacity being only about one-half that of No. 1.

The wells at Hartford, Millgrove, and Dunkirk indicate that this is an exceptionally productive portion of the Indiana gas field.

At Camden (formerly Pennville) the Trenton was reached in well No. 1 at a depth of 935 feet, and the drilling was continued 28 feet into the rock, when a fine flow of gas was reached. Four other wells have been put down in this vicinity by the Portland Natural Gas and Oil Company. The average depth to the Trenton is about 925 feet, and the average thickness of the drift is about 35 feet. The upper portion of the Trenton (the cap rock) is hard and compact for about 2 feet, when it becomes moderately porous and remains so to a depth of about 20 feet. In drilling the first of these four wells a pocket of shale gas was met at a depth of 500 feet that blew the drill out of the well and 90 feet into the air, or 15 feet above the top of the derrick. The flow, however, soon ceased. The weakest well in this vicinity yields about 750,000 cubic feet per day, and the strongest about 3,000,000, the average capacity being about 1,500,000 cubic feet per day. The static pressure is 328 pounds. These wells all show the same pressure with one exception, that of the weakest, which is somewhat removed from the others, being 331 pounds. The combined output of the five wells is about 8,500,000 cubic feet per day. All are tubed with 3-inch pipe except the smallest well, in which a 2-inch pipe is used.

The natural gas pipe line from Camden to Portland consists of (1) 20,000 feet of 4-inch pipe beginning at Camden, (2) 27,000 feet of

6-inch pipe, and (3) 4,000 feet of 8-inch pipe, extending into Portland. When the 3,000,000 well alone is turned into the main the actual service pressure varies from 250 to 300 pounds at Camden and from 200 to 290 at Portland according to the draft on the line.

A well bored at Como, 4 miles west of Portland, gave (according to the measurement of Mr. B. F. Fulton), a daily flow of 1,000,000 cubic feet.

At Bryant, 860 feet above tide, the Trenton was reached at a depth of 1,020 feet below the surface, and 30 feet lower a flow of oil averaging for a time 25 barrels a day. The well has, however, been abandoned, as pumping was not found profitable.

Randolph County.—The first well drilled at Winchester, the county seat, passed through the following strata:

	Feet.
1. Drift	147
2. Niagara limestone	110
3. Niagara shale	40
4. Hudson River	430
5. Utica shale	330
6. Trenton limestone	20
Total	1,077
Altitude of well	1,081

The drill being lost at this depth the well was abandoned. Only a feeble flow of gas and a few barrels of oil were obtained.

Well No. 2, located 1 mile north of No. 1, found the Trenton 38 feet higher, or 64 feet above the sea level; but the rock proved hard and compact, and only a feeble flow was obtained even after torpedoing. Well No. 3 was drilled about one-fourth of a mile northeast of No. 2. Here the Trenton was found at a depth of 1,008 feet, and 70 feet above sea level. This well was also shot, but the results were not satisfactory, as the flow remained feeble. Wells Nos. 2 and 3 together furnished sufficient gas for about sixty stoves. The fourth well, located about 1 mile west of No. 1, proved a failure, though like No. 1, it yielded a little gas and oil. A fifth well, located east of No. 3, also yielded a little gas and oil.

A sixth well, located about three quarters of a mile northeast of the city, reached the Trenton at a depth of 1,044 feet and a little gas at from 1,056 to 1,060 feet. This well was by far the most profitable one yet drilled, for, after being shot, it indicated a daily capacity of 200,000 cubic feet, measured in a 1-inch pipe.

A seventh well, located about 60 rods southeast of No. 6, was still more fortunate. The Trenton was reached at a depth of 1,036 feet and gas at from 1,060 to 1,071 feet. Measured in a 2-inch pipe this well showed a daily capacity of 780,000 cubic feet, and a static pressure of 340 pounds. It was not shot.

The presence of a well of such capacity and pressure was a good indication of more productive rock close at hand, and the eighth well was located one-half mile northeast of No. 7. It proved a failure. A ninth well, however, sunk about 40 rods north of No. 7 gave a flow about equal to that of No. 6. A tenth well, located south of No. 7, proved an excellent producer, the flow being estimated at 1,250,000 to 1,500,000 cubic feet per day, no torpedoing being necessary. Thus fortune at last smiled upon a deserving and persevering company, and now they are assured of a supply sufficient for the town.

The patchy character of the porous portion of the Trenton is easily seen from a study of the results of the drillings here. It is probable that the territory in this vicinity in which the rock is sufficiently porous to be fairly productive is quite limited, and confined to narrow strips or irregular patches. The rise of 50 feet in the Trenton within 1 mile indicates the uneven character of the surface of the formation. The ridge seemed, however, to have no favorable influence on the accumulation of gas, as it lacked porosity. Many observations show that over the higher portions of the Cincinnati arch the Trenton is not so porous on the swells as in the intervening depressions.

At Union City several wells were drilled, but all were failures practically, though a little gas was found in No. 3, and also in another drilled just southeast of the city, where enough gas was found to partially supply one boiler. Well No. 4, located north of the city, reached the Trenton at a depth of 1,093 feet, the altitude of the well being 1,010 feet. The upper surface of Trenton is thus 83 feet below sea level, showing a dip to the north.

The section afforded by the first Union City boring was carefully recorded by Mr. A. Jaqua, and is interesting as affording a typical section for the eastern portion of the gas area.

Union City section.

	Feet.
1. Drift	98
2. White limestone (Niagara)	72
3. Dark gray limestone	62
4. Bluish limestone	38
5. Niagara shale	40
6. Clinton (?) limestone	15
7. Bluish green shale	400
8. Gray shale	175
9. Brown shale	175
10. Black shale	80
11. Trenton limestone	525
12. Gray sandstone, St. Peter	100
Total	1,780
Altitude of well	1,079

A great thickness of the Hudson River and Utica shale is found here, and the transition from the one to the other is nicely shown.

At Farmland seven wells have been put down, three of them proving failures. The following section was constructed from samples of the drillings from No. 1:

Farmland section.

	Feet.
1. Drift	55
2. Niagara limestone	160
3. Niagara shale	40
4. Hudson River limestones and shales	495
5. Utica shale	235
6. Trenton limestone	32
Total	1,017
Altitude of well	1,030

A feeble flow of gas was obtained in this well. By shooting, it could probably be made to yield 100,000 cubic feet per day.

A second well, located west of No. 1, proved fairly productive after being shot, the flow probably reaching 500,000 cubic feet per day. A third well, then a fourth, a fifth, and a sixth were successively drilled, three of them being almost total failures, while the others gave only a light flow. The seventh well, however, located northwest of the town, secured a good flow, its capacity being about 1,000,000 cubic feet per day, or equal to the combined flow of all the others. The aggregate flow is now probably ample for the needs of the town.

At Ridgeville three wells have been drilled, but all proved failures. The Trenton was struck in the first at a depth of 981 feet, the altitude of the well being 983 feet.

A well put down at Losantsville, in the southwestern part of the county, also proved a failure. The Trenton was reached at a depth of 994 feet; altitude of well 1,140 feet; total depth, 1,105 feet; thickness of drift, 173 feet. No water was found in the Trenton.

A well drilled about a mile north of Parker yielded an excellent flow, probably 1,250,000 to 1,500,000 cubic feet per day.

The northwestern portion of this county will probably be found fairly productive, as the adjacent portions of Jay and Delaware Counties have afforded a number of vigorous wells.

Grant County.—Marion was among the first cities in Indiana to start the drill on its journey of exploration.

The Trenton limestone was reached in the first well at a depth of 865 feet, or about 60 feet below sea level, and afforded a flow of some 250,000 cubic feet of gas per day. This well was afterward deepened, and the flow increased to about 2,000,000 cubic feet per day.

The second well, located east of the city reached the Trenton at a depth of 880 feet below the surface and 83 feet below sea level. Hereabouts the dolomitic portion of the Trenton is found close to its upper surface, the hard shell or cap rock being only 3 or 4 feet thick. Owing to a fear of salt water this well at first was drilled only into the top of the porous portion, when it produced a yield of about 350,000 cubic feet per day. It was afterward deepened 35 feet, and thereby converted into a vigorous producer, the flow being estimated at 4,000,000 or 5,000,000 cubic feet per day.

A third well, located one-half mile west of the second, was the first really vigorous producer in this vicinity. The Trenton was reached at a depth of 878 feet and 58 feet below sea level. Although the flow has never been accurately measured, it may be estimated at 1,750,000 cubic feet per day. This well was recently drilled 35 feet deeper and the flow largely increased—perhaps doubled.

A fourth well, located in the northern part of the city and north of the river, found the Trenton at a depth of 880 feet, and 78 feet below sea level. There were indications of an enormous flow from this well, but unfortunately the drill was lost soon after the porous rock was reached ; yet despite this accident its capacity is probably about 2,500,000 cubic feet per day.

Well No. 6, situated west of No. 3, has an estimated capacity of about 350,000 cubic feet per day, but is not in use because drilled so deep that the gas is mingled with salt water.

Well No. 7 is located about two miles southeast of the city, and has a daily capacity of about 3,000,000 cubic feet. It can never be drawn upon for more than one-half this quantity, however, owing to the presence of salt water and oil.

Well No. 5 is located about 1 mile south of the city. It is a vigorous producer, yielding at least 4,000,000 cubic feet per day.

Well No. 8, located between No. 4 and the river, is a fine well, having a daily flow of about 3,000,000 cubic feet.

The ninth well, at the water works, has a smaller yield, probably about 1,500,000. Well No. 10, 2 miles west of the city, found oil and gas at a depth of 1,000 feet from the surface. For a time the volume of gas was sufficient to bring the oil to the top of the well, but at present the flow of gas is quite small and the oil is not in sufficient quantity to be considered of value.

Well No. 11, the "Great Baldwin," is located northeast of No. 5. The flow pressure in a 4-inch pipe is reported to be 5¾ pounds, indicating a daily capacity of 7,425,000 cubic feet. This well, having been drilled too deep, throws quite a spray of salt water.

Well No. 12, or the "Pan Handle," located 2½ miles southeast of the city, at first yielded a little oil in connection with the gas, but when visited the flow of oil had largely ceased and the yield of gas did not exceed 350,000 cubic feet per day.

Well No. 13, about 60 rods north of the Baldwin, is the finest in the vicinity. As measured by the author it gave 11½ pounds flow pressure in a 3-inch pipe, indicating a daily capacity of 5,642,000 cubic feet. Although its capacity is a little less than that claimed for the Baldwin, it is much the better well, as the gas is cleaner, showing only a little oil and no salt water.

A well drilled for the iron works proved a vigorous producer. Two others drilled in the vicinity of the city also proved good producers. Two wells recently drilled near the site selected for the Soldiers' Home, 2 miles north of the city, proved failures—salt water being struck in both.

As indicated by the foregoing figures, Marion lies on the edge of a very productive portion of the great gas field of Indiana. It should be noted that while the capacities recorded above are only estimated, the estimates are moderate and probably very near the truth. Larger claims have been made for these wells, it is true, but these claims exemplify the prevailing disposition to exaggerate capacity for personal ends, already pointed out as characterizing nearly the entire gas area.

The following section of well No. 6 shows the different strata passed through in drilling at this locality:

Marion section.

	Feet.
1. Drift	32
2. Limestone	250
3. Niagara shale	40
4. Hudson River	336
5. Utica shale	250
Total	908

The 250 feet of limestone probably represents the Springfield beds, as what is considered the Guelph formation outcrops about 4 miles down the river, where the junction of the two divisions is nicely shown.

The accompanying table gives some of the facts revealed by the drill regarding the configuration of the surface of the Trenton limestone, etc., at Marion:

Number of well	Altitude.	Thickness of drift.	Depth to Trenton.	Depth of Trenton below sea level.
	Feet.	*Feet.*	*Feet.*	*Feet.*
1	805	....	900	60
2	797	....	880	80
7	701	....	904	....
5	830	....	....	70
4	802	....	880	78
3	820	....	878	58
6	....	32	908	....
Soldiers' Home No.2.	....	200	....	....

The laws governing the arrangement of gas, oil, and salt water are exemplified by the facts revealed by the drill at this locality. The wells yield at first dry gas, but if drilled a little too deep show more or less oil, and if carried still deeper, strike salt water, i. e., all three are in the same porous stratum but separated according to their specific gravities. The static pressure here is 325 pounds.

A well at Jonesboro gave the following section:

	Feet.
1. Drift	162
2. Limestone	148
3. Bluish green shale	225
4. Gray shale	180
5. Brown shale	197
6. Trenton	23
Total	935
Altitude of well about	834

This well merits the local name applied to it, i. e., "The Cyclone." It was tested by the writer when the gas was escaping from two 2-inch pipes at the same time, the flow pressure being 12 and 13 pounds respectively, indicating a daily capacity of 5,196,000 cubic feet. It was afterward tested by Prof. Orton in a 4-inch pipe, when the daily capacity was found to be 5,567,000 cubic feet.

The well at Fairmount was prophetic of the wealth of the Indiana gas field. It gave Prof. Orton an open pressure of 3¾ pounds in the 5⅝ casing, equal to a daily flow of 11,500,000 cubic feet. This was by far the largest well known up to the date of drilling in the Indiana field, and at that time ranked as a great well among the fields of the country. It gave unexpected importance to the Indiana field, and indicated vast possibilities in future production. It was, however, soon purchased by eastern capitalists, and closed. The section reported is as follows:

Section of Fairmount well No. 1.

	Feet.
Drift	35
Limestone	290
Shale	609
Trenton limestone	31
Total	965
Altitude of well	893

When the first well was closed it became necessary to drill a second to supply the town. Although not equal to No. 1, this proved a vigorous producer, its capacity reaching 5,000,000 or 6,000,000 cubic feet per day. The vicinity of Fairmount promises well for further exploration.

The well at Upland is also a strong one, requiring a 3-inch pipe for tubing. It is claimed to equal the Jonesboro well in capacity.

The Trenton was reached at a depth of 1,010 feet; total depth 1,040 feet. Gas was found from 1,010 to 1,020 feet. The thickness of the drift here is 185 feet.

Vigorous wells are also reported at Swayzee, Sweetzer, and Point Isabel. Nothing definite could be learned concerning their capacity, though they probably range from 3,000,000 to 5,000,000 cubic feet per day each.

Van Buren is near the eastern limits of the field. In the first well put down at this point, gas and oil were struck at a depth of 972 feet, 22 feet in the Trenton formation. The gas is reported to have appeared suddenly, as though the drill had penetrated a cavity. The flow of oil is reported to have reached 5 or 6 barrels per day for a time. The gas was of limited volume. The supply not being sufficient for the town, the company drilled deeper; but instead of increasing the flow of gas, this one increased its flow of oil, which filled the well and displaced the gas, leaving the town without the lighter illuminant. Other wells drilled in this vicinity proved failures.

Section of well, No. 1, at Van Buren.

	Feet.
Drift	91
Limestone	300
Shale	559
Trenton limestone	23
Total	973
Altitude of well	843

A well at Herbst Station, west of Marion, reached the Trenton at a depth of 985 feet, the total depth of well being 1,045 feet. According to Mr. C. E. Worrell, of Marion, to whom the author is indebted for much of the information regarding the wells of Grant County, this well gave a flow pressure of 4 pounds in the open casing, equivalent to a capacity of 12,500,000 cubic feet per day. Owing to the great depth this well was drilled into the Trenton limestone, considerable salt water is present.

A well in this county 11 miles south of Wabash proved a total failure, owing to the presence of salt water in the Trenton formation.

The record of the wells in the vicinity indicates that Marion is situated close to the northern limits of the main body of the field, the productive area north of that city being largely due to the local swells in the Trenton limestone.

Fine artesian flows of fresh water are found at Marion and other localities in this county, in the Niagara limestone, at depths varying from 240 to 290 feet.

Wabash County.—La Fontaine was the first town in this county to procure gas in paying quantities. The first well was a fairly vigorous producer, but the drill was sunk a little too deep and tapped the salt water at a depth of 920 feet from the surface. A second well also brought up a mixture of gas and water. The supply of gas is, however, ample for the town.

The section, as recorded, of well No. 1 is interesting, since it shows extensive erosion of the Niagara limestone, probably marking the site of a preglacial valley.

La Fontaine section.

	Feet.
1 Drift	200
2. Limestone	175
3. Bluish green shale	300
4. Brown and black shale	225
5. Trenton limestone	25
Total	925

The first well drilled at Somerset proved a vigorous producer, having a daily flow of about 3,000,000 cubic feet. Two other wells put down in this vicinity gave fair flows. All show, however, a little salt water. A pipe line is now completed to Wabash from this locality and southeastern Miami County, and the gas is being utilized in that city.

Miami County.—The Wabash Natural Gas Company have drilled several wells in the southeastern part of this county near Xenia and Amboy. Although they have met with a few failures owing to the presence of salt water, they now have several wells of capacities ranging from 500,000 to 2,000,000 cubic feet per day. Many of these wells show a little salt water, but the Powell well, the largest of all, is dry.

The first well drilled at Xenia gave a measured daily capacity of 350,000 cubic feet. It also showed some salt water. Well No. 2 found the Trenton under more favorable conditions, and a vigorous producer was secured; its estimated capacity being about 2,500,000 or 3,000,000.

Section of Xenia well, No. 1.

	Feet.
1. Drift	58
2. Limestone	295
3. Shale	70
4. Limestone (Clinton)	6
5. Shale	477
6. Trenton limestone	30
Total	936
Altitude of well head	803
Depth of Trenton below sea level	100
Depth to Trenton in well No. 2	915
Depth of well	950
Altitude of well	818
Depth of Trenton below sea level	97

A fine artesian flow of fresh water was struck in well No. 1 at a depth of 335 feet, and brackish water at 435 feet.

Fine flows of gas are found at Amboy. The first well has a capacity of about 3,000,000 cubic feet per day, according to Mr. S. S. Gorby. A second well, drilled by the Peru Natural Gas Company, reached the Trenton at a depth of 907 feet and a good flow was obtained, though it is not equal to that of No. 1. A third well (drilled by the last-named company) proved a failure, the Trenton dolomite being charged with salt water. The Peru Company's next successful venture was on the Overman farm, 2 miles southeast of North Grove. The Trenton was reached 926 feet below the surface and gas at 3 feet in the Trenton. The total depth of well is 951 feet and the thickness of the drift 54 feet. This well, after packing with a 4-inch pipe, gave a static pressure of 300 pounds in 85 seconds.

The Abbott well is the greatest producer drilled by the Peru Company. The Trenton was reached at a depth of 899 feet, the altitude being 820 feet, and the total depth of well 927 feet. The greater portion of the flow was found in the last 6 feet penetrated by the drill. A test of its static pressure, when packed with 4-inch tubing, gave 300 pounds in 50 seconds, and 325 pounds in 2 minutes and 40 seconds. Its capacity is 4,000,000 or 5,000,000 cubic feet per day.

The Pearson well is another vigorous find of this company; after packing with 4-inch pipe it gave a confined pressure of 300 pounds in 4 minutes and 10 seconds.

The same company now have one or two other fair wells in this vicinity. One well, drilled a few rods west of the Abbott well, was a failure, the Trenton being full of salt water. The Wabash Company met with similar results in a well drilled about 80 rods east of the Abbott well. The Peru Company are now furnishing the citizens of that city gas from the wells just described. The Overman well, 13 miles distant from Peru in an air line, is a fair producer.

The greater portion of both Miami and Wabash Counties are outside of the gas area, the Trenton lying below the salt-water horizon. Only the southern portion of Wabash and the southeastern portion of Miami Counties is high enough to catch the local swells outside of the main field, with possibly a limited area of the main body.

Howard County.—Only the eastern half of this county is within the gas field, the 100-foot dead-line passing 1 or 2 miles west of Kokomo. The borings in this region illustrate the fact that where the slope of the Trenton is gradual the dolomitic or porous portion of the Trenton commonly contains gas in its upper portion and water in its lower portion; for the two wells first put down at Kokomo yielded both gas and salt water.

Kokomo was among the first of Indiana cities to drill for gas, and every effort has been successful. Mr. William Moore has kept a careful record of the wells drilled here, as well as a complete suite of drillings from well No. 4, from which the following section was constructed:

Kokomo section well No. 4.

		Feet.
1.	Drift	65
2.	Water-lime	10
3.	Bluish limestone	80
4.	Whitish shaly limestone	15
5.	Bluish limestone	65
6.	Whitish shaly limestone	15
7.	Bluish limestone	65
8.	Niagara shale (calcareous)	35
9.	Gray limestone	75
10.	Hudson River shale	255
11.	Utica shale	256
12.	Trenton limestone	22
	Total	958

The upper surface of the Trenton shows very little variation throughout the county, the dip being slight toward the west and north. Some of the data afforded by the Kokomo borings are shown in the following table:

No. of well.	Depth to surface of Trenton.	Depth to gas.	Altitude of well.	Trenton below sea level.	Thickness of drift.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1	912	922	825	87	....
2	913	922	....	....	....
3	905	910	830	75	65
4	936	944	....	....	....
5	895	901	....	....	....
6	889	893	....	....	....
7	908	912	....	....	....
8	904	914	....	....	....
9	900	....	....	....	....
10	902	....	....	....	40
11	932	....	....	....	90
12	....	....	....	....	....
13	903	....	....	....	....
14	905	....	....	....	....

Well No. 1 is located near Wildcat Creek, southwest of the city of Kokomo. The flow of gas was at first 1,500,000 cubic feet per day; it then discharged a small quantity of salt water, but a separator was put in and the well has been in constant use ever since. Its present capacity is probably somewhat less, as the salt water has been gradually increasing until it now discharges about 500 barrels per day.

Well No. 2 is located about 60 rods southwest of No. 1. Its measured capacity was 1,117,000 cubic feet per day. Owing to an accident the drill was lost in this well and never recovered, and the flow was probably somewhat reduced in consequence. Like No. 1, it showed a little salt water at first, which has gradually increased until it also discharges about 500 barrels per day.

Well No. 3, situated about 80 rods southeast of No. 1, found the Trenton at a higher altitude, and, as it was not drilled so deep, was free from salt water. Its capacity was 810,000 cubic feet per day.

The Junction well (No. 4) gave a measured flow of 1,500,000 cubic feet per day after being shot. It was dry when first drilled, but after shooting small quantities of salt water came in.

Well No. 5 (the "Big Schrader") located 2½ miles southeast of the city, when measured in a 3-inch pipe, showed a daily capacity of 4,642,000 cubic feet.

Well No. 6 (the "Akron" well) is located east of the city. Its daily capacity, after shooting, was 1,555,000 cubic feet.

Well No. 7 (the "Reed" well) was nearly a failure at first, but became a vigorous producer after having a charge of nitroglycerin exploded in it, the daily flow being 3,015,000 cubic feet. Although dry at first a little salt water came into the well after shooting.

No. 8 (the "Waterworks" well) gave an open pressure of 1¾ pounds in a 2-inch pipe, equal to a capacity of 1,072,000 cubic feet per day.

Well No. 9 (the "Tate" well), located 1 mile east of the city, had a capacity after shooting of 2,500,000 cubic feet per day; No. 10 (the "Kenner" well), 2½ miles southeast of the city, had a capacity of 2,800,000 cubic feet; No. 11 (the "Morgan" well), located north of the city, had a capacity of 2,600,000 cubic feet; No. 12 (the "Fair Ground" well) is located 1 mile southwest of the city, and has a capacity of 3,650,000 cubic feet; No. 13 (the "Plate Glass" well) is next to the Schrader in capacity, its flow being 3,727,000 cubic feet in twenty-four hours. The "Patterson" well (No. 14) is also vigorous, its daily flow being 2,335,000 cubic feet; but it shows a little salt water.

The combined output is probably twice the amount actually used in the city. This is an advantage as it enables the wells to carry considerable retained pressure, and thus insures not only drier gas but longer life for the wells. Well No. 2, which had been in constant use since first drilled, was recently closed, when the back pressure of the gas asserted itself, driving the salt water from the well. The lesson to be learned from this is not to make too heavy a draft on any area, however productive, for the salt water is everywhere beneath the gas-bearing portion of the Trenton limestone and will sooner or later make its presence felt in any portion of the field, no matter how high above sea level, if the draft upon a limited area is too great.

The Greentown well is a worthy fellow of the "Big Schrader," its daily capacity being 4,440,000 cubic feet (6½ pounds open pressure in a 3-inch pipe). Before it was brought under control, the noise produced by the escaping gas compelled the closing of the public school in the town. The Trenton was reached at a depth of 936 feet;

the total depth of the well is 965 feet, and the thickness of the drift 79 feet.

The Barrett well, located south of Greentown, in Union Township, reached the Trenton at a depth of 934 feet. The total depth of the well is 959 feet, and the thickness of the drift 107 feet. The daily capacity is 4,415,000 cubic feet. It shows a little salt water.

Sycamore also secured a good well, the capacity being about 3,500,000 cubic feet per day. The Sims well is only a trifle smaller, its capacity being about 3,000,000.

Tampico No. 1 was drilled too deep and water came in with the gas, the flow of which was not strong—only about 350,000 cubic feet per day. Tampico No. 2 reached the Trenton at a depth of 954 feet. This well proved larger than No. 1, its daily capacity reaching 1,500,000 cubic feet. The thickness of the drift at Tampico was 103 feet in the first well, and 75 feet in the second.

The Fairfield well reached the Trenton at a depth of 937 feet, the thickness of the drift being 55 feet. Its daily capacity is 5,483,000 cubic feet—the largest well so far found in the county. The flow pressure is 10½ pounds in a 3-inch pipe.

The Brobst well, in Liberty Township, near Greentown, is also a fine one, having a daily capacity of 2,500,000 cubic feet.

The McNeal well, in Taylor Township, is only a moderate producer, having a daily flow of 1,315,000 cubic feet. It shows salt water. The thickness of drift here is 32 feet, and the depth to the Trenton 925 feet.

The Alto well proved a failure, salt water being found in the Trenton. The depth to the Trenton is 965 feet, and the thickness of the drift 140 feet.

The J. C. Templin well, in Howard Township, reached the Trenton at a depth of 921 feet, the thickness of the drift being 80 feet. The capacity of this well is 3,000,000 cubic feet per day.

The Weaver well, located farther north than the one last mentioned, found only a little oil mixed with salt water. This well evidently marks the limits of the main field in this direction. The thickness of the drift here was 100 feet, and the depth to the Trenton limestone 960 feet.

The Logansport Natural Gas Company have drilled four wells in Taylor Township, southeast of Kokomo, and others are drilling. Their wells have not been tested, but probably range in capacity from 1,500,000 to 4,000,000 cubic feet per day. The thickness of the drift varies from 40 to 68 feet in this locality. This company have their pipe line nearly completed, and will soon be ready to supply the citizens of Logansport with the product of their wells. The Cuthrall well in Union Township is also a good well, and the Jerome well, just drilled, is reported a good producer. The Seward well, in Harrison Township, is fairly productive.

It will be seen from the above description that the Trenton is richly productive in Howard County, and that the demand on this portion of the field is very great, though the distance to Logansport will act as a check to the draft on the field from that point.

The static pressure, as observed by the writer at well No. 3, at Kokomo, was 320 pounds. The well had been closed for some time, and this probably represents the maximum for this vicinity. Well No. 2 after being closed for a time recently showed a static pressure of only 310 pounds. The wells around it were in use, however, and it is probable that the defect of pressure is due to the draft by the other wells on the area from which this well obtained its supply. A diminution of pressure denotes an overdraft on the field rather than a failure, though too great a draft on a limited area is apt to lead to failure by inviting in the salt water. This is especially to be feared near the margin of the gas field, where the salt-water horizon presses close upon those of oil and gas.

Tipton County.—Three wells drilled at Tipton were practically failures, though a little gas and oil was found in two of them. The upper surface of the Trenton being 129 feet below sea level, the salt water displaced both gas and oil.

Tipton section, well No. 1.

	Feet.
1. Drift	139
2. Limestone	326
3. Shale	532
4. Trenton limestone	33
Total	1,030
Altitude of well	868

Well No. 1, at Hobbs Station, 5 miles east of Tipton, passed through the following strata:

	Feet.
1. Drift	134
2. Limestone	330
3. Shale and limestone	529½
4. Trenton limestone	13½
Total	1,007
Altitude of well	875

This well gained its static pressure of 325 pounds when closed in three and a half minutes. Its capacity is probably 1,250,000 or 1,500,000 cubic feet per day. Well No. 2 proved much stronger, as it required only one and a half minutes to reach its maximum static pressure when confined in a 3-inch pipe. Its capacity must be 4,000,000 or 5,000,000 cubic feet per day. A pipe line has been constructed to Tipton, and the product of the two wells is now utilized in that city.

Windfall, northeast of Tipton, secured a well having a daily capacity of 2,500,000 cubic feet. The Trenton was reached at a depth of 973 feet, and a little salt water at 1,002 feet.

Two wells in Tipton County obtain gas at a lower level within the main field than any others thus far recorded, the upper surface of the Trenton being 119 feet below sea level. Local conditions of course have their influence in determining the salt-water horizon. These wells are located near a depression in the Trenton limestone that from present indications seems to be surrounded by productive territory.

Sharpsville obtained a fine flow of gas, the output of a single well being about 2,000,000 cubic feet per day. The strata penetrated are as follows:

Sharpsville section.

	Feet.
1. Drift	70
2. Limestone	460
3. Shale	432
Trenton limestone	8
Total	970

The flow of gas from this well might probably have been increased by going deeper, but its capacity is ample for the town and it was wise to avoid the risk of striking salt water involved in deeper drilling.

The depression at Tipton was long supposed to mark the limits of the productive territory in that direction, and it was an agreeable surprise to find quite an extensive elevation in the Trenton limestone west of that city. It is quite probable that this ridge connects the spur of the Cincinnati arch at Noblesville with the main body in southern Howard County.

The first well drilled at Kempton, west of Tipton, passed through the following strata:

	Feet.
1. Drift	306
2. Limestone	293
3. Shale	424
4. Trenton Limestone	12
Total	1,035
Altitude of well	930

The upper surface of Trenton is 93 feet below sea level.

This section indicates a rise of 36 feet in the Trenton west of Tipton, and unless the arch is sharp (which is hardly probable) we may expect to find quite an extensive area of productive territory here.

There are already eight wells drilled in this section of the field. Two of them belong to the company supplying Tipton with gas. The others belong to the Frankfort Natural Gas Company, who have constructed a pipe line and are now supplying Frankfort with natural gas from this field. Most of the wells drilled so far are vigorous producers, requiring 3-inch tubing in packing. Their capacities have not been ascertained, but each of the larger wells probably has a daily flow of 5,000,000 or 6,000,000 cubic feet. The Baldwin well, in the northwestern corner of the county, near the Clinton County line, is claimed to be one of the large wells of the State.

The rapid dip of the Trenton to the westward from this field is shown in the record of the Kirklin well, a little west of the east line of Clinton County. The Trenton was reached at a depth of 1,089 feet, the thickness of the drift being 252 feet, the altitude of well 921 feet, and the top of the Trenton 168 feet below sea level. Circleville reached the Trenton at a depth of 1,078 feet. The altitude of the well is 928 feet; the thickness of the drift is 296 feet, and the top of the Trenton is 150 feet below sea level. Both of these wells were failures.

One well in the Kempton field showed a little water at a depth of 16 feet in the Trenton. The static pressure here is 325 pounds.

Hamilton County.—The first well put down in the county was at Noblesville. It gave the following section:

	Feet.
1. Drift	140
2. Limestone	286
3. Shale	410
4. Trenton limestone	7
Total	843
Altitude of well	750

The flow of gas was rather weak, probably because the drilling was not deep enough to penetrate the porous dolomitic portion of the Trenton formation. The moderate success of the bore created considerable excitement, however, and large tracts of land in the vicinity were leased by various companies, including the Standard Oil Company. The latter company immediately put down a second well just north of Noblesville, the Trenton being reached at a depth of 898 feet, and a magnificent flow of gas a few feet lower. This well is known as the "Wainwright wonder." Its capacity is in the neighborhood of 7,000,000 cubic feet per day. A second well (known as the "Mallory" well) was soon after drilled by this company. Its capacity was between 3,000,000 and 4,000,000 cubic feet per day. Other bores were put down by the same company; by the Guffee Syndicate of Pittsburg, Pennsylvania; by the Indianapolis Natural Gas Company; and by the Citizens' Trust Company of Indianapolis, all with the view of piping gas to Indianapolis. The Citizens' Natural Gas Company of Noblesville also drilled four additional wells for the use of that city. This portion of the field has proved exceptionally productive, the wells varying in daily capacity from 1,000,000 to 10,000,000 cubic feet. The Indianapolis Natural Gas Company soon purchased all the wells, etc., of the Standard and Guffee Companies, and proceeded to construct a pipe line to Indianapolis. The main is 21 miles in length and 12 inches in diameter. There were in January, 1889, four branch lines, viz, two 8-inch lines 2 miles long; one 6-inch line 1½ miles long, and one 4-inch line. This company had in January, 1889, twenty-eight wells, twenty of which were connected with their main. Their high pressure mains in the city are 15 miles, and their low pressure mains 40 miles, in length. The loss of pressure by friction for 21 miles of main aggregates 118 pounds or $5\frac{13}{21}$ pounds per mile. Several of the largest wells of this company when closed reach 300 pounds static pressure in thirty seconds and their maximum of 325 pounds in one minute, 3-inch pipes being used in packing. The W. H. Cottingham well (the largest belonging to the company) shows the same results in a 4-inch pipe, which would indicate much greater capacity. The larger wells of this company are the W. H. Cottingham, the Wheeler, the Wainwright, the S. B. Castor, the W. B. Hare, the T. J. Craig, and the Hurlock. Quite a number of this company's wells are located to the north of Noblesville, but most of them are from 2½ to 6 miles east of that city.

There has been a gradual diminution in static pressure, amounting to about 25 pounds per square inch, during the autumn and winter up to January 15, 1889; wells 3 miles from the main and not connected with it showing the diminution as decidedly as those near the main. Three of the wells have already been drowned with salt water, and others are failing; while a few wells recently drilled are failures, since only a little oil was found mixed with salt water.

The Trust Company's main is 23½ miles in length and is composed as follows, beginning at the Noblesville end, viz: 6½ miles of 10-inch pipe, 8½ miles of 12-inch pipe, and 8½ miles of 16-inch pipe, with 5 miles of 6-inch pipe connecting with the 10-inch section. There are in the city 20 miles of high-pressure and 75 miles of low-pressure mains. The loss of pressure for 22 miles is 150 pounds, or $6\frac{9}{11}$ pounds per mile. This company had, January 15, 1889, thirty-six wells, all located southeast of Noblesville and south of those of the Indianapolis company. The Trust Company has experienced a few failures owing to salt water, and several of their wells (including their largest, the Big Granger) have been completely drowned, and others are beginning to throw salt water. In fact, it is painfully apparent that the salt-water horizon is rising here quite rapidly with the enormous drafts made upon this portion of the field. The altitude of the top of the Trenton in the Trust wells varies from 56 to 70 feet below sea level. The thickness of the drift varies from 12 to 139 feet. The thickness of the upper limestone mass ranges from 151 to 288 feet.

The following are some of the wells of the Trust Company: Granger, Nos. 1 and 2; Gashcho; Craig; Brown; Burke; George Wheeler; James Wheeler; Wheetely; Brooks, Nos. 1 and 2; Shoemaker; S. Haverstick; James Haverstick; George Haverstick; Bradley; Mallory, Nos. 1 and 2; Zeiss; Waddle; Woods, Nos. 1 and 2; Passwater; Whitesell; Crull; E. Cloverdale; Charles Cloverdale; Booth, Nos. 1 and 2; Fisher; Castor; Aldred; McKinley. Others are being drilled. The capacities range from 1,000,000 each in three wells to 10,000,000, the output of the Big Granger when first drilled. Granger No. 1 and Granger No. 2 gave flow pressures of 13 pounds, and the E. Cloverdale 11 pounds, in 4-inch pipes, indicating capacities in the neighborhood of 10,000,000 cubic feet per day. The majority of the other larger wells in the field probably range from 4,000,000 to 7,000,000 cubic feet per day in capacity, with quite a number of much smaller flow.

Both the principal companies locate their wells from one-half to 1 mile apart, except where their territory is contiguous. In such cases they are closer together.

Four of the wells belonging to the two companies named above are located at New Britton and Fisher's Station. A well at Westfield reached the Trenton at a depth of 1,040 feet from the surface and at a depth of 40 feet in the rock struck salt water. At Sheridan the Trenton was reached at a depth of 1,068 feet and gas at 1,076 feet. This well had a capacity of about 1,000,000 cubic feet per day. A second well drilled here also yielded a good flow of gas. Small flows of gas are reported from wells located at Myers, Carmel, Joliet, Eagletown and Swainville.

Atlanta and Arcadia also obtained paying wells. The latter gives the following data concerning structure:

Section Arcadia well.

	Feet.
1. Drift	130
2. Limestone	120
3. Blue limestone	130
4. Shale	581
5. Trenton limestone	13
Total	974
Altitude of well	868

Cicero found a little oil in the first well, but in a second a good flow of gas was obtained. A little oil was also found in several other wells in the county.

It is a difficult matter to determine even approximately the capacity of the eighty wells in this county; but allowing 2,500,000 cubic feet as an average (which is perhaps rather small) the estimate would be about 200,000,000 cubic feet for the daily output, 100,000,000 of which is daily consumed in Indianapolis.

An exception to the general rule regarding the flow of gas from the porous portion of the Trenton was observed in the Big Granger well. The rock had been penetrated 27 feet without finding gas, when suddenly it appeared in great volume, and the entire flow was reached in the next 3 feet (between 27 and 30 feet below the top) of the Trenton limestone. This indicates extreme porosity, or more probably an open space or cavity. A few other bores in the State have displayed like phenomena.

Marion County.—The author has been unable, with possibly one or two exceptions, to procure accurate data regarding the wells drilled in this county. This is much to be regretted because of the situation of the county with respect to the southern boundary of the gas field. It was especially desirable to trace in the borings the different formations to the southward from Kokomo; but no suites of drillings or even carefully kept records have been reported. Probably no other county in the State has expended so much in explorations and contributed so little to science, and this too when Indianapolis, the capital city, numbers among her citizens many scientists of wide reputation.

The first test bore proved that Indianapolis is not within the gas area; yet many wells were drilled in the vicinity long after it was evident that no gas of any consequence would be obtained within less than 5 or 6 miles from the city. The first flow of gas found in the county was struck at Broad Ripple, 7 miles north of Indianapolis. The Trenton was reached at a depth of 950 feet. The capacity of the well after shooting was probably 250,000 cubic feet per day. Stimulated by this partial success, the Broad Ripple Natural Gas Company proceeded to drill additional wells to the northeast and east of that village with results varying from failures to wells having a daily capacity of 2,000,000 cubic feet. An 8-inch main has been laid from Indianapolis to Broad Ripple, and lately extended to Castleton. This company had on January 15, 1889, eighteen producing wells, though thirty had been drilled, some of which were failures from the first, while others were drowned out with salt water after temporary productiveness. The great draft on the Hamilton County field to the north, with the draft made in this county, is causing the salt water horizon to rise quite rapidly, as shown by the wells near Broad Ripple, which, dry at first if not drilled too deep, soon begin to throw oil and soon after salt water. This is the fate of all gas fields.

The bore at Brightwood, 4 miles east of Indianapolis, passed through 199 feet of drift and reached the Trenton at a depth of 951 feet. A little gas and oil were found in the dolomitic portion of the Trenton, and salt water at a depth of 1,181 feet. The Capital City Company have drilled several wells northeast of Brightwood, and after some failures have obtained eight good wells in the northeastern part of the county. The gas from these wells is not now utilized.

The first well sunk at Lawrence found salt water at a depth of 1,015 feet, 5 feet within the Trenton formation. It rose 700 feet in the well. A second well located 2 miles northeast of No. 1 was reported a gusher, but as nothing has been heard of it recently it is likely that the reports concerning it were very much exaggerated. Quite a number of successful bores were put down just outside the city limits, but many of them have proved short-lived.

A well drilled at Irvington reached the Trenton at a depth of 966 feet, and salt water at 990 feet, the altitude of the well being 832 ±. A bore at Cumberland reached the Trenton at a depth of 1,039 feet from the surface. Salt water was found in this well. The thickness of the drift was 248 feet.

The following section of the bore at Bridgeport is reported by Judge E. B. Martindale:

	Feet.
1. Drift	160
2. Black shale	140
3. Limestone	360
4. Shale	490
5. Trenton limestone	50
Total	1,200
Altitude of well about	750

Here, as usual when so far below sea level, the Trenton contained salt water.

Hancock County.—The first well in this county was put down at Greenfield, the county seat, and a vigorous producer was obtained, its capacity being about 4,000,000 cubic feet per day.

Greenfield section, well No. 1.

	Feet.
1. Drift	215
2. Corniferous limestone	65
3. Shale (Upper Niagara)	17
4. Limestone (Niagara)	68
5. Shale soapstone	135
6. Black shale	45
7. Bluish green shale	138
8. Limestone	2
9. Brown shale	300
10. Trenton limestone	14½
Total	999½
Altitude of well	902

This section is difficult to interpret, as the elements of No. 5 are combined. It is probable, however, that the soapstone represents the lower Niagara shale, and probably 20 feet is about the thickness that should be assigned to it. It is evident that if the Lower Helderberg and Waterlime are present they are very much reduced in thickness and are inseparable from the Corniferous. It is probable that the shore line during their deposition was far to the westward. The thickness of the Upper Silurian limestone has been very much reduced in the interval between Greenfield and Noblesville.

A second well, drilled by an Indianapolis company, one-half mile north of No. 1, proved a fair well after torpedoing. The depth to Trenton was 970 feet.

A third well, put down by the same company one-half mile west of No. 2, yielded a fair flow of gas with some oil and salt water. Instead of accepting the presence of oil as an indication that salt water was near at hand and locating their next well farther to the east, it was located three-fourths of a mile west of No. 3, and, as was to be expected, gave a fine flow of salt water. A fifth well, put down northeast of Greenfield, furnished a fine flow of gas.

Two wells at Fortville, though not large producers, furnish sufficient for the town. McCordsville also has a fair well, and Charlottesville has a good producer.

Very little exploration has yet been made in this county, but if the wells at Greenfield are criteria fairly productive territory may be looked for here.

Considerable buried timber was found just above the limestone at the base of the drift, in the wells at Greenfield and Palestine.

A well sunk at Palestine afforded the following section:

	Feet.
1. Drift	285
2. Limestone	122
3. Shale	593
4. Trenton limestone	60
Total	1,060
Altitude of well	839½

Salt water was found at 3½ feet within the Trenton, and rose 660 feet in the well. Shale gas was struck at 625 and 900 feet respectively. Trees and leaves were found in the drift at a depth of 195 feet.

Shelby County.—Five wells have been drilled in the vicinity of Shelbyville, but all are failures. The general section afforded by the bores is as follows:

	Feet.
1. Drift	48
2. Limestone	265
3. Shale	527
4. Trenton limestone	100
Total	937
Altitude of well	772

The Shelbyville Natural Gas Company have, after repeated efforts, obtained several wells of moderate flow 4 or 5 miles east of the city, the capacities ranging from 100,000 to 500,000 cubic feet per day. A pipe line has been constructed to Shelbyville, and the gas is now utilized. It is to be hoped that these wells will prove persistent, though it is hardly to be expected that they will bring returns sufficient to justify the outlay.

A well drilled at Morristown passed through the following strata:

	Feet.
1. Drift	140
2. Limestone	20
3. Niagara limestone	120
4. Hudson River and Utica shale	638½
5. Trenton limestone	23
Total	921
Altitude of well	844

Capacity of well as measured by Mr. S. S. Gorby, assistant State geologist, 1,205,465 cubic feet per day.

A letter just received from the owner of this well, Mr. Charles F. Muth, informs me that there is now 500 feet of salt water in the well, and that the flame is only 5 feet in length, the gas having been almost completely drowned out by the water.

Waldron and St. Paul both are reported as having obtained gas, the first well at the latter place having sufficient gas for about one hundred stoves. The depth to the Trenton at St. Paul is 820 feet, the thickness of the drift is 90 feet, and gas is found from 10 to 16 feet within the Trenton. The altitude of well is 844 feet.

Decatur County.—A large number of wells have been drilled at Greensburg, but while nearly every one finds gas, the flow is not strong. Probably the capacity of the best well would not exceed 500,000 cubic feet per day. The gas is usually found from 8 to 12 feet within the Trenton rock. The average well furnishes enough fuel for from ten to twenty-five residences.

The following section shows the different strata passed through in the Greensburg City well, No. 1:

	Feet.
1. Drift	10
2. Corniferous limestone	4
3. Niagara limestone	66
4. Niagara shale	35
5. Hudson River and Utica shale	747
Total	862

The static pressure of the gas is 200 pounds per square inch.

Here as elsewhere the surface of the Trenton appears to be undulating, as shown in the accompanying table.

Number.	Depth from surface to Trenton.	Altitude.
	Feet.	*Feet.*
1	865	920
2	886	925±
3	883	925±
City well	862	930

St. Omer and Adams, in the western portion of the county, have obtained gas, but so far all the wells are small producers, about like those at Greensburg.

Rush County.—Three wells at Rushville found gas in limited quantities, two yielding perhaps 15,000 cubic feet per day each. Owing to the depth to which the third was drilled into Trenton rock, salt water soon displaced what little gas there was at first. Mr. George W. Clark preserved a fine and complete suite of drillings from one of the Rushville wells, from which the following section was constructed:

			Feet.
1.	Drift		48
2.	White limestone		42
3.	Blue limestone		30
4.	Bluish green shale		25
5.	Gray limestone (Clinton)		5
6.	Hudson River limestones and shales		420
7.	Utica shale		262
8.	Gray limestone	Trenton	25
9.	Brown limestone		35
10.	White limestone		30
	Total		922
	Altitude of well		996

A well drilled at Carthage passed through the following strata:

		Feet.
1.	Drift	50
2.	Limestone	100
3.	Shale	670
4.	Trenton limestone	20
	Total	840

The Trenton limestone here was much more porous and proportionately more productive than at Rushville, and a fair flow of gas was obtained, the yield approaching 750,000 cubic feet per day. The prospect of finding fairly productive territory in the vicinity is very good, as it adjoins territory that has been proved rich in gas.

Several wells were drilled 4 or 5 miles to the northwest of Rushville, but although gas was found in all of them the volume was considered too small for piping. A well drilled at Milroy was a failure, as was the one at Glenwood, where the Trenton was reached at a depth from the surface of 950 feet, the altitude of the well being 1,116 feet, placing the top of the Trenton 166 feet above sea level.

Henry County.—New Castle, the county seat, though persistent in the search for gas, has not been rewarded as her energy and perseverance deserve. Enough gas was found to excite hope that further explorations would prove more successful. Eleven wells have been drilled, but to-day the total output supplies only about three hundred stoves. In the wells yielding gas the porous stratum was found at a depth of between 50 and 60 feet within the Trenton. Salt water is gradually encroaching upon those that yield gas, with the exception of the best well, which is still dry. One well found salt water at a depth of 7 feet within the Trenton, rising 400 feet in the well. The behavior of the wells at this locality and the presence of salt water in the upper porous stratum is an indication that this locality is cut off from the main body of the field by intervening compact rock. If there were free communication with the main reservoir the flow of gas would be more persistent, and the salt water would not be so likely to invade the wells. It seems to be an isolated or independent reservoir of very limited area, which is only feebly productive. It would have been fortunate for the city if no gas had been found. Several of the wells seemed quite vigorous at first, but the flow soon decreased in volume, and is now insignificant.

Some interesting facts have been developed during the explorations for gas in this county. It appears that the present valley of Blue River marks the site of a preglacial valley. In well No. 1, located one half-mile north of the city and near the valley, there were 380 feet of gravel and sand; in No. 2, located one-half mile southeast of No. 1, there were 240 feet of like materials; in No. 4, located within the present valley, there were 365 feet (and the base was not reached); and in No. 5, located a little southeast of the city, there were 500 feet of drift materials. The records show that the old valley was wider than the present one, and that in the deeper portion its rock bottom is at least 480 feet below the present level of Blue River. These records give the greatest thickness of drift yet found in the State.

The variation in the surface of the Trenton about New Castle is shown in the accompanying table:

No.	Depth from surface to Trenton.	Altitude.	Altitude of Trenton above sea level.
	Feet.	*Feet.*	*Feet.*
1	870	995	125
2	932	1,050	118
3	930	1,055	125
5	923	1,060	137

A well drilled at Mount Summit passed through the following strata:

	Feet.
1. Drift	230
2. Limestone	50
3. Shale	736
4. Trenton limestone	66
Total	1,082
Altitude of well	1,110

Top of Trenton above sea level, 94 feet.

Salt water was struck at a depth of 4 feet within the Trenton, and rose 300 feet in the well. The inequality of preglacial erosion here is evident, as the limestone outcrops near by, yet the drill passed through 230 feet of drift materials before reaching it.

Two wells drilled at Springport were failures, the rock proving hard and nonporous. The first well gave the following section:

	Feet.
1. Drift	156
2. Limestone	90
3. Bluish green shale	600
4. Black shale	111
5. Trenton limestone	63
Total	1,020
Altitude of well	1,004

Top of Trenton above sea level, 47 feet.

A second well found the Trenton at a higher level.

A well at Sulphur Springs proved a failure. The thickness of the drift here is 232 feet. Honey Creek was more fortunate, as the flow from their well is about 2,000,000 cubic feet per day; the depth from surface to the Trenton 980 feet, and the thickness of the drift 216 feet. Middletown reached the Trenton, in the first well, at a depth of 935 feet from the surface, or 61 feet within the Trenton; the altitude being 971 feet. This well, after being shot, showed a capacity of about 2,000,000 cubic feet per day, though a little salt water came in with the gas. A second well yielded a still better flow of gas. Mechanicsburg, after two failures, obtained a fine flow of gas in a third well. Cadiz also got a flow of about 1,000,000 cubic feet per day in a well drilled at that point. The drift was 300 feet thick. Greensboro reported three failures, but a fine flow was obtained at the Valley Mills, a little southwest of that point. Spiceland, about midway between Knightstown and New Castle, secured two fair wells, one unfortunately, however, showing a little salt water after shooting. The second well is located 1,600 feet southwest of the first and is much the better well. Its flow has not been measured. The gas reaches a static pressure of 200 pounds in about three minutes. No. 1, on being tested after having been in use for over a year, gave a flow pressure of 1 pound in a 1½-inch pipe, indicating a daily capacity of 450,000 cubic feet.

The section at Spiceland is as follows:

	Feet.
1. Drift	151
2. Hard cherty limestone	2
3. Limestone	67
4. Shale	10
5. Bluish green and brown shale	710
6. Trenton limestone	62
Total	1,002
Altitude of well	1,023

Dunreith and Ogden both obtained good flows of gas from the Trenton limestone. Six wells have been drilled at Knightstown with varying success, though all have yielded gas. The capacity of No. 3 is estimated at 1,000,000, and No. 2 at 600,000 cubic feet per day, while No. 1 is smaller. The other three wells are probably about like Nos. 2 and 3. Two wells drilled for the Soldiers' Home, supply that institution with fuel.

The following table shows the variation of the upper surface of the Trenton at this point:

Well.	Depth to Trenton.	Altitude.	Top of Trenton above sea level.
	Feet.	*Feet.*	*Feet.*
1	823	935	112
2	838	959	121
3	881	1,002	121

Franklin County.—Seven wells have been drilled in Brookville and vicinity. The first was located 4 miles south of the city, in the White Water River Valley. The following section is reported:

	Feet.
1. Drift	157
2. Shale	243
3. Trenton and St. Peter	854
Total	1,254
Altitude of well	575

Salt water was struck at a depth of 800 feet from the surface.

Well No. 2 was located in the town. The depth to the Trenton was 550 feet, and the altitude of the well 700 feet.

A well drilled by W. Bracken furnishes sufficient gas for seven houses. The well of Tony Freese was better, but hardly sufficient to supply the fuel necessary for his brickyard. The seventh well, recently drilled, is by far the best well yet found in the vicinity, but even it is small compared with those of the main field.

Dearborn County.—Although this area is distinct from the main gas field, it is included in this chapter because the wells have proved profitable. Two wells drilled at Lawrenceburg yield gas. In the first the Trenton limestone was reached at a depth of 325 feet; gas was struck in a 28-foot limestone at a depth of 261 feet, but a much stronger flow was found when the Trenton was reached. A bed of black shale 36 feet thick was found between the 28-foot limestone and the Trenton. A capacity of 1,052,000 cubic feet per day was claimed for this well when it was first drilled.

A well drilled at Aurora passed through the following strata:

			Feet.
1.	Drift		92
2.	Bluish green shales		148
3.	Utica...	Dark shale	25
4.		Limestone (gas)	2
5.		Shales and limestones	18
6.		Shale	25
7.	Trenton limestone		521
8.	St. Peter	about..	170
	Total	about..	1,000
	Altitude of well		472

Brackish water was struck at 195 and brine at 831 feet from the surface. A heavy flow of gas was struck at a depth of 267 feet, but it did not prove persistent. As 450 feet of the Hudson River shales and limestones are exposed in the hills above the well, the total thickness of that formation in this locality is about 600 feet. The Utica has thinned to 70 feet. The thickness of the drift here is of interest as it shows the depth to the rock bottom of a preglacial valley.

Wayne County.—Only a small portion of this county, in the vicinity of Hagerstown, can be considered productive, though very feeble flows have been found in many wells. It is possible that this small isolated area may be connected with the main body, though the connection has not been established.

Seven wells have been drilled at Hagerstown and vicinity. Two of these were failures. The others range in capacity from 100,000 to 1,000,000 cubic feet per day according to recent measurements, though the better wells may have given a greater flow when first drilled. Two of the wells show salt water, owing to having been drilled too deep.

A recent (and second) bore at Dublin yielded gas in paying quantities.

At no other localities has gas been found in paying quantities, though the drill has been sent on its journey of exploration in every township.

The data obtained in the several bores in the county are shown in the following table:

Well.	Thickness of drift.	Depth to Trenton.	Altitude of surface.	Altitude of Trenton.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Richmond No. 2		945		
Washington	212	976	1,100	124
Russel Farm		909	1,029	120
Richmond No. 1		880	944	64
Richmond No. 6		972	1,097	125
Centreville		886	1,008	122
Cambridge City No. 1	96	766	942	176
Cambridge City No. 2	160	847	982	135
Fountain City	185	1,025	1,111	86
Dublin	300	868	1,066	193
Dalton	275	960		
Walnut Level	280	867		
Hagerstown	100	846	1,013	167

The Dublin well was drilled into the St. Peter; salt water was struck at 1,250 feet, and rose 1,000 feet in the well. A fine artesian flow of water was struck at Centreville, at a depth of 246 feet, in the drift.

Madison County.—This county lies entirely within the gas area as determined by actual exploration, wells having been drilled in every township. Only a few failures have been noted and the proximity of those to productive territory render it probable that they would respond to a good charge of nitroglycerin.

A well at Summitville passed through the following strata:

	Feet.
1. Drift	98
2. White limestone	45
3. Blue limestone	195
4. Soft, bluish green shale	388
5. Black shale	200
6. Trenton limestone	45
Total	971
Altitude of well	896

A strong artesian flow of water was struck at a depth of 140 feet in the Niagara limestone. The well proved a vigorous producer, having a daily capacity of over 4,000,000 cubic feet, a quantity far in excess of the present needs of the town.

The first well drilled at Elwood reached the Trenton at a depth of 936 feet, or 78 feet below sea level. The drill was sunk only 7 feet into the Trenton formation, but nevertheless the flow probably reached 750,000 cubic feet per day. A second well proved much stronger than No. 1, but after being shot salt water made its appearance. Well

No. 3 is a vigorous producer, its daily flow being about 3,000,000 cubic feet.

At Alexandria the Trenton was reached in the first well at a depth of 887 feet from the surface. This well, after being in use for a year, was drilled deeper and the flow greatly increased; the capacity, as measured by the author in the open casing, being 5,526,000 cubic feet per day. A second well put down just preceding the deepening of No. 1 is a vigorous producer, its capacity being between 3,000,000 and 4,000,000 cubic feet per day.

At Frankton the Trenton was reached at a depth of 840 feet and a flow of 2,500,000 cubic feet per day was secured.

The first well drilled at Pendleton passed through the following strata:

1. Drift	5
2. Corniferous limestone	2
3. Sandstone	14
4. Upper Niagara shale	20
5. Limestone	200
6. Shale (Lower Niagara)	5
7. Limestone	4
8. Shale (green and brown)	610
9. Trenton limestone	87
Total	947
Altitude of well	841

Gas was struck at 3 feet within Trenton limestone and the daily flow approached 500,000 cubic feet.

Well No. 2, after being shot with nitroglycerin, proved a vigorous producer, its daily capacity being reported as about 2,000,000 cubic feet. A third well is reported as a good one.

Markleville, in the southeastern portion of the county, secured a fair flow of gas at a depth of 960 feet and 12 feet within the Trenton. Its daily capacity is probably about 750,000 cubic feet.

Perkinsville also obtained a good flow of gas. The well, after packing with a 3-inch pipe, gave a static pressure of 316 pounds in five and one-half minutes. The daily capacity is probably about 3,000,000 cubic feet.

Several wells have been drilled at Chesterfield. The first was put down by the Citizens' Company. The Trenton was reached at a depth of 874 feet. The altitude of the well is 910 feet; the thickness of the drift is 108 feet; and the gas was struck at a depth of 2 feet within the Trenton. The flow pressure in a 3-inch pipe was 7 pounds, showing a daily capacity of 4,553,000 cubic feet. A second well drilled by the Doxey Company yielded a flow of about 3,000,000 cubic feet per day, after being shot with nitroglycerin. Of the eight wells drilled by this company, four have a daily capacity of between 3,000,000 and 4,000,000 cubic feet. One was a failure. The last one drilled gave a flow of 1,500,000 or 2,000,000 cubic feet per day. One well just across the river and north of the town is, next to the McCollough well at Anderson, the largest well in the county. Its flow pressure, measured by the author in a 3-inch pipe immediately after packing, was 15 pounds, indicating a daily capacity of 6,260,000 cubic feet. A subsequent measurement of this well by other parties gave, it is claimed, 17½ pounds flow pressure, or about 6,630,000 cubic feet per day. It is not uncommon for wells to show a little stronger flow after having been packed a few days. Another well belonging to this company is claimed to be nearly equal to it in capacity.

The Doxey Company's pipe line from Chesterfield is 46 miles in length. The retained pressure carried at the wells is 210 pounds, and the greatest difference yet observed between the pressure at Chesterfield and Richmond is 84 pounds. The high pressure lines at Richmond carry 9 pounds. It will not be possible to determine the loss of pressure from friction until the main is used to its full capacity. At present the capacity of both wells and the main is in excess of the demands made upon them at Richmond.

The first well drilled at Anderson (known as the Doxey well) was put down by the Citizens' Natural Gas Company. The drill reached the Trenton 851 feet below the surface and 36 feet above sea level. This well, when tested in two 2-inch pipes from both of which the gas was freely escaping, gave a flow pressure of 5 pounds in one and 6 pounds in the other, indicating a daily capacity of 3,640,000 cubic feet.

Well No. 2 (the "McCollough" well), located on the west bank of White River, just east of the city, passed through the following strata:

	Feet.
1. Drift	114
2. Hard limestone	20
3. Soft limestone	141
4. Niagara shale	25
5. Limestone (probably Clinton)	20
6. Bluish shale	240
7. Brown shale	254
8. Trenton limestone	24
Total	838
Altitude of well	845

Gas was struck soon after the Trenton was reached, and the flow steadily increased for 15 or 20 feet, culminating in a flow of great volume, and one of the largest in the State. An unsuccessful effort was made to pack this well with a 3-inch pipe, but the flow was too strong, and a 4-inch pipe was used instead. When tested by the writer the gas was escaping from a 2-inch pipe and a 2½-inch pipe.

The flow pressure in the 2-inch pipe was 20 pounds, and in the 2¼-inch pipe 19 pounds, indicating in round numbers a daily capacity of 7,000,000 cubic feet. This test, however, was not entirely satisfactory, owing to the conditions under which it was made. A second test of this well by Mr. Charles Gerard, of Anderson, with a mercurial gauge gave, it is claimed, a flow pressure in the 5⅝-inch casing of 4⅞ pounds. This would indicate a daily capacity of about 14,000,000 cubic feet. The discrepancy in the results of the two tests would suggest the possibility of some error in measurement; although the figures given above from the first test should probably be increased by 1,500,000 or 2,000,000, they are probably the nearer to what would be shown if the flow was measured from the 4-inch pipe with which it is packed.

Two wells were put down by the Standard Oil Company at Anderson. The first of these, located a mile southeast of the city, is said to be a larger producer than the Doxey well, its capacity being estimated at about 5,000,000 per day; and the second, a half mile southwest of the first, is reported to be very much smaller, probably not over 750,000 or 1,000,000 cubic feet in daily capacity. A static pressure test of this well in a 2-inch pipe showed 295 pounds in 7 minutes.

A fifth well was subsequently put down by the Citizens' Cooperative Company. It is located just west of the city. The Trenton was reached at a depth from the surface of 835 feet, and a vigorous flow of gas was obtained. Although it has not been found practicable to test this well, its daily capacity may be safely estimated at 3,500,000 cubic feet. Well No. 6, also put down by the Citizens' Cooperative Company, is located northwest of the city. It was the author's good fortune to witness the drilling of this well. The Trenton was reached at a depth of 838 feet, and gas at 848 feet. The flow increased rapidly for the next 15 feet, and it soon became evident that this was to be a great well—in fact a rival of the McCollough well. The open pressure in the 5⅝-inch casing was 1 pound, indicating a daily capacity of 6,382,000 cubic feet, but as it was packed with a 3-inch pipe the flow is probably reduced to about 5,500,000 cubic feet per day.

No. 7, the Nut and Bolt Works well, is considered smaller than the Doxey well. Its capacity is probably about 2,500,000 or 3,000,000 cubic feet per day.

The Hazlewood Nos. 1 and 2, located about three-fourths of a mile southwest of the city, are each estimated at about the capacity of the Doxey well, or in round numbers 3,500,000 cubic feet per day. The Straw-Board Company's well is much smaller, its estimated flow not exceeding 1,000,000 cubic feet per day.

The Brick Works well, north of the city, and the Free well, east of the city, are both vigorous producers, with daily capacities ranging from 3,000,000 to 4,000,000 cubic feet per day. The Hodson well, west of the city, is larger, its flow probably reaching 5,000,000 or

6,000,000 cubic feet per day. The Butter Dish Company's well is smaller, its estimated capacity being 2,500,000 or 3,000,000 cubic feet daily.

Several wells have been put down in the county by farmers. The Huntzinger and Davis wells, both about 5 miles west of the city, are reported vigorous producers, as is the Black and Bell well, 2½ miles northeast of Anderson.

A second well near Markleville gave a fair flow of gas. A well put down at Florida, 3½ miles north of Anderson, is reported practically a failure, but another, half a mile north of it, proved a good producer. A fair well is also reported at Lapelle. Huntsville, near Pendleton, has secured a fair flow.

Delaware County.—The first considerable flow of natural gas from the Trenton limestone in Indiana was struck at Eaton, this county, in September, 1886, and settled forever the question whether the Trenton limestone would be found productive in this State.

The Eaton bore was originally put down in 1876, and a moderate but rapidly diminishing flow was met in the Hudson River shale. In consequence of the excitement attending the discovery of gas at Findlay, Ohio, it was in 1886 deemed advisable to enlarge the bore, and continue the drilling to the Trenton limestone. The success of this well stimulated investigation in every section of the State. Portland, Marion, Kokomo, Muncie, Anderson, Noblesville, and other cities and towns soon sent the drill on its journey of exploration, and within three months from the time gas was struck at Eaton nearly every large town and city within the gas field claimed the largest gas well in the State, while many failures were reported by less favored towns and cities. The section afforded by the Eaton bore is as follows:

	Feet.
1. Buff limestone	5
2. Bluish limestone	20
3. Buff limestone	30
4. Bluish gray limestone	45
5. White limestone	35
6. Shale, bluish green	35
7. Buff limestone (Clinton)	10
8. Shale, Hudson River and Utica	690
9. Trenton limestone	32
Total	922

Gas was struck at a depth of 915 feet. The flow has never been measured, but it may safely be estimated at 1,000,000 cubic feet per day.

A second well, located west of the town, and nearly north of the first, is much larger in yield, having a daily flow of 3,500,000 cubic feet.

The Nixon well, located 4 miles west of Eaton, has an estimated daily flow of about 2,000,000 cubic feet.

A well put down at Shideler gave a daily flow of 1,225,000 cubic feet. The Trenton was reached at 884 feet. Shale gas was struck in a pocket at 400 feet and it blew the 1,800-pound drill out of the well, but the flow soon subsided. A static pressure test of this well, carefully taken by Mr. C. A. Reznor, is as follows: 100 pounds in fifteen seconds, 200 pounds in seventy-five seconds, 300 pounds in four minutes, and 320 pounds (the maximum) in seven minutes. The test was made in a 2-inch pipe.

A well at Royerton yielded a vigorous flow of gas, requiring a 3-inch pipe for packing. The daily flow is probably 3,500,000 or 4,000,000 cubic feet.

At Cowan a bore passed through 145 feet of drift and reached the Trenton at 935 feet. After being treated to a good charge of nitroglycerin, the flow, weak at first, was increased to about 1,000,000 cubic feet per day.

Oakville, south of Cowan, also obtained a good flow of gas, about 1,250,000 cubic feet per day, the thickness of the drift and depth to Trenton being the same as at Cowan. At Daleville the Trenton limestone was reached at a depth of 870 feet, the thickness of the drift being 85 feet, and the altitude of the well 923 feet. The estimated flow is 2,000,000 cubic feet per day.

Yorktown, 6 miles west of Muncie, secured a vigorous flow at a depth of 940 feet, 18 feet within the Trenton formation. The altitude of the well is 940 feet. The daily flow is about 2,500,000 cubic feet.

A bore at New Corner reached the Trenton limestone at a depth of 908 feet, and at a few feet lower a flow of gas measuring 1,225,000 cubic feet per day.

A well drilled by a company composed of farmers residing near the Six-Mile House, northwest of Muncie on the Wheeling pike, yielded a great volume of gas, the well probably having a daily capacity of 5,000,000 or 6,000,000 cubic feet. Another well north of this and near the Mississinewa River, at Union Grove, gave a flow of gas equally large. The section of the latter well is as follows:

	Feet.
1. Drift	24
2. Limestone	250
3. Niagara shale	50
4. Clinton limestone	Trace
5. Shales	593
6. Trenton	27
Total	944

A good flow of gas was also reached in a well drilled about 2 miles northwest of Shideler, the flow being so strong that great difficulty was experienced in packing with a 2-inch pipe. The daily flow is about 3,000,000 cubic feet.

A flow of about 2,000,000 cubic feet per day was obtained at Albany from a well giving the following section:

	Feet.
1. Drift	8
2. Limestone	200
3. Shale (Niagara)	68
4. Hudson River and Utica shale	658
5. Black shaly limestone	30
6. Trenton limestone	14
Total	978
Altitude of well	940

One of the most vigorous wells in the State is located at Selma, 6 miles east of Muncie. No precise measurement of the flow has been made. When visited by the writer the gas was burning from a 3-inch pipe at the top of the derrick, and the flame was at least 5 or 6 feet from the orifice. Its daily capacity must be in the neighborhood of 5,000,000 cubic feet. The section indicated by the drillings is as follows:

	Feet.
1. Drift	90
2. White and buff limestone	85
3. Soft red ferruginous shale	15
4. Bluish limestone	75
5. Niagara shale	40
6. Hudson River	485
7. Utica shales	210
8. Trenton limestone	25
Total	1,025
Altitude of well	1,015

A bore at De Soto, north of Selma, and another about 3 miles northeast of Selma, both struck fine flows, the former being estimated at 2,500,000, and the latter at 1,250,000 cubic feet per day. A third well, 2 miles south of Selma, gave a 2,000,000 flow. The depth to the Trenton here is 930 feet and the thickness of the drift 148 feet. Another well in the Fullharts neighborhood, about 4 miles southeast of Muncie, obtained a flow of about 1,500,000 cubic feet per day, after shooting. All the wells are dry, no salt water being found in any of them so far as now known.

A well located about 7 miles northwest of Muncie found the Trenton exceedingly porous, a flow of 5,000,000 or 6,000,000 cubic feet per day being obtained.

The principal gas tract in the county thus far fully developed is at Muncie. This tract has also proved one of the richest in the State, since the daily output of gas is equal to if not greater than that of any other town or city in the gas area.

The following is a partial list of the wells now in operation, none of the borings here having been failures:

Well.	Altitude.	Depth to Trenton.	Height of Trenton above sea level.	Capacity.
	Feet.	*Feet.*	*Feet.*	
Natural Gas Company No. 1	936	876	60	500,000
Natural Gas Company No. 2	933	889	44	(?)
Reid well	955	887	68	1,000,000
Highlands	949	884	65	1,380,000
Bent Works	946	894	52	1,820,000
West Main street	930	872	58	1,580,000
Fay	938	887	51	4,225,000
Winton	936	892	44	1,867,600
Waterworks	938	891	47	500,000
Anthony	956	891	65	1,000,000
Cooperative No. 1				1,580,000
Cooperative No. 2				1,580,000
Boyce No. 1				1,000,000
Boyce No. 2				1,136,000
Boyce No. 3				1,136,000
Boycetown No. 1	944	886	58	1,377,000
Boycetown No. 2				500,000
Boycetown No. 3				2,000,000
Truit's				1,250,000
Adams street				1,250,000
Walling's				1,225,000
Hemingway's				1,750,000
Tuthill's				1,235,000
Martin's				2,000,000
Pulp Mill No. 2				2,000,000
Rubber				1,000,000
Pulp Mill No. 1				850,000
Flint Glass Works				3,500,000
Over's 1 and 2				1,500,000
Nail Works				2,000,000
Buck Creek				500,000
O'Neel's				750,000
Prutzman's				2,025,000
Total				46,516,500

All the above wells are located within 2 miles of the court-house and on an area but little exceeding 2 square miles. The above figures are from actual measurements or fair estimates, and are certainly not excessive. The total output is enormous for such a small area. So far no salt water of any consequence has been found in any of the wells. No separators are necessary, though drips are usually placed at all the wells as a safeguard against the little moisture in the gas.

The first well (No. 1) struck gas at 15 feet within the Trenton, and the rock being hard and compact the flow was at first quite weak. A 60-quart charge of nitroglycerin was then exploded in it, increasing the flow materially but not sufficiently to raise it to a high rank. The partial success in this well stimulated other prospectors and the excitement became intense. It was at first thought by some that the supply from this well, limited as it was, would furnish the whole city with fuel; but it was found sufficient for only about one hundred stoves and two or three boilers; much gas being wasted, however, by leakage from the pipes.

In well No. 2 the drill reached a light flow of gas at 25 feet below the surface of the Trenton, but in the ignorance prevailing in that stage of investigations it was decided to sink the well further instead of torpedoing it at this point as experience would have suggested. Of course no more gas was struck but when the drill reached the St. Peter sandstone, at a depth of 1,390 feet, a strong flow of brine rose 1,100 feet in the well.

The combined section of wells Nos. 1 and 2 is as follows:

	Feet.
1. Cedarville limestone	90
2. Bluish limestone (Springfield beds)	135
3. Niagara shale	40
4. Hudson River limestones and shales	100
5. Hudson River shale	340
6. Utica shale	270
7. Trenton limestone	481
8. St. Peter sandstone	150
Total	1,606

Had No. 2 been shot it is probable that a flow of at least 1,000,000 cubic feet per day would have been obtained, as a well subsequently drilled within 40 rods of it gave a fine flow of gas without shooting.

The Highlands well was drilled by the Artificial Gas Company. Gas was struck at 4 feet within the Trenton, and the flow was so great that when burning from a 2-inch pipe its roar could be heard in every part of the city and its light was distinctly visible everywhere within a radius of 10 miles. The gas, however, was soon piped to the factories or purified in the company's works, and within a few weeks was furnishing fuel for twelve boilers and light for a large portion of the city. Its capacity was not determined until one year after it was drilled and during that year it had been in almost constant use. It has now been in use three years with little if any diminution in flow. An incomplete test of its static pressure, made soon after it was packed, by Mr. Highlands, the manager of the company, gave 100 pounds in ten seconds, 150 pounds in twenty seconds, 200 pounds in thirty-five seconds, 250 pounds in one minute, 280 pounds in one and one-half minutes, 290 pounds in one and three-fourths minutes, 300 pounds in two minutes and twenty-five seconds and 305 pounds in three minutes, the maximum being 320 pounds.

The next two wells were put down by the same company. The first was only moderately successful, but might have been greatly increased by shooting, though as it is it furnishes sufficient fuel for the waterworks. The other was feeble at first and with the leaky casing first put in was practically a failure, but upon being properly cased and then shot it gave a fine flow, reaching about 1,000,000 cubic feet per day. This well was sunk 50 or 60 feet into the Trenton in the hope of striking oil, and a light pocket of brine was reached. After shooting, however, the gas came with sufficient force to clear all this out, and the well soon became dry and is today in use, requiring nothing but a drip to catch what little moisture there may be.

Certain phenomena exhibited by a few of the Muncie wells after shooting, show that there are small pockets of salt water in the Trenton below the gas-bearing portion, but so far they have soon blown out, giving no trouble.

The Reid well and the Bent Works wells were put down by the Muncie Natural Gas Company, and the Trenton was hard and nonporous in both; but they responded promptly to 80-quart charges of nitroglycerin, and gave a flow of 1,000,000 and 1,820,000 cubic feet per day respectively.

The West Main street well, or No. 5 of this company, also proved a vigorous producer after shooting. The gas from this well is reported as perfectly dry, but it throws a saline powder that interferes with its use in the mains by forming incrustations in the valves and mixers and thus preventing the free flow of gas. If the well was blown off repeatedly or allowed to blow continuously for a few weeks, this material would probably be blown out.

The Tuthill well is a good average producer, though located near territory that has proved only moderately porous.

The wells thus far drilled pointed to the territory southwest of the city as that in which the Trenton was most porous. The inference was substantiated when the Fay well was drilled, its flow pressure, measured in a 3-inch pipe, being 3 pounds, standing for a capacity of 3,000,000 cubic feet per day. Subsequent tests of the Fay well, made after it had been in use six months, during which time it had been often exhibited to visitors, showed a great increase, the flow pressure reaching 6 pounds, indicating a capacity of 4,255,000 cubic feet per day. The same capacity was given by measurement with a mercurial gauge in the 5⅝-inch casing; and when the 3-inch escape pipe was reduced to two inches, the high pressure gauge indicated a retained pressure of 40 pounds, and the open pressure rose beyond the capacity of a 30-pound gauge, which was broken in the attempt to measure the flow. A similar increase of pressure was noticed in the Boyce well No. 1, which when first packed did not move the pointer of the gauge, though after an interval of several days the flow increased to 1½ pounds flow pressure. This increase in capacity must be attributed to the cleaning out of the pores and interstices in the porous rock surrounding the bore.

The Winton well, or No. 7 of the Natural Gas Company, is a vigorous producer, giving a daily flow of 1,857,600 cubic feet per day, its flow pressure being 5¾ pounds in a 2-inch pipe.

The second Boyce well gave only a feeble flow at first, but after shooting it became a fair producer. The history of the first well drilled by the Cooperative Company is similar, the flow at first probably reaching 750,000 cubic feet per day, but being more than doubled by shooting. This company's second well, located one-fourth of a mile northwest of the Fay well, yielded an equal flow without shooting.

The Pulp Mill well, the Rubber well, O'Neel well, and Boyce No. 3 were all located in the interests of convenience simply. All proved good or fair producers, as did the Nail Works and Over's wells, though located where the Trenton was known from previous experience to be hard and only moderately porous. Boycetown wells Nos. 1 and 3 are vigorous producers, No. 3 having a daily flow of about 2,000,000 cubic feet without shooting. Truit's well also proved a fair producer. Both the Pulp Mill No. 2 and Prutzman's wells are vigorous, the flow being a little above 2,000,000 cubic feet per day in each. Martin's well, west of the city, also proved a vigorous producer, having a daily capacity of about 2,000,000 cubic feet. The Flint Glass Works well, though a good one, was given a dry shot and the flow greatly increased. It is now nearly equal to the Fay well, requiring a 3-inch pipe for packing.

Experience has shown that just beneath the city the Trenton is only moderately porous, while to the west of the city the thickness of the porous portion rapidly increases as seen in the wells drilled in that vicinity. The average for the Muncie wells, now a little less than 1,500,000 cubic feet per day each, has been steadily increasing as explorations are extended.

The combined capacity of all the wells in Delaware County is some 97,000,000 cubic feet per day; and of this the wells at Muncie produce about one-half.

CHAPTER V.

RECORD OF BORINGS OUTSIDE OF THE GAS FIELD.

General remarks.—While the results of investigations outside of the gas area are of little immediate economic value, they are quite important in that they elucidate the geological structure of the State throughout considerable areas in which the rocks are not otherwise accessible. Moreover, the data thus procured have contributed to the solution of the problems of the accumulation and distribution of gas and petroleum.

Since the exploration of Indiana for gas was made energetically and over a large area at the same time, and since, moreover, the author thought it best to confine his personal observations largely to what from the first promised and afterward proved to be the great gas field, few of the data have been collected in person. The records were generally obtained by correspondence with well-drillers, the officers of the various interested corporations, school superintendents, teachers, and personal friends throughout the State; and whenever possible suites of the drillings were obtained in the same way. A few localities were, however, visited in person and sections made from full suites of drillings.

No one can be more fully alive than the author to the uncertainty necessarily attaching to identification of formations from the meager data afforded by well records, even when supplemented by drillings; but each record affords a check upon the rest, and all have been roughly tested by comparison with surface observations; and the entire body of testimony has been found fairly consistent. Even were it less so it would seem wise to place the data on record for the use of students, since there is little probability that another such drilling fever will seize upon the people of Indiana for many decades at least.

Union County.—Section at Liberty:

	Feet.
1. Drift	70
2. Limestone (Hudson River)	15
3. Grayish shale	450
4. Dark shale	356
5. Gray Trenton limestone	25
6. Blue Trenton limestone	55
Total	971
Altitude of well	965

Upper surface of Trenton above sea level, 74 feet.

No gas was found in the Trenton, but a little shale gas appeared at 500 feet in Hudson River shale.

Fayette County.—Two wells have been drilled at Connersville by Hon. J. N. Huston, who has collected also the data afforded by the three other Connersville bores, and with characteristic courtesy submitted all for use in this report.

Mr. Huston's wells were drilled just south of the city, and in each a small flow of gas was found. That of the second was greatly increased by shooting, but soon decreased until it furnished only enough for one grate. The static pressure of this well was 18 pounds, indicating that it is not near any large body of gas. A well just north of the city gave a small flow of gas and a static pressure of 27 pounds. One 2½ miles northwest of the city yielded a much better flow and the static pressure is said to have reached 50 pounds. There was probably sufficient gas to supply one house.

The depth to the Trenton and the altitude of its upper surface are given for each of the Connersville wells in the accompanying table:

No. of well.	Depth to Trenton.	Altitude of Trenton above sea level.
	Feet.	*Feet.*
1	710	127
2	705	112
3	780	122
4	731	103
5	691	116

General section at Connersville.

		Feet.
1.	Drift	85
2.	Blue limestone	75
3.	Hudson River shales	275
4.	Utica shales	250
5.	Trenton limestone	500
6.	Black shale	25
7.	Sandstone (St. Peter)	47½
	Total	1,257½

These wells being located in the White Water River Valley, the above section indicates the depth to the rock bottom of the preglacial valley. As there are at least 125 feet of Hudson River strata exposed in the adjacent hills, the thickness of this formation here is 535 feet, or 785 feet for the Hudson River and Utica combined.

A well drilled in the western part of Fayette County proved a failure.

Bartholomew County.—Two wells drilled in this county are reported to have found gas in paying quantities, the first at Elizabethtown, and the second (which is just drilled) at Hartsville. The former found the Trenton at a depth of 905 feet and gas at 914 feet, or 274 feet below sea level. The latter is reported to have struck gas at 861 feet from the surface.

Two wells were drilled at Columbus, but both were failures. In No. 2 salt water was struck in the Trenton and rose in the well until it overflowed at the mouth.

Section of well No. 1, Columbus.

		Feet.
1.	Drift	75
2.	Black shale	13
3.	Blue shale with flints	5
4.	Blue shale	5
5.	Blue shale with sandy bands	5
6.	Black shale	10
7.	Black shale	6
8.	Gray limestone	31
9.	Calcareous shale	10
10.	Gray and blue limestone	10
11.	Buff limestone	25
12.	Light blue shale	35
13.	Bluish limestone	50
14.	Bluish shale	45
15.	Shale and limestone	5
16.	Bluish shale	50
17.	Shale with chert	60
18.	Bluish green shale	380
19.	Brown shale	185
20.	White Trenton limestone (salt water)	15
21.	Gray Trenton limestone	15
22.	Brownish Trenton limestone	10
23.	Reddish Trenton limestone	65
24.	Trenton limestone with varying colors	440
25.	St. Peter sandstone	150
	Total	1,700
	Altitude of well	635

It is difficult to assign the different elements given above to their formations, as more shale than usual is reported. No. 8 evidently represents the Upper Helderberg, and if so No. 9 is the upper Niagara shale, though it is possible that No. 12 should be assigned to that horizon. Examination of a full suite of drillings from this locality is necessary before any positive identifications can be made.

Jennings County.—A bore put down at North Vernon is reported to give the following strata:

	Feet.
1. Drift	5
2. Hard limestone, varying colors	132
3. Dark soft limestone	133
4. Hard blue limestone	10
5. Bluish shale (Hudson River)	430
6. Dark shale (Utica)	220
7. Trenton limestone	470
8. St. Peter sandstone	60
Total	1,460
Altitude of well	700

Salt water, struck at a depth of 1,400 feet, rose about 1,200 feet in the well.

Of two wells drilled at Vernon, the first reached the Trenton at 870 feet from the surface, the altitude of the well being 750 feet. The drilling was carried into the Trenton 53 feet. No gas was found in the Trenton, but quite a flow was struck in the Niagara limestone, first at a depth of 74 feet from the surface, with a still stronger flow at a depth of 145 feet. The capacity of this well was reported to be about 900,000 cubic feet per day at first, but the flow has been gradually decreasing ever since. At present the output is but a small proportion of the initial volume. Within three months it had fallen to about 150,000 cubic feet per day. The highest static pressure recorded for this well is 40 ounces. In the second well gas appeared at a depth of 155 feet, but the supply was much less than in No. 1. The history of these wells indicates that no large or permanent supply need be expected from this horizon at this locality.

Jefferson County.—The following record of the bore put down at Madison is reported by Dr. W. T. S. Cornett:

	Feet.
1. Hudson River above well head to base of Clinton on the hills	281
2. Hudson River shales in bore	330
3. Limestone	110
4. Black shale	90
5. Trenton limestone	474
Total	1,004
Altitude of well	500

Salt water was struck at a depth of 950 feet and rose 250 feet in three days. A small quantity of oil was also observed. The unusual thickness assigned to the Hudson River (611 feet) in this section suggests that the subjacent limestone (No. 3) may belong to the Utica.

Clark County.—Seven wells have been drilled in the vicinity of Jeffersonville. Mr. Orlando Hobbs has kept a careful record of them, and from a complete suite of the drillings received from him the following section has been constructed:

	Feet.
1. Drift	40
2. Hamilton limestone	15
3. Corniferous limestone	25
4. Niagara limestone	88
5. Clinton limestone	22
6. Hudson River limestones and shales	510
7. Utica shales	127
8. Trenton limestone	389
Total	1,216
Altitude of well	436

The subdivisions of the Niagara and Clinton are shown in the following detailed section taken from well No. 2, at Jeffersonville:

	Feet.
1. Buff limestone	40
2. Gray limestone	5
3. White limestone	35
4. Buff limestone	5
5. Reddish calcareous shale	20
6. White limestone	15

Nos. 5 and 6 should probably be considered as Clinton. It will be seen that the upper and lower Niagara shales have entirely disappeared in the southern extension of the Niagara; which has also become much thinner than in the northern.

Quite strong flows of shale gas were found in well No. 1 at depths of 80, 110, 276, and 313 feet, but the supply did not prove persistent.

A little gas was found in the Trenton limestone, in a well drilled 3 miles north of Jeffersonville, at a depth of 910 feet and 50 feet within the formation.

Floyd County.—Two wells have been drilled at New Albany (just west of Jeffersonville), but both have been failures.

Harrison County.—There are five gas wells in this county, all fair producers, though the daily capacity of the strongest hardly exceeds 1,000,000 cubic feet, and the others are much less. Gas is struck at depths varying from 350 to 500 feet below the surface, in what the drillers call black shale. Salt water is also reported in close proximity to the gas, as it is seldom that the gas-bearing rock is penetrated far enough to obtain a free flow of gas without also tapping the water. This shows very little structural relief in the local reservoir. The static pressure is 115 pounds.

Considerable discrepancy appears in the reports of geologists concerning the age of the formation in which the gas is found. Usually it is referred to the Knob shales, or Waverly. The drillers, however, speak of it as black shale.

A portion of the artesian boring at Corydon, reported by Prof. Collett, in the report of the Indiana Geological Survey for 1878, p. 353), is as follows:

	Feet.
1. Drift	12
2. St. Louis and Keokuk	218
3. Knob shales	421
4. Black shales	110

Prof. Collett reports exposures of the Knob shale in the bank of the Ohio River above Brown's Landing, 7 miles in an air line above Brandenburg, Kentucky.

The following is a section of a well near Brandenburg, Kentucky, according to Major Davis, of Louisville, Kentucky:

	Feet.
1. Keokuk	475
2. Lick shales	15

The well has a daily flow of 1,000,000 cubic feet.

The section at Tobacco Landing, Indiana, about 3½ miles from Brown's Landing and 5 miles above Brandenburg, is given as follows:

	Feet.
1. Keokuk	375
2. Lick shales	25

The well at this point has a flow of 805,000 cubic feet per day.

Comparison of these data indicates that after making reasonable allowance for difference in altitude of the wells, the Keokuk must rapidly increase in thickness and dip, striking to the west from Brown's Landing.

Four producing wells have been drilled at Tobacco Landing, and one at Boone Landing, and there is another opposite Brandenburg, Kentucky. A daily capacity of 3,000,000 or 4,000,000 cubic feet is claimed for a well recently drilled in this vicinity.

Washington County.—Two wells have been drilled at Salem. The first reached the Trenton limestone at a depth of 1,741 feet, the total depth of the well being 1,800 feet. This well was a failure, since only a weak flow of gas was obtained. The second well struck quite a flow of gas in the Devonian limestone at depths of 715, 742, and 727 feet. It has so far proved persistent, and of sufficient volume to supply about one hundred stoves. Salt water was struck in this well at depths of 138 and 715 feet from the surface. The following section is reported from the second well:

	Feet.
Keokuk limestone	150
Knob shale (Waverly ?)	458
Black shale	115
Devonian limestone	27
Total	750
Altitude of well	720

The encouragement afforded by the small flow of gas in these wells will induce the drilling of others, but it is hardly probable that the structural relief is sufficient to cause any great accumulation of gas in the Devonian limestone, and the presence of brine mixed with the gas at 715 feet is evidence of very little relief in the gas-bearing rock. This limestone has proved productive at no other locality in the State so far.

Jackson County.—Brownstown reports a failure in the well put down at that point. The section is as follows:

Brownstown Section.

			Feet.
1.	Drift		42
2.	Bluish shale (Knob shale)		275
3.	Black shale	Devonian	108
4.	Gray shale		20
5.	Drab shale		15
6.	Gray limestone		20
7.	Whitish limestone		25
8.	Drab limestone		12
9.	Gray limestone		38
10.	Blue limestone		120
11.	Buff limestone		15
12.	Shale, greenish (Hudson River)		285
13.	Greenish shale		150
14.	Blue shale (Utica)		45
15.	Dark blue shale (Utica) (probably brown)		183
16.	Trenton limestone, with bands of shale, all varying from gray to bluish		491
17.	St. Peter sandstone		47
	Total		1,891
	Altitude of well		650

An artesian flow of magnesian water was struck at a depth of 565 feet. Salt water was struck at a depth of 1,891 feet and rose 1,600 feet in the well.

Two wells were drilled at Seymour, very feeble flows of gas being found in each. The second showed some salt water after shooting.

The following section of well No. 1 at Seymour was made from a complete suite of drillings:

			Feet.
1.	Drift		75
2.	Shale (Knob shale)		8
3.	Rockford limestone		7
4.	Bluish shale	Devonian	4
5.	Black shale,		21
6.	Yellowish shale		2
7.	Brown shale		53
8.	Blue shale		10
9.	Black shale		25

		Feet.
10.	Brown limestone	13
11.	Blue limestone	6
12.	White limestone	13
13.	Brown limestone	13
14.	Brown limestone (siliceous)	7
15.	Bluish shale	73
16.	Gray limestone	10
17.	Blue limestone	5
18.	Bluish gray limestone (sulphur water)	40
19.	Blue limestone	10
20.	Gray limestone	15
21.	Blue limestone	10
22.	Brown limestone	10
23.	Brown shale	10
24.	Bluish green shale (Hudson River)	505
25.	Black Utica shale	165
26.	Gray Trenton limestone	94
	Total	1,204
	Altitude of well	630

Sulphur water was struck between 250 and 257 feet, and again between 345 and 385 feet.

Well No. 2, situated 1 mile southwest of No. 1, reached the Trenton at 1,090 feet.

Taking the upper surface of the black shale as a datum plane, the dip of that formation appears to be 213 feet from Seymour to Brownstown, a distance of 11 miles, making the dip 19+ feet per mile. The black shale outcrops at Rockford, 2 miles north of Seymour, and the dip to the south is 17 feet per mile.

A bore at Martinsville reached the Trenton at a depth of 1,376 feet, the altitude of the well being 598 feet. Water was struck at 580, 600, 620, and 660 feet, and rose in an open pipe 25 feet above the surface.

Johnson County.—A well drilled at Franklin gave the following section, reported by Prof. D. A. Owen:

		Feet.
1.	Drift	170
2.	Black shale	34
3.	Blue and gray limestone	71
4.	Sandstone	27
5.	Blue shale (upper Niagara)	23
6.	Gray and white limestone	120
7.	Greenish blue, varying to black shale	597
8.	Trenton limestone	71
	Total	1,113
	Altitude of well	736

The following section is reported from Edinburg:

	Feet.
1. Drift	115
2. Shale	20
3. Limestone	230
4. Shale	622
5. Trenton limestone	500
6. Shale	83
7. White sandstone	10
Total	1,580
Altitude of well	670

Salt water was struck at 1,583 feet and rose 1,500 feet in the well. An analysis of this water by Dr. J. M. Hurty, of Indianapolis, is as follows (each United States gallon of 231 cubic inches contains 993,240 grains):

Sodium chloride	874,324
Sodium carbonate	10,423
Calcium sulphate	2,107
Calcium carbonate	5,061
Calcium chloride	65,484
Silica	1,994
Iron oxide	997
Magnesian sulphate	32,933
Total	993,323
Hydrogen sulphide, cubic inches per gallon	12.6
Carbonic acid gas, cubic inches per gallon	9.76
Specific gravity	1.0115

A bore at Greenwood gave the following section:

	Feet.
1. Drift	210
2. Black shale	90
3. Limestone	280
4. Whitish shale	40
5. Gray shale (probably greenish)	300
6. Dark Utica shale	300
7. Trenton limestone	555
8. St. Peter sandstone	200
9. Lower magnesian limestone.	

"Blue Lick water" was struck at 1,840 feet; salt water was struck at 1,865 feet and rose 1,700 feet in the well.

Hendricks County.—A well drilled to a depth of 1,386 feet at Plainfield reached the Trenton at a depth of 1,199 feet, the altitude of the well being 742± feet. Quite a flow of gas was reported at a depth of 350 feet from a sandstone, probably corresponding to the Pendleton sandstone.

Montgomery County.—Several wells have been drilled at Crawfordsville. All have been failures. The section given below is reported :

		Feet.
1.	Drift	140
2.	Limestone	12
3.	Light blue shale	13
4.	Limestone	28
5.	Gray shale	45
6.	Limestone (with water)	2
7.	Gray shale	95
8.	Blue shale	13
9.	Gray limestone	72
10.	Gray shale	15
11.	Hard blue shale	25
12.	Blue shale	90
13.	Black shale	80
14.	Hard gray shale	55
15.	Niagara limestone	425
16.	Hudson River and Utica shales	365
17.	Trenton limestone	69
	Total	1,544
	Altitude of well	764

Sulphur water was struck at 750 feet.

Parke County.—The following section is reported from Rockville :

		Feet.
1.	Drift	96
2.	Gray sandstone	44
3.	Brown shale	25
4.	White sandstone	10
5.	Whitish shale	25
6.	Black shale	105
7.	White sandstone	50
8.	Limestone	175
9.	Gray shale	305
10.	Sandstone (salt water)	100
11.	Whitish shale	214
12.	Black shale	102
13.	Limestone	118
14.	Brown sandstone	36
15.	Limestone (Niagara)	220
16.	Shale (Hudson River and Utica)	472
17.	Trenton limestone	69
	Total	2,169

The upper members of this section belong to the Coal Measures. No. 8 undoubtedly represents the Subcarboniferous limestones. Nos. 9, 10, and 11 belong to the Waverly, while No. 12 is the Devonian black shale. The brown sandstone is reported at the same horizon at nearly every point west of its outcrop at Pendleton.

Boone County.—A bore put down at Lebanon passed through the following strata:

		Feet.
1.	Drift	210
2.	Blue and black shales	204
3.	Limestone	401
4.	Shale	412
5.	Trenton limestone	373
	Total	1,600
	Altitude of well	925

A full suite of drillings received from Dr. J. O. Hurst, of Zionsville, shows the following section for the well drilled at that town:

		Feet.
1.	Drift	160
2.	Black shale (trace).	
3.	Devonian limestone with a sandstone at the base	75
4.	Lower Helderberg and Waterlime	50
5.	Niagara limestone	165
6.	Clinton limestone(?)	30
7.	Hudson River and Utica shales	525
8.	Trenton limestone	33
	Total	1,038
	Altitude of well	777

Salt water was struck at 1,013 feet and rose 600 feet in the well.

A bore at Thorntown reached the Trenton limestone at a depth of 1,250 feet from the surface. The altitude of the well is about 806 feet.

Clinton County.—Frankfort section:

		Feet.
1.	Drift	280
2.	Limestone	370
3.	Shale	430
4.	Trenton limestone	366
	Total	1,446
	Altitude of well	840

Salt water was struck at 1,200 feet and rose 600 feet in the well.

A bore 4 miles east of Frankfort reached the Trenton at a depth of 1,105 feet, the altitude of the well being 915 feet. The thickness of the drift is 300 feet.

The first well started at Frankfort was abandoned on account of the great thickness of the quicksand above the rock.

Carroll County.—A well drilled at Delphi passed through the following strata:

	Feet.
1. Drift	4
2. Limestone	590
3. Hudson River shales	140
4. Utica shale	170
5. Trenton limestone	10
Total	914
Altitude of well	618

Salt water was struck at 910 feet and rose nearly to the top of the well.

White County.—The following section is reported for Monticello:

	Feet.
1. Drift	205
2. Limestone	515
3. Bluish shale	120
4. Brown shale	170
5. Trenton limestone	40
Total	1,050
Altitude of well	672

Salt water was struck at 1,150 feet. It rose 500 feet in the well.

The Monon section is reported as follows:

	Feet.
1. Limestone	530
2. Shale	30
3. Petroliferous limestone (Clinton)	25
4. Shale	285
5. Trenton limestone	50
Total	920
Altitude of well	664

Salt water was struck at 880 feet and rose nearly to the top of the well. No. 1 in the above gives the thickness of the Upper Silurian limestone. The Lower Helderberg forms the surface rock at this locality.

Pulaski County.—Several wells have been drilled at Francesville, but all are practically failures, though quite a flow of gas was at first reported from one well. A little oil was found in both the Clinton and Trenton limestones. The section agrees very closely with that given for Monon. The Trenton was reached at a depth of 890 feet, the altitude of the well being 680 feet.

No record was obtained of the well at Winnamac, except that limestone was the first rock struck after penetrating the drift.

Cass County.—A well drilled at Galveston reached the Trenton at a depth of 927 feet, and 17 feet below struck a heavy vein of salt water. The altitude of the well is 805 feet. A bore at Walton reached the Trenton at a depth of 1,007 feet and salt water at 1,028 feet, the altitude of the well being about 775 feet. A little oil was found with the salt water. The altitudes of these towns were taken from a single reading of an aneroid barometer.

Two wells were put down at Logansport, and from natural exposures in the vicinity and from a complete suite of drillings saved by Dr. J. H. Shultz, the following section was constructed:

		Feet.
1.	Upper Helderberg limestone	40
2.	Lower Helderberg limestone	30
3.	Waterlime	108
4.	Bluish limestone (Niagara)	55
5.	Argillaceous limestone	110
6.	White and gray limestone	135
7.	Bluish green shale (Niagara)	2
8.	Clinton limestone, steel-gray with red grains	53
9.	Hudson River limestones and shales	90
10.	Utica shale	281
11.	Trenton limestone	200
	Total	1,104
	Altitute of well	611

Salt water struck in the Trenton limestone rose in the well until it overflowed at the top.

Two wells drilled at Royal Centre found a little oil in the Trenton. About 10 barrels per day might be furnished. A little salt water was found with the oil. The thickness of the drift was 109 feet, the depth to the Trenton 925 feet, and the altitude of the well 730 feet. The oil was struck at 940 feet.

The Trenton shows quite a rise from Logansport to Royal Centre, its altitude being 145 feet, the greater at the latter point. The reason for this has already been given.

Miami County.—A bore at Bunker Hill reached the Trenton at a depth of 986 feet, the altitude of the well being 790 feet. Salt water was struck at 1,012 feet.

Four wells were put down by the citizens of Peru. The section of well No. 1 is as follows:

		Feet.
1.	Drift	38
2.	Niagara limestone	334
3.	Niagara shale	40
4.	Hudson River limestone and shales	208
5.	Utica shales	250
6.	Trenton limestone	33
	Total	903
	Altitude of well	655

Salt water from the Trenton at 900 feet rose 800 feet in the well. A small flow of oil was also found in this well, but it was soon replaced by brine. A second well, 2½ miles north of the city, passed through 318 feet of drift. The altitude of this well is estimated to be 125 feet higher than that of No. 1, and the great thickness of drift thus indicates erosion of 200 feet of limestone in the more northerly locality. It probably marks the site of a preglacial valley.

Fulton County.—Section at Rochester:

	Feet.
1. Drift	245
2. Limestone	535
3. Shale	381
4. Trenton limestone	21
Total	1,182
Altitude of well about	790

Salt water was struck at 1,175 feet and rose 800 feet in the well.

A well drilled at Kewanna gave the following section:

	Feet.
1. Drift	167
2. Limestone	498
3. Niagara shale	20
4. Limestone (probably Clinton)	40
5. Bluish green Hudson River shales	134
6. Black Utica shales	200
7. Trenton limestone	30
Total	1,089

Salt water was reached at 1,074 feet and rose 990 feet in the well.

Porter County.—The section given below was made from a full suite of drillings furnished by Mr. C. W. Dickover, of Valparaiso:

Valparaiso section.

	Feet.
1. Drift	125
2. Black shale	65
3. Corniferous Lower Helderberg and Waterlime	230
4. Niagara limestone	380
5. Niagara shale	5
6. Clinton limestone	55
7. Bluish green Hudson River shales	160
8. Chocolate brown limestone (Galena)	256
9. Trenton limestone	68
Total	1,344
Altitude of well	715

No attempt was made to separate the elements of No. 3, as the drillings were fine and differed little in color.

A well drilled at Hebron passed through 108 feet of drift and 80 feet of black shale. The remainder of the section was not obtained.

No attempt was made to separate the elements of No. 3, as the drillings were fine and differed little in color.

A well drilled at Hebron passed through 108 feet of drift and 80 feet of black shale. The remainder of the section was not obtained.

Lake County.—Section at Crown Point:

		Feet.
1.	Drift	176
2.	Black shale	76
3.	Limestone	433
4.	Bluish green shale	55
5.	Clinton limestone	57
6.	Bluish green Hudson River shale	122
7.	Trenton limestone	342
8.	White limestone (sandy)	89
9.	Limestone	15
	Total	1,365
	Altitude of well	736

Well filled with salt water from the Trenton to within 120 feet of the top.

La Porte County.—No complete records were obtained from the bores at Michigan City and La Porte. In the former city the drift was 250 feet thick and limestone was the first rock struck, while in a well drilled for the prison black shale was the first rock struck beneath 170 feet of drift. At La Porte 295 feet of drift is reported, with 125 feet of black shale immediately beneath it.

St. Joseph County.—The section given below was made from a full suite of drillings sent the author by Mr. J. D. Oliver, of South Bend.

South Bend section.

			Feet.
1.	Drift: Sand 25, gravel 20, clay 30, sand 25, gravel 37.		137
2.	Waverly shale (bluish green calcareous)		143
3.	Black shale		70
4.	Brown shale		25
5.	Gray limestone	Upper Helderberg	60
6.	Blue limestone		20
7.	Lower Helderberg (with gypsum)		170
8.	Waterlime		55
9.	Niagara limestone (gray, buff, and white)		470
10.	Buff Clinton limestone		30
11.	Hudson River limestones and shales		220
12.	Utica shales		185
13.	Trenton limestone (chocolate-colored)		85
	Total		1,670
	Altitude of well		725

Salt water was struck at 375 and 610 feet, and also in the Trenton at 1,670 feet, when it rose 1,470 feet in the well. The gypsum-bearing beds are near the middle of the Lower Helderberg limestones. It is possible that the lower strata assigned to the Lower Helderberg really belong to the Waterlime.

Marshall County.—A well drilled at Plymouth reached the Trenton at a depth of 1,324 feet. Salt water was struck at 1,368 feet, and rose 900 feet in the well. The altitude of the well is 783 feet. The drift is 242 feet thick, and beneath it 64 feet of black shale were found.

Elkhart County.—Partial section of Elkhart boring:

	Feet.
1. Drift	122
2. Waverly shale	213
3. Black shale	215
4. Grav limestone	65
Total	615

An artesian flow of salt water was struck at 550 feet.

The following section was made of the bore at Goshen from drillings sent the author by Thomas Miller, Esq.:

	Feet.
1. Drift	162
2. Bluish-green Waverly shale (calcareous)	200
3. Devonian black shale	93
4. Devonian brown shale	18
5. Hamilton limestone (dark gray)	27
6. Hamilton shale (brown)	20
7. Upper Helderberg (buff and whitish)	30
8. Lower Helderberg limestone (gray)	265
9. Waterlime (brownish)	150
10. Niagara limestone (white)	295
11. Niagara limestone (blue)	115
12. Clinton limestone (steel gray with red grains)	30
13. Hudson River limestones and shales	230
14. Utica shales (lower fifteen feet bluish)	185
15. Trenton limestone (buff and brown)	239
Total	2,059
Altitude of well	785

Salt water was found in the Trenton under sufficient pressure to force it to the surface, 2,000 feet above. This is equal to about 875 pounds per square inch. It is possible that No. 7 may have a greater thickness than is here assigned to it—the colors of the drillings vary so little that it is almost impossible to draw division lines between the Upper Helderberg and the Lower Helderberg. Even allowing a possible thickness of 75 feet for No. 7 brings the upper gypsum bed nearly to the top of the Lower Helderberg. A second gypsum bed was found near the base of the Lower Helderberg. The Waterlime shows the same color as in its natural outcrops.

A second well at Goshen struck salt water in the Niagara limestone, the water rising to the surface.

Kosciusko County.—A well drilled at Warsaw passed through the following strata:

	Feet.
1. Drift	248
2. Limestone	652
3. Shale	487
4. Trenton limestone	50
Total	1,437
Altitude of well	815

Salt water was struck at 20, 35, and 50 feet within the Trenton limestone. It rose 1,000 feet in the well.

Whitley County.—Section at Columbia City:

	Feet.
1. Drift	224
2. Limestone	350
3. Shale	776
4. Trenton limestone	25
Total	1,375
Altitude of well	816

Salt water was struck at 900 feet and rose 880 feet in the well; also at 1,375 feet, rising from the latter depth 300 feet in the well (the upper stream having been cased out). A bed of salt 25 feet thick was reported at a depth of 872 feet from the surface.

Larwell section.

	Feet.
1. Drift	365
2. Blue limestone	300
3. White limestone	200
4. Bluish limestone	22
5. Niagara shale	43
6. Clinton limestone (salt water)	14
7. Shale	43
8. Limestone (salt water)	43
9. Bluish green shale	212
10. Black shale	300
11. Trenton limestone	51
Total	1,593
Altitude of well about	950

The first vein of salt water was struck at 935 feet and it rose 800 feet; a second vein was struck at 997 feet and rose 850 feet; and brine again appeared in the Trenton at 1,566 feet from the surface and rose 1,366 feet in the well. The well was cased at 915, 949, and 1,165 feet. It is quite probable that No. 8 of the above section belongs to the Medina, which formation is well displayed in the Albion section.

Noble County.—Albion sections:

		Feet.
1.	Drift	375
2.	Devonian black shale	65
3.	Upper Helderberg limestone	65
4.	Oriskany sandstone (?)	5
5.	Lower Helderberg and Waterlime	320
6.	Niagara limestone	400
7.	Niagara shale (bluish green)	20
8.	Clinton limestone (red)	30
9.	Clinton shale (reddish, calcareous)	16
10.	Medina limestone (steel gray, siliceous)	59
11.	Hudson River limestones and shales	85
12.	Hudson River shale	200
13.	Utica shale	250
14.	Trenton limestone	24
	Total	1,914
	Altitude of well	729

This section is of especial interest in that it exhibits a well defined rock-mass apparently representing the Medina. This formation probably exists throughout the northeastern corner of the State, but want of care in saving the drillings prevented recognition of it before the Albion well was bored. Mr. W. B. Vangorder, of Albion, saved a complete suite of drillings, and from samples of the divisions numbered 7, 8, 9, 10, and 11 in the above section the above identifications have been made. A comparison with the Larwell section shows exactly the same order of succession, and this correspondence attests the correctness of both. The contrast between the bluish green Niagara shale and this steel gray, siliceous limestone is too marked to admit of error in separating these formations, while the contrast between the Medina and Hudson River is also very marked.

A bore at Kendallville reached the Trenton at a depth of 1,920 feet. The thickness of the drift was 485 feet, all sand and gravel except 60 feet of clay at the base.

De Kalb County.—The Trenton limestone within a portion of this county seems to assume a gentle swell, giving the necessary structural relief to separate the gas and water, though the bores thus far indicate that this relief is exceedingly slight—salt water being found in connection with the gas in all the wells.

The first well put down at Auburn reached the Trenton at a depth of 1,933 feet, and the drilling was continued 36 feet into the limestone. The altitude of the well is 872 feet. The flow of gas was estimated at about 1,000,000 cubic feet per day. Considerable salt water was present. When the well was closed the static pressure reached 200 pounds in ten minutes, 300 pounds in twenty minutes, and 460 pounds in two and one-half hours. A second well passed through 282 feet of drift and reached the Trenton at 1,925 feet. The measured daily flow of gas was 450,000 cubic feet. It, too, showed some salt water. A third bore also struck gas, but is almost useless on account of the admixture of salt water.

Bores put down at Waterloo gave a small flow, perhaps 100,000 cubic feet per day; but the wells are likely to be drowned out by the salt water. The thickness of the drift was 365 feet. A small flow of gas is also reported at Garrett.

A bore at Butler passed through the following strata:

	Feet.
1. Drift	378
2. Black shale	108
3. Limestone	1,064
4. Shale	500
5. Trenton limestone	89
Total	2,139
Altitude of well about	865

A light flow of gas was struck near the top of the Trenton, and a little salt water at 2,139 feet.

Allen County.—Several wells have been put down at Fort Wayne, but all are practically failures, though two found a little gas in the Trenton limestone. The data shown in the following table were furnished by Mr. C. B. Dryer:

Fort Wayne wells.

Well.	Altitude.	Thickness of drift.	Trenton below sea level.	Total depth.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Court-house	772	88	638	3,000
Bass Foundry	788	110	649	1,458
Abbott's Addition	796	106	617	1,900

Wabash County.—Wabash section, well No. 1:

	Feet.
1. Drift	36
2. Bluish limestone	54
3. White limestone	20
4. Bluish limestone, varying to gray	140
5. Whitish limestone	30
6. Bluish limestone	60
7. Bluish green Niagara shale	35
8. Bluish gray limestone (Clinton)	20
9. Hudson River limestone and shales	205
10. Utica shale	280
11. Trenton limestone (salt water)	7
Total	887
Altitude of well	680

The above section was made from a complete and satisfactory suite of drillings. The well is located in the Wabash Valley, and as between 75 and 100 feet of Niagara limestone is exposed in the hills to the south, the total thickness of this formation here is about 450 feet.

Well No. 2 was located 2 miles south of the city. The depth to the Trenton limestone was 931 feet; the altitude of well was 785 feet; and the thickness of the drift 180 feet.

Salt water was struck at 14 feet within the Trenton, together with a feeble flow of gas.

Well No. 4, located 7 miles south of Wabash, reached the Trenton at 875 feet, the thickness of the drift being 133 feet.

A bore at North Manchester passed through the following strata:

	Feet.
1. Drift	274
2. Limestone	426
3. Shale	440
4. Trenton limestone	40
Total	1,180
Altitude of well	780

Salt water was struck at 1,180 feet. It rose 990 feet in the well.

Huntington County.—Section at Huntington, well No. 1:

	Feet.
1. Drift	2
2. Limestone	400
3. Shale	595
4. Trenton limestone	39
Total	1,036
Altitude of well	726

Salt water from the Trenton rose 750 feet.

A second well reached the Trenton at a depth of 1,012 feet, and salt water, which rose 950 feet in the well, at 1,037 feet.

A little oil was found in a third well at a depth of 1,025 feet.

A bore at Warren passed through the following strata:

	Feet.
1. Drift	39
2. Limestone	325
3. Shale	575
4. Trenton limestone	30
Total	969
Altitude of well	710

This well yielded 5 to 10 barrels of oil per day until it was shot with nitroglycerin, when the salt water soon displaced the oil. A fine artesian flow of water was struck at a depth of 67 feet which proved of great value to the people in the vicinity during the drought that prevailed in 1887, hundreds of people being compelled to resort to this never-failing source of water supply.

Wells County.—Several wells were put down at Bluffton, but all were failures save that No. 1 gave the following section:

Bluffton section, well No. 1.

	Feet.
1. Drift	12
2. Limestone	283
3. Clinton (?)	75
4. Hudson River shale	395
5. Utica shale	285
6. Trenton limestone	150
Total	1,200

Salt water was struck at 1,130.

Adams County.—Decatur section, well No. 1:

	Feet.
1. Drift	47
2. Limestone	436
3. Bluish shale	667
4. Black shale	110
5. Trenton limestone	40
Total	1,300
Altitude of well	800

A second well drilled to the same depth was abandoned after filling up with salt water from the Trenton limestone.

CHAPTER VI.

THE CARE OF GAS WELLS.

It is important that gas wells should be properly cared for when first drilled. In every instance the casing should be sunk deep enough to shut out the water from the Hudson River shale, usually found about 100 feet within the formation. When the casing leaks, or when it is placed too high in the well, the water will fill the bore above the packer; and when the well is used to its full capacity the water will meet only the resistance offered by the packer, and (especially when there are 600 or 700 feet of water above the packer, as is often the case) will in time force its way around the packer and into the reservoir, and wet gas will be the result. Sometimes, too, withdrawal of the packer and recasing at considerable expense are required.

Wells should be so arranged that they can be blown off occasionally to clear out any water or petroleum that may accumulate; and, when in use, a drip should be placed between every well and the mains in order to catch any material that may be thrown out by the gas. The drip is a large pipe, 5 or 6 feet in length, placed near the well, in a vertical position, and about one-half below the surface of the ground. The gas is allowed to enter at the top, and is also drawn off near the top; and the water, oil, etc., settle at the bottom of the pipe and may be blown off through an escape pipe provided for that purpose. It is also advisable to place a burner under the discharge pipe as the gas thus heated is less liable to have its moisture frozen in the mains.

All strong wells should be packed, but wells of feeble flow (10,000 to 25,000 cubic feet per day) do not require packing, provided the casing is tight and the well perfectly dry. In no instance should the packer be placed in the casing; for should the latter become loosened, water will then find its way into the reservoir. As a rule the packer should be placed in the Trenton limestone, or a few feet above it in the black shale. If the well has been torpedoed, the packer should be placed as low as it can be made to hold.

Efforts are often made to shut out the water that comes in with the gas, but this is impossible and a waste of money. If the flow of gas is strong, a separator can be used; but if the flow is feeble, the salt water will soon drown it out.

It is always advisable to carry from 25 to 100 pounds retained pressure in each well where possible, as the gas will thereby be made cleaner; and this pressure will go far towards keeping out the salt water, especially if the well is near the lower limits of the field.

The packing tube should be securely anchored, preferably to heavy timbers buried beneath rocks and earth. But if the drive pipe is sufficiently long it will answer every purpose.

From 8 to 12 ounces is all the pressure necessary for low-pressure mains, though many small towns are using from 5 to 6 pounds. This high pressure is not only unnecessary, but wasteful and dangerous. Every effort should be made to prevent waste of gas, for the draft on the field is enormous, and if present indications are of any value the supply will not hold out indefinitely. While the supply will probably last a long time, it is, to say the least, the part of wisdom to practice economy in the use of Nature's gift—this sunlight of past ages, stored away in invisible form to await the coming and serve the purposes of man.

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