SECOND ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1880-'81

BY

J. W. POWELL
DIRECTOR

WASHINGTON
GOVERNMENT PRINTING OFFICE
1882

REPORT

OF THE

DIRECTOR

OF THE

UNITED STATES GEOLOGICAL SURVEY.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 1, 1881.

The Honorable the SECRETARY OF THE INTERIOR.

SIR: I have the honor to transmit herewith my report of the operations of the Geological Survey for the fiscal year ending June 30, 1881.

Please accept my thanks for the courtesies you have shown me, for the interest you have exhibited in the Survey, and for the encouragement you have given to scientific research.

I am, with respect, you obedient servant,

J. W. POWELL,
Director.

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UNITED STATES GEOLOGICAL SURVEY.

BY J. W. POWELL, *Director.*

INTRODUCTORY.

On the 11th of March, 1881, Mr. Clarence King retired from his office as Director of the Geological Survey. The following is his letter of resignation:

To the PRESIDENT OF THE UNITED STATES,
Executive Mansion, Washington, D. C.

SIR: Finding that the administration of my office leaves me no time for personal geological labors, and believing that I can render more important service to science as an investigator than as the head of an executive bureau, I have the honor herewith to offer my resignation as Director of the Geological Survey.

Very respectfully, your obedient servant,

CLARENCE KING.

On the 12th of March the above resignation was accepted by the following letter:

EXECUTIVE MANSION, *March* 12, 1881.

DEAR SIR: In accepting your resignation, which I do with reluctance, permit me to express my appreciation of your efficient services to the government during your term of office, and my regret that you do not find it possible to longer remain in charge of the Geological Bureau.

Very truly, yours,

JAMES A. GARFIELD.

Mr. CLARENCE KING, *Washington, D. C.*

On the 14th day of the same month the President nominated John W. Powell, of Illinois, as Director of the Geological Survey. On the 18th the nomination was confirmed by the Senate, and on the 19th the oath of office was administered to him.

It will thus be seen that at the close of the fiscal year for which this report is prepared the Director has held the position for less than three and a half months. Under these circumstances it is thought best that he should not himself give an extended account of the operations of the Survey for the year, but should publish in lieu thereof the administrative reports of the several heads of divisions, which are subjoined.

Coming to the work from a long and successful experience, Mr. King elaborated a comprehensive plan of operations and vigorously prosecuted the same through the assistance of a wisely selected corps of geologists and specialists. It would have been fortunate if this work could have been completed and published under his administration. As it was, no change was made in the plan of operations or methods of investigation. To complete what he had begun was the proper course.

At the close of the fiscal year it is found that a large amount of matter is ready for publication. The whole will be issued in a series of monographs, prepared by the gentlemen who have prosecuted the work in the field. In this volume a synopsis of each appears.

The monographs are designed for specialists, and in each case present a vast array of facts on which conclusions are based.

The summaries present the great facts and conclusions reached, in a manner adapted to the reading public of the United States.

TERTIARY HISTORY OF THE GRAND CAÑON DISTRICT, BY CAPT. C. E. DUTTON.

The monograph of Captain Dutton on the Grand Cañon District is now nearly ready for the printer. It is the first discussion in monographic form of the results obtained by the study of this remarkable region.

The district was for many years the field of research of the present Director. Some of the results of his investigations have appeared in the report on the Colorado River and in the report on the Uinta Mountains.* The first exploration of the country was made by himself; its geographic survey was largely made under his own eye; and to its geologic structure he has given years of laborious study During this time he hoped finally to present an extended monograph on the district, which should be the chief work of his life, but administrative duties ever pressed upon him and occupied his time, and the wide scope of research under his direction made it necessary for him to devote a portion of his energies to other branches—especially to geography and anthropology.

During the progress of his geologic investigations new questions in structural and in dynamic geology were presented, demanding more extended examination and re-examination; and thus it happened that when the various United States geographic and geologic surveys were consolidated the work was incomplete. At that time, with his hearty support, Mr. Clarence King was made Director of the Survey, and Mr. Powell himself, Director of the Bureau of Ethnology.

Thus the present Director was by circumstances taken from the field of geologic research so long cultivated by him, and placed in a field in which he had intermittently been engaged for many years. The change was supposed to be permanent, and he gave up all thought of continuing his work as a geologist. The abandonment of his long-cherished hope and ambition caused less regret from the fact that the subject of study could be transferred to Captain Dutton, who had been his assistant and collaborator for several years, and who had already completed a monograph upon an adjoining and intimately re-

*Exploration of the Colorado River of the West and its tributaries. Explored in 1869, 1870, 1871, and 1872, under the direction of the Secretary of the Smithsonian Institution Washington. Government Printing Office 1875. 2 p ll pp. I–XI, 1–291, 4°.

Department of the Interior. U. S Geological and Geographical Survey of the Territories. Second Division. J W. Powell, Geologist in charge. Report on the Geology of the Eastern Portion of the Uinta Mountains and a region of country adjacent thereto. With atlas. By J. W. Powell. Washington: Government Printing Office. 1876. pp. I–VII, 1–218, 4°.

lated district—that of the High Plateaus of Utah. Captain Dutton's assumption of the work was a source of special gratification because he entertained views substantially identical with those of the present Director concerning the physical laws and processes which have combined to produce the wonderful features of the region.

Scientific men will regret the change even less than the present Director, for Captain Dutton has pursued wise methods of research and arrived at philosophic conclusions that make his monograph a great contribution to knowledge.

In his report appearing in this volume, and in the monograph soon to appear, he does not undertake to give an exhaustive account of the entire range of the geology of the district, but limits himself to the discussion of its Tertiary history and of the problems of physical geology involved therein. The history and structure of the older rocks offer problems of equal interest, and to these the Director hopes to turn his attention at no distant day.

Within the district three great groups of facts are presented—displacement, degradation, and volcanism.

By far the most striking of these is the vast amount of atmospheric degradation to which the region has been subjected. He arrays the evidences which lead to the conclusion that the entire district wherein Carboniferous beds now occupy the surface was formerly covered by the whole Mesozoic system found in the geologic province, and probably also by the lower Eocene, and that these strata, having a thickness of from 8,500 to 11,000 feet, have been eroded since the middle Eocene from the Carboniferous platform.

Progressive uplifting was the accompaniment of this progressive denudation—the uplifting in most localities being more than 16,000 feet. With the progressive upheaval the region was divided into blocks by faults and monoclinal flexures crossing chiefly in a north and south direction.

This faulting and differential uplifting took place in such a manner that the blocks lying between the faults and monoclinal flexures were rarely themselves greatly flexed or tilted. They preserved approximate horizontality, but were uplifted in differing amounts, so that a common geologic horizon is found at different altitudes in passing from block to block.

The uplifting of these great blocks and the concomitant faulting and flexing at their margins or lines of severance were at some periods accompanied by volcanic outbreaks, chiefly basaltic.

The phenomena of displacement appearing in the uplifting of the blocks and in the faulting and flexure at their margins, the phenomena of drainage and atmospheric degradation and the climatic changes revealed therein, and the phenomena of volcanism, have been grouped by Captain Dutton in such a manner as to show the progressive evolution of the physical features of the region through Tertiary to the present time.

The geologic history deduced is substantially as follows:

From the beginning of the Carboniferous period to the close of the Cretaceous the Plateau Province was an area of continuous deposition. In that long succession of periods, from 12,000 to 15,000 feet of strata accumulated over its entire extent. At the close of the Cretaceous, important disturbances took place, as a result of which the province, which had been a marine area, became a lacustrine area, and for a time Eocene lacustrine strata were deposited over the greater part of its surface. But at length new displacements began by faulting, flexing, and upheaving; the lacustrine area was drained, and as the waters receded over its surface a river system was laid out.

The configuration of that system was determined by the form of the emerging surface. Its trunk was the Colorado, and the larger tributaries were in part the longer and more voluminous affluents which still exist. Perhaps some minor tributaries have been obliterated. The new-made land was attacked by the atmospheric agencies of degradation, which carried away the greater part of the Cenozoic and Mesozoic formations, and the steadily increasing elevation of the country accelerated the degradation.

Captain Dutton concludes that the greater part of the denudation was accomplished during Eocene and Miocene time, and that at the close of the latter the Grand Cañon district had lost nearly the whole of its Mesozoic strata. From this point of time—the close of the Miocene or beginning of the Pliocene—is dated the origin of the present Grand Cañon of the Colorado. Prior to that time the river had been engaged in cutting through 8,000 to 10,000 feet of strata which formerly covered the formations now seen in the crests of the cañon walls. The excavation of the present chasm is the work of the Pliocene and Quaternary periods.

The paper in this volume, as well as the more formal monograph, will be illustrated by drawings and sketches from the pencil of Mr. W. H. Holmes, who combines artistic ability with wide experience in geologic research. Only the artist and geologist combined could have graphically presented the subject in a manner so instructive and beautiful. With the monograph will appear an atlas of maps, sections, and other illustrations.

THE HISTORY OF LAKE BONNEVILLE, BY MR. G. K. GILBERT.

Mr. Gilbert's study of Lake Bonneville, the lake which during Quaternary time occupied the desert basin of western Utah, was begun ten years ago, at which time he was attached to the geographic corps of Capt. George M Wheeler, of the United States Engineers. Since that time his duties as a member of the Survey of the Rocky Mountain Region have carried him repeatedly to the same district and permitted him to continue his study of the ancient lake. He had thus accumulated before the organization of the present Survey a considerable body of facts, and had already published an outline of the subject. As a member of the new organization he has devoted his time almost exclusively to this research, complementing the material previously gathered and setting at rest the greater number of the questions that had been raised. His field investigation was completed last summer, and he is now engaged in preparing a monograph on the subject—the principal conclusions of which are outlined in his paper appearing in this volume.

His work is especially interesting to students of the glacial phenomena of the Quaternary—not, indeed, because he has dealt largely with similar phenomena in the Great Basin, but because the rise and fall of an inland lake which has no outlet, record in a peculiarly accurate manner the local oscillations of climate, so that his results serve to determine by the aid of entirely independent data a succession of climatic events coeval with those recorded by the ancient glaciers

The history of Lake Bonneville as deduced by Mr Gilbert is as follows

First, the waters were low, occupying, as Great Salt Lake now does, only a limited portion of the bottom of the basin Then they gradually rose and spread, forming an inland sea nearly equal to Lake Huron in extent, with a maximum depth of one thousand feet Then the waters fell and the lake not merely dwindled in size but absolutely disappeared, leaving a plain even more desolate than the Great Salt Lake Desert of to-day Then they again rose, surpassing even their former height, and eventually overflowing the basin at its northern edge, sending a tributary stream to the Columbia River And, last, there was a second recession, and the water shrunk away—until now only Great Salt Lake and two smaller lakes remain

Translated into terms of climate these changes imply that there were two epochs of excessive moisture—or else of excessive cold—separated by an interval of superlative dryness and preceded by a climatic period comparable with the present The first epoch of humidity was by far the longer, and the second, which caused the overflow of the waters, the more intense

A similar study of a similar Quaternary lake has been initiated under Mr Gilbert's direction by Mr I C Russell, and it is intended that the entire district of the Great Basin shall be subjected to investigations of this nature If other districts prove as instructive as the basin of Lake Bonneville, the climatic history of Western America during the last geologic period will become well known

GEOLOGY OF THE EUREKA DISTRICT, BY MR. ARNOLD HAGUE.

The field of Mr. Hague's researches, known as the "Eureka District," is in Central Nevada, and embraces a tract about twenty miles square.

Between the Sierra Nevada on the west and the Rocky Mountains on the east lies the Great Basin, broken by a system of individual mountain ranges usually lying in a north and south direction. The general type of its orographic structure is quite distinct from that of the mountains on the west, the Sierra Nevada and Coast Ranges, and also from the Rocky Mountains on the east and the Appalachian of the Atlantic region.

In general, the rocks of the Great Basin are known to be greatly faulted. The mountains usually consist of uplifted and uptilted blocks of strata, severed from each other and from the non-uplifted portions by fault planes; and these blocks are complicated with and sometimes masked by formations of volcanic origin. For the more thorough comprehension of this type of structure it is necessary to add to their general examination a special and elaborate study of limited portions. This has been well accomplished by the labors of Mr. Hague and his assistants.

The Eureka District is a center of important mining operations, and for economic considerations its elaborate and thorough study is demanded. The general structural geology must be known in order to determine the extent and geologic relations of the ore bodies, and it is proposed to supplement this study of its general geology by another of its mining geology.

Mr. Hague's field work in general geology is now completed and a monograph upon the subject is in an advanced state of preparation. With his executive report he gives a brief summary of its contents, announcing that it will comprise—

1st. A detailed account of the rock formations as exhibited on the map and shown in a series of comparative cross-sections.

2d. A detailed description of the great series of Paleozoic sedimentary formations, embracing 20,000 feet of strata and extending from the base of the Cambrian into the upper Coal Measure limestone The various escarpments of the faulted blocks have afforded excellent opportunities for tracing the series and obtaining the relations of the sedimentary formations

3d An account of some of the more important movements in displacement, by which the formations have been broken into blocks and brought into their present positions

4th A history of the Tertiary volcanic action with its geologic phenomena, an activity which prevailed through a long time, during which all the principal types of volcanic rock, except trachyte, found their way to the surface

5th A discussion of the relations of the volcanic rocks to the sedimentary formations, and of the connection between the great north and south lines of faulting and the lines of igneous outburst

6th A statement of the position and geologic horizon of the more important properties of the several mining districts, and of the relations of the ore deposits to the Tertiary and pre-Tertiary crystalline rocks

An atlas of twelve sheets will accompany the monograph, the map being published on a scale of 1,600 feet to the inch, with 50 vertical intervals of 50 feet each between contours—a scale large enough to lay down with accuracy the boundaries of the geologic formations and to indicate the lines of faulting

The Paleozoic system of the district embraces the Cambrian, Silurian, Devonian, and Carboniferous periods, and to represent the several formations of each, twenty-five color distinctions are needed, while among the igneous rocks nine types are recognized and nine colors required for representation These particulars show how elaborately the survey has been made

Mr Hague's report will constitute an important contribution to structural geology, will contain valuable information in economic geology, and will be the foundation essential to a final monograph on the economic geology of the district

This report goes to the printer at a later date than that of

Mr Hague's letter in the body of this volume, and he desires me to publish the following statement

Accompanying the report of progress in the Eureka survey will be found a small map of Ruby Hill and the immediate vicinity, in which nearly all the more important silver producing mines are situated It was prepared from one of the larger topographic maps, in advance of other map work, for the purpose of presenting it with the annual letter

By reference to the map (Plate IX) it will be seen that the limestone body upon the north and east sides of Ruby Hill, which carries the great ore deposits of the Richmond, Eureka Consolidated, and adjoining mines, is placed upon structural and paleontological evidence in the Prospect Mountain limestone, which has been placed in the Cambrian period

On this map the Cambrian beds have been carried up in the conformable series of quartzites, limestones, and shales to include the Eureka quartzite at the summit, but since the map was printed it has been thought best to draw the line between the Cambrian and Silurian periods at the base of the Pogonip limestone, between it and the Hamburg shale Drawing the line in this way places the ore bodies of Ruby and Adam hills in the Cambrian, while those to the northward in the neighborhood of the Bullwhacker and Williamsburg mines are referred to the Silurian

GEOLOGY OF LEADVILLE, BY MR S F EMMONS

From the date of its organization the Geological Survey has been engaged in prosecuting investigations in economic geology, that is, in researches having in view questions of immediate and direct importance to the mining industries of the country All wisely conducted geologic investigations ultimately result in a practical benefit to mining and correlated industries The influence of general geology—that is, structural geology, with the aid of paleontology—is indirect, while that of mining geology is direct But mining geology is superficial and almost valueless unless it has a solid foundation in structural geology

The occurrence, magnitude, and value of all ore deposits are primarily related to geologic structure The laws of this relation are but partly known, as the science of mineral deposits is but imperfectly developed, but every year adds new facts, and geologists are gradually groping their way into the light of a clearer knowledge of the subject For this reason it is the policy of the Survey to conduct both lines of research in every special district it attempts to examine

The origin of ore deposits is a question involved in much obscurity Its study requires careful and accurate chemical and mineralogic work, and involves the expenditure of much time and money to obtain trustworthy results The information derived from actual excavations within the crust of the earth is of importance The student of general geology may often neglect these in safety, relying for the observation of his facts on the exposures of formations appearing in the escarpments of mountain gorges, hill sides, cañon walls, and banks of streams But for the investigation of the phenomena of ore deposits it is necessary to penetrate deeply below the present surface so as to study in detail the forms, characteristics, and relations of ore bodies beyond the disturbing and bewildering influence of surface alteration The study of a single group of mines which have been opened to a great depth affords more valuable information than many districts where workings have penetrated but a few feet below the surface

For the above reasons it is the plan of the Survey to make accurate and detailed monographs of single mining districts, selecting first the most important from an economic and geologic point of view

In pursuance of this policy Mr S F Emmons with a corps of assistants has been engaged in the study of the structural and mining geology of a small district of country about Leadville, Colorado

The problem presented at Leadville is one in which the form and extent of the ore deposits are unusually dependent on geologic structure Argentiferous lead ores are found impregnating a certain bed of dolomitic limestone of Carboniferous age, which is overlaid by intrusive sheets of porphyry of varying character and thickness These rich ores are contained in a matrix or gangue of iron, manganese, and clay, the whole forming a vein material which has to a greater or less degree replaced the limestone bed—in some places to such an extent that none of the original sediment remains

By the forces involved in the uplift of the Mosquito Range, in which these deposits are found, the whole sedimentary series, including the ore-bearing limestone, together with the intrusive sheets of igneous rock, have been folded, faulted, and shattered, and subsequent degradation, acting since the commencement of the Tertiary period, has laid bare irregular outcrops of the ore-bearing stratum These have again been largely covered by an accumulation of surface gravels during and subsequent to the Glacial period

In view of such complications of structure it is not surprising that varying and antagonistic views have been put forth by those who have studied different portions of the district without possessing a comprehensive view of the whole It has only been by a most laborious and painstaking investigation, aided by accurate and elaborate maps, that Mr Emmons and his assistants have been enabled to unravel this geologic tangle and present in a clear and consistent form the simple facts which underlie the whole

As a result of these labors, the material has been gathered for a monographic report on the Geology and Mining Industry of Leadville, and its preparation is now in progress Mr Emmons's paper in this volume gives an abstract of the report and presents the general geologic structure as well as may be without the aid of the numerous and detailed maps of the final atlas In it he has also given the conclusions he has been enabled to draw concerning the origin and the manner of formation of the ore deposits, and has pointed out their probable continuance in ground as yet unexplored The practical value of these indications to the mining community is evident at once There seems good reason for assuming that hitherto only a small proportion of the ore-bearing area has been developed, and that by a systematic and rational system of exploration, based on the data to be furnished by the maps and explanations of the report, the present output of the district may be kept up, and even increased, for many years to come

Mr Emmons's views of the origin and manner of formation of the deposits differ essentially from those generally held, but although novel, they are not simple theories. They are substantiated by facts and actual investigations which will be explained in full in his report. He concludes that the metallic minerals of the deposits were originally contained in the associated porphyries in a finely disseminated condition—only to be detected by the most delicate tests. Percolating waters gathered them, little by little, and deposited them in the limestone bed, dissolving out the limestone by chemical interchanges This took place before the movements which disturbed the beds, and the deposits were originally all sulphides Subsequently (by the agency of water from the surface) the sulphides were gradually changed to the carbonates, chlorides, and oxides now found in the mines. These are comparatively near the surface, and when those portions of the deposits which have been less exposed to the action of surface waters are reached the proportion of sulphides will be found to increase and the ores may become poorer in silver than those near the outcrops, where a sort of natural concentration process has been going on.

Whatever may be the judgment of the scientific world upon Mr. Emmons's theoretic deductions, his monograph will prove of great practical value for the future development of the metallic wealth of the Rocky Mountains, since the extent of this hitherto little studied class of deposits—of which Leadville may properly be considered the type region—is probably far greater than has heretofore been suspected, and a knowledge of their true character will greatly further their development.

Mr. Emmons's work will also be a valuable contribution to structural geology. The area surveyed presents a series of sedimentary formations and laccolitic igneous intrusions, the whole broken by faults and flexures into blocks which are tilted and twisted in diverse directions; and the general structure of the country in all its important details has been carefully studied and will be delineated in his report.

GEOLOGY OF THE COMSTOCK LODE, BY MR G. F. BECKER

The Comstock Lode is in every respect a remarkable occurrence. The fact of its enormous production is familiar, but it is not equally well known that its vertical workings are carried to a greater depth than any in the world except those of Przibram, in Bohemia. It also presents scientific problems of equal obscurity and interest, which have attracted great attention It would be a reproach to American geology to leave the character of so prominent a mining district unsettled, and the present investigation was undertaken in the hope that the additional facilities presented by the great extension of the mine workings during late years and by recent advances in science would permit a more satisfactory solution than has yet been reached.

Mr. Becker has reopened the discussion of propylite, a rock the existence of which as an independent species was asserted largely in consequence of its supposed occurrence in this locality, and aided by the use of the microscope as a field instrument, he has come to the conclusion that the rocks classed under this name in the Washoe District are merely decomposed forms of rock species previously known.

The Comstock mines show temperatures which are not known to exist in any other workings in the world. The heat has ordinarily been ascribed to volcanic action, but of late years has been attributed to kaolinization of feldspar. Observations and experiments have been made to test the question, and the results are not in favor of the kaolinization hypothesis. No rise of temperature could be clearly traced to this action, while the vertical and horizontal curves of heat-increment indicate that the source of heat is at a distance of more than two miles from the surface. It appears to have been transmitted to the surrounding rock bodies laterally from the walls of the lode. There is also strong evidence that this action was, and to a trifling extent still is, accompanied by the presence of the gases characteristic of the hot springs which attend volcanic eruptions, and Mr. Becker reaches the conclusion that the immediate neighborhood of the Comstock lode must be considered as a solfatara, now almost extinct

The rock forming the east wall of the lode was found, when fresh, to contain small quantities of the precious metals—quantities which are continually reduced by decomposition The facts accord well with the supposition that the ore was deposited by "lateral secretion" at or near the contact between the diorite (foot wall) and the diabase (hanging wall). It is on this contact that all the important ore bodies have been found, and the inference is unavoidable that the future discovery of remunerative ore elsewhere is most unlikely. This forms a practical guide of the utmost importance in the workings of the mines, for of late the yearly expenditure on the Comstock in prospecting where there was no chance of finding ore would suffice for the support of the Geological Survey for a decade. It is pointed out that explorations should be confined to the neighborhood of this contact, and the conditions under which masses of the remunerative ore, or bonanzas, are likely to be encountered, are considered.

The report also contains discussions of some physical questions of interest. Veins usually occur on faults, and Mr. Becker shows that where faulting is accompanied by horizontal compression the results can be mathematically discussed. He thus explains certain topographic features as the result of faulting.

At Mr. Becker's suggestion, and under his direction, Dr. Carl Barus has investigated the electric activity of ore bodies, both at the Comstock and at the lead-silver mines in Eureka. The results are interesting from a theoretic point of view, and afford hope that in certain classes of mines essential aid may be rendered in prospecting by an examination of the electric isopotentials.

Mr. Becker arrays a large body of facts in explanation of the relation of ore bodies to the containing formations; of facts relating to general structure produced by faulting; of facts relating to the metamorphism of the rocks and the paragenesis of minerals and ores; of facts relating to earth temperature and its laws of increment; of facts relating to electric phenomena; and of facts relating to the general structure of the mountain. The report will be an important contribution to mining and structural geology, and will play no small part in the establishment of sound theories respecting ore deposits and geologic dynamics.

STATISTICS OF IRON, COAL, &C., BY PROF. RAPHAEL PUMPELLY.

In the organization of the Survey a division in charge of Professor Pumpelly was entrusted with the gathering of statistics relating to the mines and mining of the non-precious metals, coal, and lesser mineral substances. Its work has consisted, first, in gathering statistics of mines and mining; second, in a special investigation of the iron ores of the United States, both in the field and in the laboratory; and third, in the study of the distribution and character of the copper-bearing rocks of Lake Superior.

The collection of the statistics was performed in co-operation with the Tenth Census, and involved the canvassing of 10,440 mining establishments. At each the inquiry was made to cover a wide range of topics, including capacity, production, value of product, subdivision of labor, capital, material consumed, cost, power, accidents and insurance, destination and adaptation of product; and the great majority of establishments were visited in person by agents of the joint organization.

The investigation of the iron ores involved the collection of commercial samples from most of the iron-ore deposits of the United States. These samples were taken to show the average chemical constitution of the product for the census year, and wherever it was important the separate portions of the deposit were sampled in order to show the bearings of the different portions upon the chemical character of the whole output. Each sample consists of several thousands of pieces, and weighs from ten to twenty pounds, and they number more than thirteen hundred. All these have been, or will be, analyzed, excepting those from Pennsylvania, for which state it has been decided to adopt the results of the State Geological Survey. The analyses are made for the most part to determine the amount of iron, phosphorus, and sulphur, but in every district the more important and typical are also being subjected to an exhaustive analysis. The results of this work will show not only the amount of ore produced in each district but also its quality and adaptation.

As this volume goes to press the compilation and digestion of the mining statistics have reached such a stage that Professor Pumpelly is enabled to report the most important totals. The following tables give the grand summaries for the non-precious metals, coal, and lesser mineral substances, for the year ending June 1, 1880. Table I presents the production and a variety of collateral data for the United States as a whole. Table II shows the amount and value of each mineral produced by each state.

TABLE I.—*Condensed Statement of Statistics of Regular Mining Establishments for the United States, by Substances.*

1880	Number of States and Territories	Number of counties	Number of establishments	Tons of 2,000 pounds produced during census year, 1880	Value of product	Value of materials consumed	Men employed
Bituminous coal	24	335	2,990	41,860,055	$52,427,868	$4,860,493	93,957
Anthracite coal	3	11	277	28,621,371	42,139,740	6,732,592	54,616
Iron ore	21	160	805	7,061,829	20,470,756	2,896,011	30,080
Copper ore	21	27	53	1,007,245	8,886,295	1,391,826	5,966
Lead and zinc ore	10	29	206	177,008	4,182,685	331,970	7,323
Minor minerals	21	107	189	.....	3,387,444	625,347	4,026
Total	..	669	4,520	.....	131,494,788	16,838,239	195,968

1880	Boys employed	Total hands employed	Wages paid annually	Number of steam engines	Horse-power of steam engines.	Value of all machinery, including engines	Capital employed and invested
Bituminous coal	6,159	100,116	$32,601 460	855	26,168	$2,668,861	$103,109,807
Anthracite coal	16,132	70,748	22,693,407	1,667	105,807	15,908,415	154,504,336
Iron ore	1,588	31,668	9,538,117	821	24,838	3,211,538	61,782,287
Copper ore	292	6,258	3,214,031	136	13,541	2,634,600	31,807,596
Lead and zinc ore	160	7,483	2,640,265	167	6,739	484,340	7,442,983
Minor minerals	176	4,202	1,305,222	86	4,958	.....	6,262,315
Total	24,507	220,475	71,992,502	3,732	182,051	24,907,754	364,909,324

TABLE II —*Quantities and values of mineral production, by States and Substances.*

State	Anthracite coal	Value	Bituminous coal	Value	Iron Ore	Value	Lead ore	Value
	Tons	*Dollars*	*Tons*	*Dollars*	*Tons*	*Dollars*	*Tons*	*Dollars*
Alabama			322,934	475,559	184,110	189,108		
Alaska Territory								
Arizona Territory								
Arkansas			14,778	33,535				
California			236,950	663,013				
Colorado			462,747	1,041,350				
Connecticut					35,018	147,799		
Delaware					2,726	6,553		
Georgia			154,644	231,605	72,705	120,692		
Idaho Territory								
Illinois			6,089,514	8,739,755			772	30,200
Indiana			1,449,496	2,143,093				
Iowa			1,442,333	2,473,155			384	19,172
Kansas			763,597	1,498,168			10,681	460,980
Kentucky			935,857	1,123,046	33,522	88,930		
Maine					6,000	9,000		
Maryland			2,227,844	2,584,455	57,940	118,050		
Massachusetts					62,637	226,130		
Michigan			100,800	224,500	1,834,712	6,034,648		
Missouri			543,990	1,037,100	386,197	1,674,875	28,315	1,478,571
Montana Territory			224	800				
Nebraska			200	750				
Nevada								
New Hampshire								
New Jersey					754,872	2,900,442		
New Mexico Ter'y								
New York					1,239,759	3,499,132		
North Carolina			350	400	3,276	5,102		
Ohio			5,932,853	7,629,488	198,835	448,000		
Oregon			43,205	97,810	6,972	4,669		
Pennsylvania	28,612,595	42,116,500	18,075,548	18,267,151	1,820,561	4,318,999		
Rhode Island	6,176	15,440						
South Carolina								
Tennessee			494,491	628,954	89,933	129,951	60	2,500
Texas								
Vermont					560	2,750		
Virginia	2,600	7,800	40,520	92,837	169,683	384,331	11,200	33,000
Washington Ter'y			145,015	389,046				
West Virginia			1,792,570	1,971,847	60,371	88,595		
Wisconsin					41,440	73,000	1,728	78,525
Wyoming Ter'y			589,595	1,080,451				
Total	28,621,371	42,139,740	41,860,055	52,427,868	7,061,829	20,470,756	53,140	2,102 948

TABLE II.—*Quantities and values of mineral production, by States and Substances.*—Cont'd.

State	Zinc ore	Value	Copper ingots	Value	Minor minerals	Value	Total	Total value
	Tons	*Dollars*	*Pounds*	*Dollars.*	*Tons*	*Dollars.*	*Tons*	*Dollars*
Alabama							507,044	664,667
Alaska Territory			3,933					
Arizona Territory			3,183,750					
Arkansas							14,778	33,535
California			720,000		2,597	19,948		682,961
Colorado			1,578					1,041,350
Connecticut							35,018	147,799
Delaware					14,510	163,310	17,236	169,863
Georgia			922			120,135		472,432
Idaho Territory			150,000					
Illinois	3,000	39,000				102,324		8,911,279
Indiana					7,599	22,291	1,457,095	2,165,384
Iowa							1,442,717	2,492,327
Kansas	7,248	477,693					781,526	2,436,841
Kentucky							969,379	1,211,976
Maine			102,500	18,040	1	2,000		29,040
Maryland	672	7,200	30,910			159,303		2,869,008
Massachusetts						101,970		328,100
Michigan			45,830,262	7,979,232		41,057		14,279,437
Missouri	34,344	599,373	230,717	25,730		13,196		4,828,845
Montana Territory			1,212,500					800
Nebraska							200	750
Nevada			134,730		50			
New Hampshire			34,050	5,993		112,550		118,543
New Jersey	39,381	451,070			33,828	40,270	828,081	3,391,782
New Mexico Ter'y			4,055					
New York						1,623,011		5,122,143
North Carolina			1,640,000	350,000		79,855		435,357
Ohio							6,131,688	8,077,488
Oregon							50,177	102,479
Pennsylvania	20,459	394,568	214,736	36,256		426,102		65,559,576
Rhode Island							6,176	15,440
South Carolina					7,427	27,709	7,427	27,709
Tennessee	3,699	22,145	153,880					783,550
Texas			5,084					
Vermont			2,647,894	469,495		48,788		521,033
Virginia	10,448	24,126	678			179,125		721,219
Washington Ter'y							145,015	389,046
West Virginia						4,500		2,064,942
Wisconsin	4,617	64,562	18,087	1,549		100,000		317,636
Wyoming Ter'y							589,595	1,080,451
Total	123,868	2,079,737	56,320,266	8,886,295		3,387,444		131,494,788

The returns of lead and zinc reduced to the metallic state in smelting establishments are as follows:

LEAD.

	Pounds.
Smelted from ores	66,970,838
Refined from base bullions, the principal value of which was silver	95,967,267
Total yield of metallic lead in census year	162,938,105

ZINC.

Metallic zinc or spelter	46,477,999
Zinc oxide produced in chemical works from ore 20,213,631 pounds, equivalent to metallic zinc	16,203,460
Total metallic zinc, census year	62,681,459

The grand total of the production of the non-precious metals—bringing together the regular industrial production, the irregular production, and the production as a bye-product in precious-metal mining—is as follows:

	Tons.	Value
Anthracite coal, regular product	28,621,371	$42,139,740
Anthracite coal, irregular product	28,441	56,938
Bituminous coal, regular product	41,860,055	52,427,868
Bituminous coal, irregular product	916,569	1,092,305
Total coal	71,426,436	95,716,851
Iron ore, regular product	7,061,829	20,470,756
Iron ore, irregular product	909,876	2,686,201
Total iron ore	7,971,705	23,156,957
Metallic copper	54,172,017	9,458,434
Metallic lead	162,938,105	7,935,140
Metallic zinc	62,681,459	4,240,006
Minor minerals		3,387,444
Total value of all non-precious mineral product		143,894,832

Three of Professor Pumpelly's assistants will publish extended reports on the investigations specially assigned them—Mr. Charles F. Johnson, jr., on the collation of the statistics, Mr. Andrew A. Blair on the analysis of iron ores, and Dr. R. D. Irving on the Lake Superior Copper Region.

Mr. Johnson's report will set forth in a comprehensive way the scope of the mining census so far as the non-precious metals, coal, and the minor economic minerals are concerned; will describe the methods employed in gathering the information, including the various checks to which the completeness and accuracy of the work were subjected; will place on record the methods of compilation employed, and will discuss a portion of the results.

Mr. Blair's report on the iron ores will consist chiefly of tabulated statements of the quantitative results of the analyses, but will contain also a description of the analyses themselves, explaining in great detail both the mechanical processes by which the various samples were treated preparatory to chemical analyses and the chemical processes employed to obtain quantitative results. The number of samples is so great that it is of the utmost importance not only that the methods of analysis are the best known to science, but that a full and permanent record be made of the actual processes; and minute descriptions of all the steps cannot fail to be of great service to science. As an incident to his work, Mr. Blair has made an elaborate investigation of the various methods in use for the determination of the percentage of phosphorous in iron ores, and his report will contain an historic and comparative discussion of the subject.

THE COPPER-BEARING ROCKS OF LAKE SUPERIOR, BY DR. R. D. IRVING.

The copper-bearing beds of Lake Superior have excited much interest and received an equal share of discussion. The diversity of opinion in regard to them, which has occasioned the discussion, is owing largely to two facts—first, that their exposures occur in a country densely wooded and but sparsely settled, so that the well-known localities are of limited extent; and, second, that no one geologist has obtained a personal acquaintance with all the known exposures. It is only recently that they have been extensively explored.

One of the latest contributions to our knowledge of them was made by Dr. R. D. Irving as a member of the Wisconsin Geological Survey, and he has devoted the past year, under the auspices of the United States Geological Survey, to an exploration intended to complement his knowledge and render possible a general discussion of the nature and distribution of the rocks. His field work is now practically complete, and his report, constituting one of the monographic series of the Sur vey, will shortly be ready for the printer.

It will embrace—a brief account of his own explorations and of the work and views of those who have preceded him; a chapter on the general nature and extent of the copper-bearing series; a chapter on the lithology of the series, including the tabulated results of a microscopic study of some 800 sections; a chapter on the general stratigraphy of the series; full descriptions of all local developments of the rocks throughout their whole extent; a discussion of their relations and the several associated formations; a discussion of the structure of the Lake Superior Basin; a brief description of the mode of occurrence of the copper, accompanied by general economic conclusions; and a summary of theoretic conclusions as to the origin and structural relations of the formation.

The geographic extent of the series, now for the first time known with an approach to completeness, will be given for the basin of Lake Superior proper, with an extension into the valley of the Upper Mississippi, embracing an area of about 41,000 square miles; and to this will be added a *résumé* of recent explorations in Canada.

The total rock thickness of the series is very great, amounting in some localities to upwards of 40,000 feet. Of this, 25,000 to 30,000 feet belong to a lower division, mainly made up of lava flows, with more or less interbedded detrital material, of which the characteristic beds are conglomerates; and the remainder to an upper division, which is wholly detrital or nearly so. The subordinate statigraphy of the lower division is from the nature of the case not constant; yet certain broad facts have been made out which obtain throughout the extent of the formation.

The fragments of which the conglomerates are composed are found by Dr. Irving to be of three types of acidic rocks, between which there are gradations These are: (1) A non-quartziferous porphyry; (2) A quartziferous porphyry; and (3) Certain granite-like rocks, including a syenite, a granitic prophyry, and a true granite. The origin of these pebbles has long been a matter of speculation, the common opinion being that they have been worn from rock masses included in the Huronian; but Dr. Irving finds their original beds in the copper series itself, of which they form a prominent feature, although subordinate to the basic rocks in quantity.

The porphyries, which are more abundant than the granitoid rocks, occur in great beds that are relatively thick and of small lateral extent as compared with those of the predominant basic rocks. The granitoid varieties appear chiefly in the form of veins. All are regarded by Dr. Irving as ancient rhyolites and trachytes, from the degradation of which the conglomerates of the series have resulted.

The basic rocks of the series are conspicuously of eruptive origin, and for the most part have originated as lava flows—that is, they were extravasated at the time of their formation upon the then existing surface of the country. Some of the more coarsely crystalline beds may be intrusive, but this does not appear probable. They range from 45 to 60 per cent in their silica content, and thus include kinds exhibiting intermediate acidity as well as true basic kinds. Indeed, microscopic study shows a complete gradation from the most basic to the most acid. Thus, in this region of ancient eruptions, as in modern volcanic regions, three kinds of eruptive materials—basic, intermediate, and acidic—present themselves. Here, however, the chronologic succession of intermediate, acidic, and basic, which has been made out for so many modern volcanic regions, is announced by Dr. Irving not to obtain He finds the most acid rocks occurring in veins traversing the most basic, and again in flows overlying them; while the basic rocks in turn overlie the acidic, and the intermediate varieties are scattered through the series.

One of the most important conclusions of the paper pertains to the general structure of the Lake Superior basin. Foster and Whitney first pointed out the synclinal-like appearance of the lake basin between Isle Royale and Keweenaw Point.

Twenty-five years afterwards Dr. Irving showed that this synclinal extends westward into northern Wisconsin, and later, in conjunction with Messrs. Sweet and Chamberlin of the Wisconsin Survey, described its position and shape in this region more fully. Now he is able to announce that the entire lake basin, including not only the western half but the eastern as well, is a great synclinal depression; that this depression certainly affects the copper-bearing rocks throughout their extent, except in the Neepigon Lake basin; that it as certainly affects in very large measure the underlying Huronian; that the axis of this depression has, like that of the lake itself, at first a northeasterly direction and then a southeasterly, with minor bends corresponding to the several bends of the axis of the lake; that the eastern termination of the depression is buried beneath the newer formations in the vicinity of the Sault Sainte Marie; that its western extension passes on to the south shore of the lake with a course curving more and more to the southward, until at the western termination in the Saint Croix Valley it lies nearly north and south; that in the regions of the Porcupine Mountains, and of the "Copper Range" of Douglas County, Wisconsin, there are minor folds superinduced upon the great synclinal; and that in both of these regions, as also on the south side of the Keweenaw Point Range, there are further complications due to faulting.

Dr Irving's discussion of the chronologic position of the copper-bearing series is full, and his principal conclusions are definite. The series is older than the Cambrian and younger than the Huronian—the separation from the former being by an intervening disturbance and erosion, and from the latter by an intervening erosion and possibly also by an intervening folding and alteration.

PRECIOUS-METAL STATISTICS, BY MR. CLARENCE KING.

In this work, which properly comes within the province of the Geological Survey, but which forms a special branch and should be conducted by a distinct corps of assistants, Mr.

King was enabled to lay a broad foundation by assuming charge, at the request of the Superintendent of Census, of the precious-metal statistics for the Tenth Census The direct supervision of this work in the district west of the 100th meridian, where the greater portion of the precious metals are produced, was assumed by Messrs. Emmons and Becker in their respective divisions. The scope of the investigation is not limited to the quantity of production of the metals, but involves also all the technic questions connected with mining and the reduction of ores; and in the same connection a large body of geologic data has been gathered. Probably never has so elaborate a series of technic data been obtained in regard even to special mining districts as is now in the possession of the Survey with regard to the mining industry of the whole country.

The work of compilation and tabulation is now progressing rapidly under the efficient management of Mr. A. Williams, jr. As a specimen of the character of the results, an abstract is given in this volume of the "Production of the Precious Metals in the United States for the year ending May 31, 1880."*

An examination of the table shows that while the Com stock Lode, the great producer of the country, has a greatly decreased output, this loss is compensated by a corresponding increase in other districts, notably the Leadville of Colorado. As a whole, the mining industry of the country is in a healthy state, and the product of the precious metals in the future promises to show a regular and permanent increase.

The paper in this volume on the production of the precious metals in the United States gives in brief the results of the first systematic attempt to procure, synthetically, from the actual producers, complete statistics of the bullion yield of the country. It is published in advance of the forthcoming technic report upon the mining industry, which will embrace the investigations conducted in that field by the United States Geological Survey, consisting of examinations of 1,967 deep mines, 325 placer mines, 327 amalgamating mills, concentration works, chlorination and leaching establishments, etc., 86 smelting works, and 25 arrastras.

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* Published as a Census Bulletin

This final report will contain a discussion of the distribution and exploitation of the precious-metal mines, with the topographic and geologic questions involved; machinery and appliances; accidents; the various mechanic and metallurgic processes involved in the reduction of ores; and an inquiry into the relations of capital, labor, power, supplies, and transportation, in mining, based upon the abundant data already collected and now in process of compilation.

The output for the year ending May 31, 1880, was $33,379,-663 gold and $41,110,957 silver, a total of $74,490,620 (coining value). Although these figures are somewhat less than those reached in three or four exceptional years, they represent a yield considerably higher than the average annual product; while the outlook for the future is most encouraging. From the beginning of mining operations in 1804 up to the above date, over a billion and a half of gold, and nearly half a billion of silver were produced. The vast importance of this element of the national resources is shown by the fact that one-third of the gold and one-half of the silver yearly produced in the world are mined within our borders.

The leading mining States are Colorado, California, and Nevada, followed by the Territories of Utah, Montana, Dakota, Arizona, and Idaho, in the order named. The proportionate amounts of gold and of silver furnished by each vary greatly. Thus, while Colorado produces 40 per cent of all the silver of the United States, she yields but 8 per cent of the gold. California, on the other hand, the source of over half of the gold, yields less than 3 per cent of the silver. A similar divergence is observed in other portions of the mining region; the two precious metals occurring side by side, but often in widely disproportionate quantities.

The study of the relation of production to population develops some curious figures, ranging from an average of one mill per capita in Alabama to $278.14 per capita in Nevada, the intervening series indicating with great precision to what extent mining is a factor of wealth in the several localities

The product per square mile varies from one cent in the case of Alaska to $185.20 in that of Colorado, the intermediate averages forming another standard of developed richness in the precious metals, from a different point of view, but roughly corresponding to that of the relation of production to population.

An examination of the tenor of placer gold has resulted in fixing the average fineness for the United States at .876; and it is found that the placers produce over $100,000 of silver annually, in alloy with the gold—an item hitherto disregarded by statisticians.

Carefully prepared conversion tables of fine metal by weight into its equivalent in money, and conversely from dollars to ounces, are appended in view of their utility to metallurgists and others. A series of graphic charts is also added, illustrating some of the more striking comparisons and deductions reached in the statistic compilation.

During the fiscal year, Mr. W. R. Eckart, with a number of assistants, has been engaged in preparing a monograph on the mechanic appliances used in mining and milling on the Comstock Lode. When his work is completed it will be found of much practical value to all persons engaged in exploiting deep mines.

HISTORY OF THE COMSTOCK LODE, BY MR. ELIOT LORD.

The bodies of ore found in the Comstock Lode have led to the development of a group of mines of greater magnitude, importance, and interest than any other known in history. The value of the product, the depth to which the mines have been worked, the internal heat discovered, the geologic relations of the ore bodies, and the machinery developed under the stimulus of enormous profits, render the study of the lode one of prime importance to political economists. In addition to the monographs previously referred to, another by Mr. Eliot Lord is in course of preparation, having for its theme the history of the discovery and exploitation of these mines, the growth of the industries resulting therefrom, and the development of mining law to which these industries gave rise.

This history is the story of the birth of the silver-mining industry in this country and the record of a struggle which has materially affected the mining interests of the world. Its scenes present the toil of placer miners in an isolated cañon, the search of prospectors for silver, the chance discovery of the greatest lode ever cut by a miner's pick, the odd immigration called tersely "the rush to Washoe," the original method of locating and recording mining claims under crudely drawn and inapplicable mining laws, the extraordinary litigation arising therefrom, the anarchic condition of a turbulent mining camp and its ultimate crystallization into a thriving city.

In the prosecution of his study Mr. Lord has not only availed himself of the copious documentary data contained in the principal libraries of California and Nevada, but has taken great pains to familiarize himself with all modern phases of the local mining industry and mining life, and has been enabled to draw a large share of his material from the very individuals by whom were enacted the eventful history he records. It is believed that his work will be accepted as a trustworthy contribution to the history of the growth of the mining industry of this country.

NEW METHOD OF HYPSOMETRY, BY MR. G. K. GILBERT.

Mr. Gilbert's paper on the measurement of heights by means of the barometer is the only contribution to this volume which is not the *avant courier* of a more extended memoir.

Not only the present Geological Survey but its predecessors in the same field have been compelled to make maps for their own use, and in this way have come to perform an amount of geographic work which has proved even more expensive than the geologic investigations to which it is accessory. Although a geologist by profession, Mr. Gilbert has been called upon from time to time, and especially as a member of the Survey of the Rocky Mountain Region, to conduct geographic work, and this paper is the embodiment of the results of a series of investigations initiated in connection with those duties.

The new method of hypsometry which he develops is so simple and direct that it appears strange its discovery should have been so long delayed. Up to the present time it has been put in practice in a single instance only, but in the future work of the Geological Survey it will be adopted.

In the measurement of heights by means of the barometer that instrument is used simply as a scale for the weighing of the atmosphere, or rather for ascertaining the pressure imposed by the air. Two barometers are always employed, one being placed at a point at which the height is known and the other at a point whose altitude is desired. Each tells the weight of the superimposed atmospheric column, and the difference between these two measurements gives the weight of the differential column or of the column of air extending from the lower station up to the level of the higher. Knowing the weight of the differential column, it would be a simple matter to compute its height if its density were known. But the density of the air is not uniform and its variability depends upon a number of conditions, chief among which are its temperature and the amount of moisture it contains In all the earlier practice it has been the custom to investigate its density by means of observations of its temperature and of the percentage of aqueous vapor, but the results have never been satisfactory.

In the method proposed by Mr. Gilbert three barometers are used instead of two, and two of these are placed at points whose heights are known, the third being read at the point to be determined. From the reading of the two barometers at the points of known height the weight of the intervening air column is deduced; and both the weight and height of the column being known, its density is computable. The density thus derived is then used in the computation of the height of a second column of air contained between one of the known points and the point to be determined.

To those who are familiar with hypsometric computations this direct method commends itself at once as preferable on theoretic grounds to the indirect methods it proposes to supersede. But Mr. Gilbert has not contented himself with a mere *a priori* presentation. He has submitted his method to a series of rigorous tests, comparing it by an extended series of competitive computations with the best hypsometric methods in use, and the result leaves no room to doubt that he has made an important and immediately practical contribution to geographic science.

In the course of his investigations he has incidentally made a discovery which appears to be of some moment in meteorology, as well as in hypsometry. In discussing a series of barometric observations made upon Mount Washington he detected some anomalous fluctuations of the barometer, which he was enabled finally to trace to the influence of the wind upon the tension of the air in the observatory, and this influence was found to be so great during the prevalence of gales as utterly to vitiate the record of the barometer.

He has not carried his inquiry so far as to ascertain the best means of eliminating the errors thus caused; but the nature of the difficulty having been pointed out, the invention and application of remedial appliances will certainly follow, and eventually the accuracy of barometric observations will be materially enhanced.

PLAN OF PUBLICATION.

The great and elaborate investigations forming the basis of the monographs thus described were planned and prosecuted under the direction of Mr King, and in justice to him his name will appear on the publications as Director of the Survey. Only the publication of the material will belong to the administration of the present Director, and his responsibility covers merely the form in which the work is presented to the public.

In providing for the publication of this large body of material, it seemed wise to adopt a common system of general nomenclature, a uniform color scheme for geographic geology, a system of conventional characters for diagrams, and a form for geologic and topographic charts and atlases. After a survey of the field with such thoroughness as time would permit, the conclusions presented below were reached.

On the 26th of September next a congress of the geologists of the world will assemble at Bologna, Italy, to confer on this subject. It is unfortunate that advantage cannot be taken of the deliberations of so great a body of savants in the publication of these monographs, but the exigencies of the work will not permit of longer delay even for so important a purpose. The following remarks on this subject will be transmitted to that body:

GENERAL CONSIDERATIONS.

The literature of geology has grown to large proportions. To obtain a detailed and comprehensive knowledge of the reported facts and the discussions based thereon is a task of magnitude. In territories governed by civilized nations geologic research is actively prosecuted, and geologists are penetrating the lands inhabited by savage and barbaric tribes; and thus a large body of men are engaged in geologic investigations. From year to year more refined methods of study are introduced, and new classes of facts are discovered; and the old fields are ever becoming new fields for examination.

So the literature, already great, is rapidly increasing, and its prospective magnitude is such as to demand of geologists the adoption of all methods and devices that will secure economy of time and thought to scholars and students.

The adoption of a nomenclature is to an important extent an attempt to establish the categories of classification; but every stage in the progress of knowledge is marked by a stage in the progress of classification, and any attempt to fix permanently the categories for a nascent science must be futile. In so far, then, as proposed uniform methods of nomenclature and representation are designed to establish the fundamental categories, no good can be accomplished. On the other hand, useful results can be obtained by the employment of a uniform nomenclature and system of representation in the presentation of like facts. From time to time new classifications will be advanced, and new terms for more refined distinctions must be multiplied *pari passu* with the growth of the science, but diverse terms for the same classes and distinctions should be eradicated. A multiplication of means for like purposes in the presentation of scientific subjects is a characteristic of low development, in the same manner as is the multiplication of organs for like purposes in a living being. Economy of time and thought is the goal to be attained.

In the United States Geological Survey a few rules have been adopted relating to general geologic nomenclature, cartography, and diagrams. This has been done after a somewhat careful consideration of the history and present status of the science in America, and under guidance of the principles enunciated above. These rules and the more immediate reasons for their adoption will be briefly set forth.

GENERAL NOMENCLATURE.

The publication in 1862 of Dana's Manual of Geology was an important epoch in the progress of this science in America. Its effect was more thoroughly to organize and correlate the work of many men scattered widely over a territory stretching from the Atlantic to the Pacific. This was accomplished by a masterly presentation of the known facts of American geology and by seizing upon the best methods of presentation developed by the leading geologists of the country.

In respect to the nomenclature of geologic formations, or the succession of groups of strata and beds recognized by American geologists, a general scheme was given, based upon American practice, which has been widely accepted. In a later text-book by Mr. Le Conte, Mr. Dana's system of nomenclature has been substantially followed.

The formulation of American practices by Mr. Dana and its subsequent acceptance by Mr. Le Conte, and the profound impression thus made upon all recent geologic publication, lead to the conclusion that no material change in this branch of geologic nomenclature can safely be made in this country.

The grand divisions recognized by these authors are as follows:

Dana.	Le Conte.
V. Era of Mind.	5. Psychozoic.
IV. Cenozoic.	4. Cenozoic.
III. Mesozoic.	3. Mesozoic.
II. Paleozoic.	2. Paleozoic.
I. Azoic.	1. Archæan.

In a later edition Mr. Dana has dropped the fifth grand division—Era of Mind—and changed the name of the first to Archæan, of which title he was the author.

The grand divisions are called Times by Dana and Eras by Le Conte. For use in biologic discussion these authors divide the Eras into Ages as follows:

Dana.	Le Conte.
The Age of Man, or Quaternary.	Age of Man.
The Age of Mammals, or Tertiary.	Age of Mammals.
The Age of Reptiles.	Age of Reptiles.
The Age of Coal-plants, or Carboniferous.	Age of Acrogens.
The Age of Fishes, or Devonian.	Age of Fishes.
The Age of Invertebrates, or Silurian.	Age of Invertebrates.
Eozoic Age.	Archæan.
Azoic Age.	

These divisions perhaps fairly represent the present stage of knowledge of the biologic record contained in the rocks; but the subject must for a long time be held open for revision.

By both of these authors the Times or Eras are again divided into Periods, and, by Dana, the Periods into Epochs and Subepochs. The Periods of Mr. Le Conte are modifications of those of Mr. Dana and represent American opinion at a somewhat later date

The following are the general schemes of Ages and Periods presented by these authors:

DANA.

Age of Man, or Quaternary.		
Mammalian Age.		Tertiary Period.
Reptilian Age.	Cretaceous.	
	Jurassic.	Wealden (Epoch).
		Oölitic (Epoch).
		Liassic (Epoch).
	Triassic.	
Carboniferous Age.		Permian.
		Carboniferous.
		Sub-carboniferous.
Devonian Age, or Age of Fishes.		Catskill.
		Chemung.
		Hamilton
		Corniferous.
Silurian Age, or Age of Invertebrates.	Upper Silurian	Oriskany.
		Lower Helderberg.
		Salina.
		Niagara.
	Lower Silurian.	Trenton.
		Canadian.
		Primordial, or Cambrian.

LE CONTE.

Psychozoic ..	Recent.
Cenozoic ..	Quaternary.
	Pliocene.
	Miocene
	Eocene.
Mesozoic ..	Cretaceous.
	Jurassic
	Triassic
Paleozoic ..	Permian.
	Carboniferous.
	Devonian.
	Silurian.
Archæan ..	Huronian.
	Laurentian.

To the extent thus indicated, American practice in the partition of the succession of strata and beds has arrived at substantial uniformity, though there are minor departures from the plan.

In respect to the subdivision of periods, practice in America is widely divergent. No clear differentiation is made between *epochs* and *subepochs;* many working geologists employ the term *formation* for any division of the period; and the epochs of one district are not recognized in the other districts. The refined correlations which this recognition postulates cannot in the present state of our knowledge be made throughout an area so vast as America presents to the explorer.

In the survey of New York by Mr. Hall the first great series of American formations was demonstrated. In subsequent surveys of other States and regions attempts have been made to correlate the formations of the areas surveyed with those of New York, but these attempts have not generally been successful; and the assumption that such correlation should be made has led to unnecessary and unseemly controversy, which finally has resulted in its virtual abandonment.

In various districts various schemes of formations are made for the better presentation of the facts discovered in each. Hence there is a number of inchoate series of names for geologic formations, each representing a special district. To a large extent these local names of formations are geographic in origin, but sometimes they are lithologic or biologic. This state of affairs has obtained in opposition to received opinions, and in spite of the almost universal efforts of geologists to attain uniformity; *it therefore represents the logical and necessary growth of the science.*

In passing from district to district it is found in practice that a typical series will never be reproduced, but new series with new structural, lithologic, and biologic characteristics will be discovered; and these facts should be represented in the nomenclature.

Such being the state of affairs in the districts most thoroughly studied, it seems especially unwise for the exploring geologist to commit himself in early stages of investigation to refined and exact correlations, and in practice it is found that a great number of local names are used tentatively until further research demonstrates approximate identity or establishes diversity. Thus the names of formations are ultimately fixed by a process of selection.

In America the terms ERA and PERIOD have a well-defined significance with which they are widely used. In like manner the terms for the several Eras and Periods are fixed by wide usage, and the terms for the several Ages used from the biologic standpoint are nearly as well determined by common consent. Era is sometimes, and Time is frequently, used for other purposes than the designation of a grand division. System is generally used for the series of formations included in an Era, but sometimes for the series embraced in an Age. Epoch and Subepoch are not clearly differentiated. Epoch, Formation, and Group are used synonymously, but sometimes Group is used to include the series of formations of a Period, and sometimes Formation is used as synonymous with Series. The restricted use of Formation is common among working geologists, which testifies to its value for this purpose. In structural geology it is the grand unit. In detailed geologic cartography each Formation is represented by a distinct color. It is also the principal element in the discussion of physical geography from a geologic standpoint; *i. e.*, the origin of land forms—a study which in America is assuming important proportions. The term for this purpose is felicitous.

Perhaps it would be well if Era, Period, and Epoch could be used in speaking from the standpoint of history, and System, Group, and Formation as their synonyms, severally, from the standpoint of structural geology; Time to be used as a general historic, Series as a general structural term.

Concerning the classifications and terms used from the biologic standpoint the writer does not venture an opinion. To a large extent in American usage the historic and structural classifications and terms are used, but to some extent the paleontologists are departing therefrom by suggesting classifications adapted each to the department of biology represented. In certain fields vertebrate paleontology, invertebrate paleontology, and paleobotany, ask for classifications distinct from each other, and distinct from that recognized by geologists as expressing the facts of structure. Perhaps the biologists may come to use the distinctions adopted by geologists.

Throughout the regions where exploration has been conducted with some care, the periods as adopted by the Survey can usually be discriminated, but instances are not wanting where up to the present time such discriminations have been impossible. Perhaps, on the one hand, examination has not been thorough, or, on the other, planes of demarkation are not exhibited in nature.

Accepting the conditions actually imposed by the facts, a number of schemes of formations into which periods are divided will ultimately be recognized in this country, and it should be the endeavor of geologists to reduce this number to a minimum. The result attained will have the effect of dividing the areas occupied by formations of the several periods into districts for each, and each such district will have a distinct series of formations. It will sometimes be difficult to draw hard and fast lines between such districts, but when this has been accomplished as best it may be, the facts will be classified in a manner most valuable for the purposes of the science.

The following is the general scheme adopted by the United States Geological Survey:

Era or System.	*Period or Group.*	Epoch or Formation.
Era of Man..........	Quaternary	To be formulated in various districts as the facts demand.
Cenozoic or Tertiary	Pliocene.............	
	Miocene	
	Eocene	
Mesozoic	Cretaceous	
	Jurassic	
	Triassic	
Paleozoic	Permian	
	Carboniferous	
	Devonian	
	Silurian	
	Cambrian	
Archæan	Huronian ?	
	Laurentian ?	

COLORS FOR GEOLOGIC CARTOGRAPHY.

In this department American practice has been extremely diverse, but of late years there is a growing tendency to unification. A review of the field has led to the adoption of a scheme of colors controlled by the following principles:

1. The scheme should represent common usage as far as possible.

2. The scheme should not commit the geologist to distinctions and correlations not warranted by the facts at his command.

3. The colors should be so distinct as to be easily determined on the charts.

4. The desired results should be secured with the greatest economy in color printing.

5. The needs of the various portions of the country for distinctions necessary to represent the formations recognized therein by geologists should be subserved; and the several portions of the color scale should be equitably divided.

It may be well further to explain and illustrate the distribution of the color scale to the parts of the geologic column.

The geologists of America require in the representation of the Quaternary a large number of distinctions, as will appear from a brief enumeration of the formations already recognized.

First. In the far West, between the Rocky Mountains and the Sierra Nevada, is the area known as the Great Basin. Within this region and still southward and eastward many great lakes existed in early Quaternary times, represented at present, to some extent, by small undrained seas; a number of distinctions are required to represent the formations of these almost extinct lakes.

Second. In the eastern prairie region, especially in northern Illinois, Indiana, Wisconsin, and Minnesota, in later Quaternary times, many thousands of small lakes existed. Some of these have continued to the present time. The lake beds are ofttimes bogs, underlaid by marls compounded of lacustrine shells. In the bogs the remains of mammals are found. In New England the deposits of a great number of similar lakes are discovered, and they are scattered at intervals throughout the United States. These formations, when more thoroughly studied, will require color distinctions on the charts.

Third. The great body of glacial drift stretching from the Atlantic far into Dakota, and extending southward into the middle latitudes of the country, requires its color distinctions; and the glacial formations of the mountain districts farther to the south and west have like requirements.

Fourth. The marine formations added to our coast in Quaternary times on the east, south, and west, must be represented.

Fifth. The lake formations of the same age on the north require representation.

Sixth. The extensive accumulations of loess in the bluffs of the Mississippi and its tributaries must be represented.

Seventh. The flood-plain formations of the river systems of the country must be delineated.

Eighth. The overplacements and alluvial cone deposits on the flanks of mountain chains must not be neglected.

These Quaternary formations have already been the subject of extended research, and in the future it is probable that a proportionately greater amount of study will be given them, from the fact that the methods of geologic research and the laws of the science must to a large extent be established by the aid of the facts they present.

The grays, which have been selected to represent these formations, admit of many distinctive modifications in tint, tone, and arrangement.

In like manner it can be shown that the variations of yellow are needed for the formations of the Cenozoic; of green for the Mesozoic; of blue for the Permian and Carboniferous of the Paleozoic; and of purple for the Devonian, Silurian, and Cambrian, of the Paleozoic.

Refined distinctions are not yet made in the Archæan, but it is probable that when these rocks are more thoroughly studied the various distinctions afforded by the browns will be needed.

In the Igneous rocks the entire capacity of the reds will be required. It is hoped that a somewhat more thorough distribution of them will result from investigations now in progress.

Thus it is believed that the distribution of the colors has been made in proportions as nearly correct as the present state of our knowledge will permit.

The assignment of portions of the color scale to portions of the geologic column, as indicated above, is deemed sufficiently minute for the purposes to be subserved in a certain class of publications, viz, charts of limited areas where many minor distinctions are made; but for charts of larger areas, where many periods are represented, more specific rules should be observed.

In the general plan the colors have been arbitrarily classified as gray, yellow, green, blue, purple, red, and brown.

Of gray, yellow, green, purple, red, and brown three tones each are selected; of blue, two tones only. Of each tone two tints are selected—one dark, the other light. Further distinctions are made by using the light tints as bases and the dark tints as overprints in various mechanic arrangements, as follows:

1. In horizontal lines.
2. In vertical lines.
3. In right-oblique lines. (Lines directed downward from left to right are called "right-oblique lines.")
4. In left-oblique lines.
5. In broken horizontal lines.
6. In broken vertical lines.
7. In crossed lines.
8. In dots.

The color distinctions thus produced are relegated to the geologic column in the following manner:

Quaternary formations are represented by grays, and thirty color distinctions are provided, as shown in Plate I. It is not deemed wise at present to distribute the grays definitively to the several classes of Quaternary formations, as further experience is needed.

The Cenozoic is represented by yellow (Plate II) in three tones—one for each period—Pliocene, Miocene, and Eocene.

Each tone with its modifications by tints and combinations gives ten color distinctions; so that there are that number of distinctions for each period.

Mesozoic formations are colored in green (Plate III), and in the manner above described ten color distinctions are used for the Cretaceous, Jurassic, and Triassic periods each.

The Permian and Carboniferous periods, constituting the upper Paleozoic, are represented by blue (Plate IV)—one tone with ten distinctions for each.

The Devonian, Silurian, and Cambrian periods, constituting the Lower Paleozoic, are represented by purple (Plate V) in three tones—one for each period, with tints and combinations—making ten distinctions for each.

Archæan rocks are represented by brown (Plate VI) with three tones multiplied by tints and combinations—producing in all thirty distinctions.

The Igneous rocks are represented by red (Plate VII) with thirty color distinctions.

It is manifest that these distinctions may be multiplied to any desired extent without confusion—

First. By using each base tint with each superimposed tint (of the same color division) throughout the entire scale of lines and dots;

Second. By multiplying the mechanic arrangement of lines, dots, &c ;

Third. By multiplying the tints and tones; and

Fourth. By combining the colors as classified—using one as a base and a second as an arranged overprint.

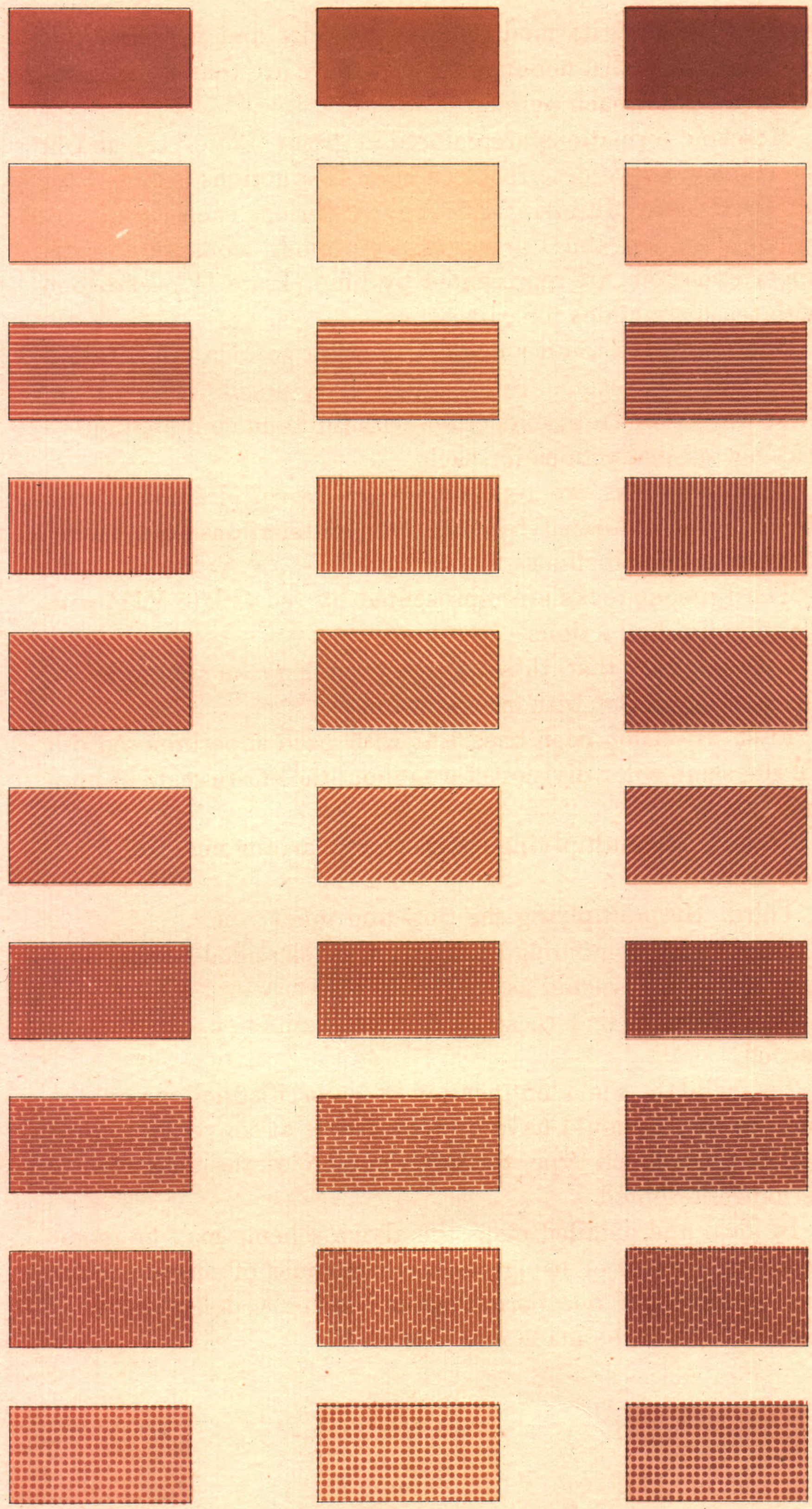
It is probable that these additional distinctions will not be needed.

To facilitate the identification of color distinctions on the map, each one should have printed over it at convenient intervals, in clear block type, the letter symbol of the formation or period represented.

In local and detailed maps the above scheme may be modified to the extent of using the several tones of one color for the formations of one period, whenever by so doing the color distinctions will be made more clear.

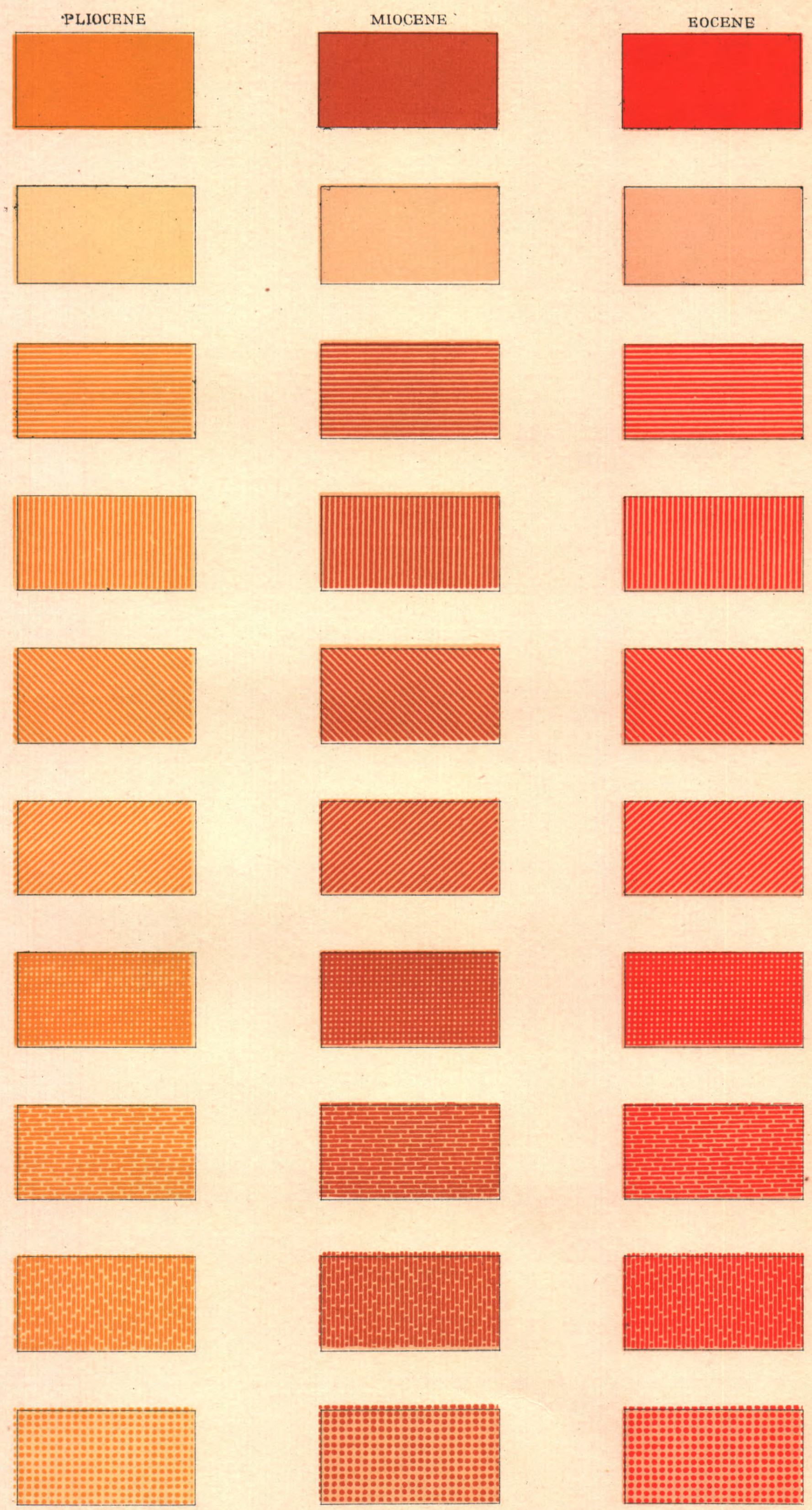
SCHEME OF COLORS ADOPTED FOR THE CHARTS OF THE U.S. GEOLOGICAL SURVEY.

ERA OF MAN
QUATERNARY.



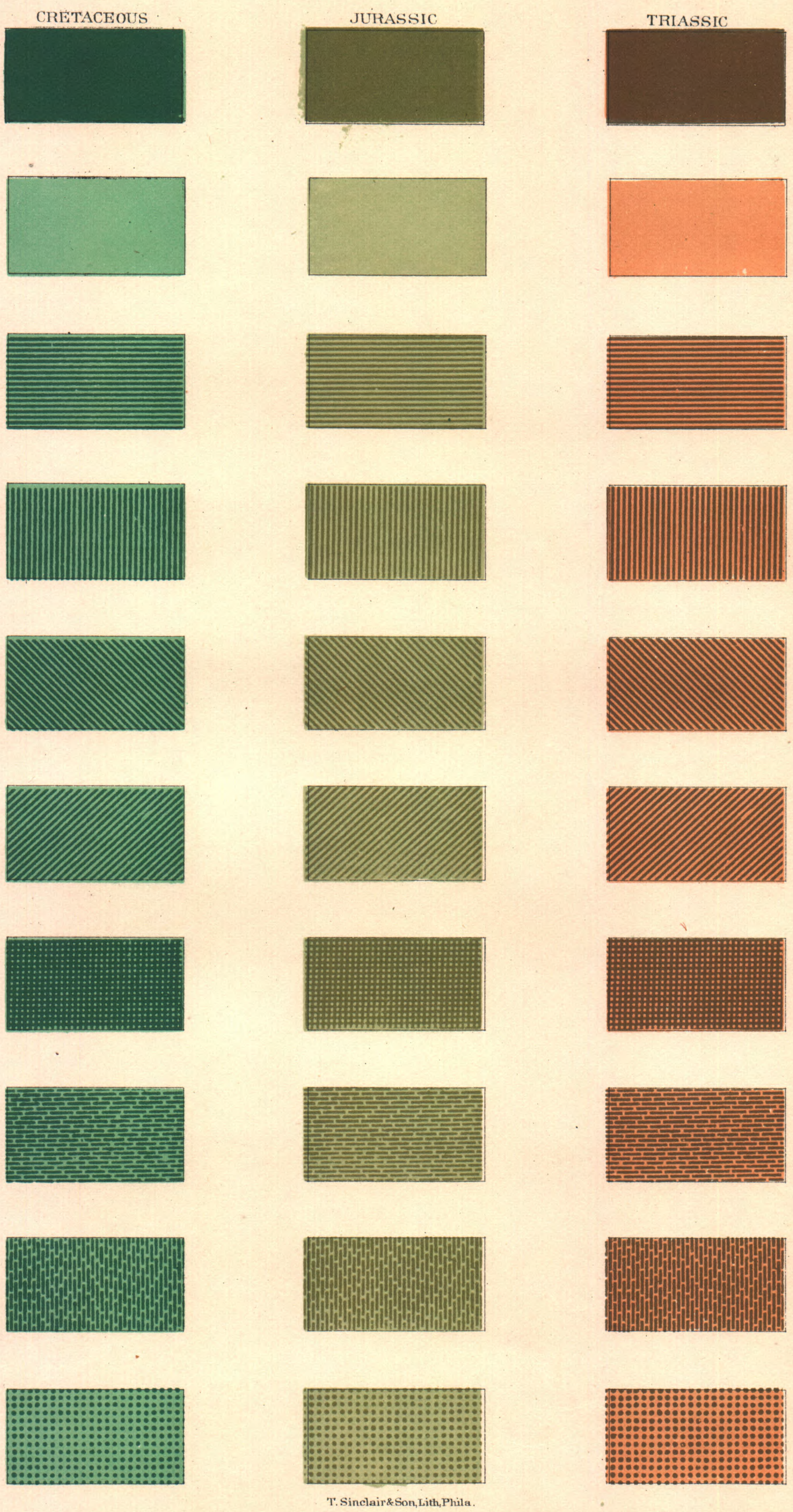
T. Sinclair & Son, Lith, Phila.

CENOZOIC.



T. Sinclair & Son, Lith, Phila.

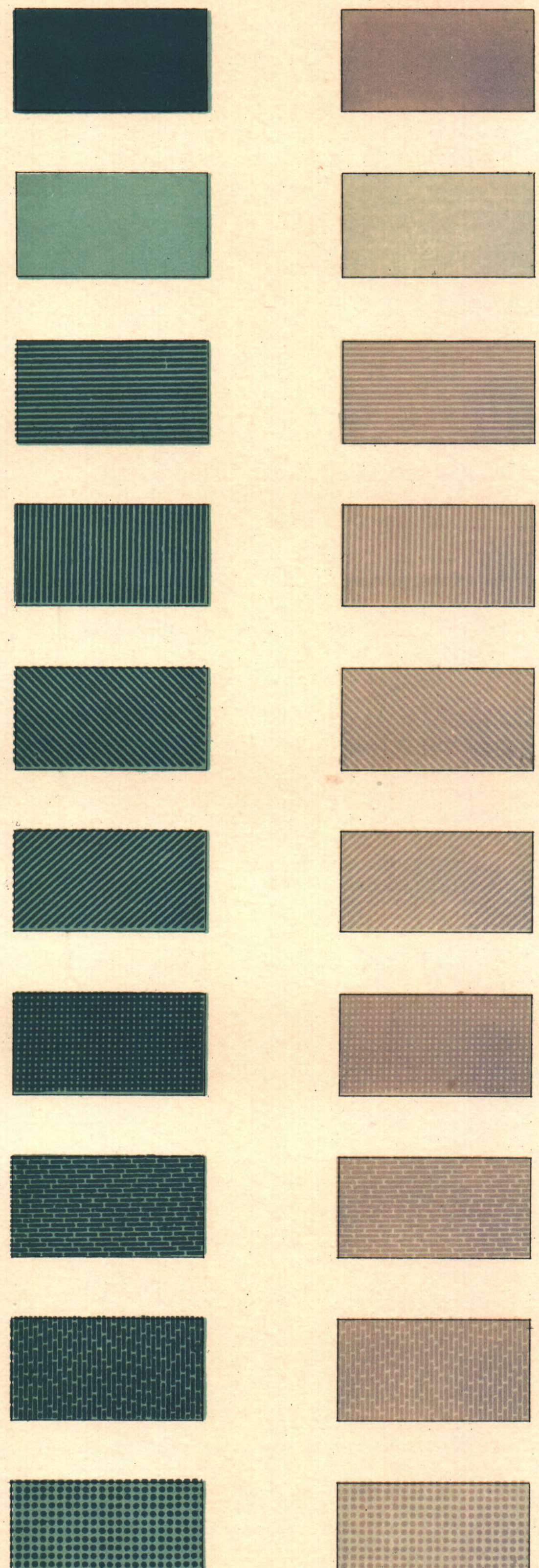
MESOZOIC.



T. Sinclair & Son, Lith, Phila.

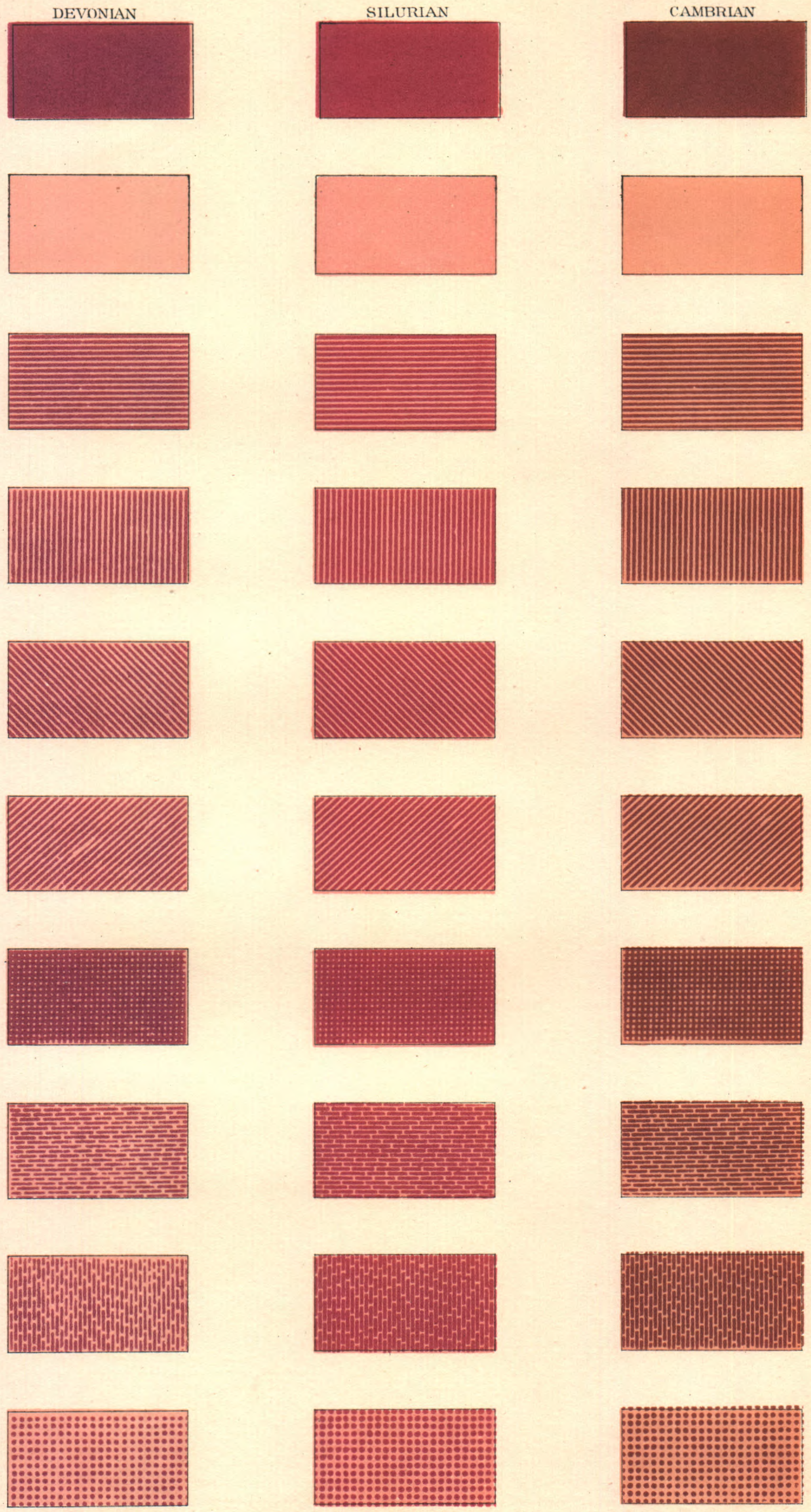
PALEOZOIC.
(UPPER PALEOZOIC)

PERMIAN. CARBONIFEROUS



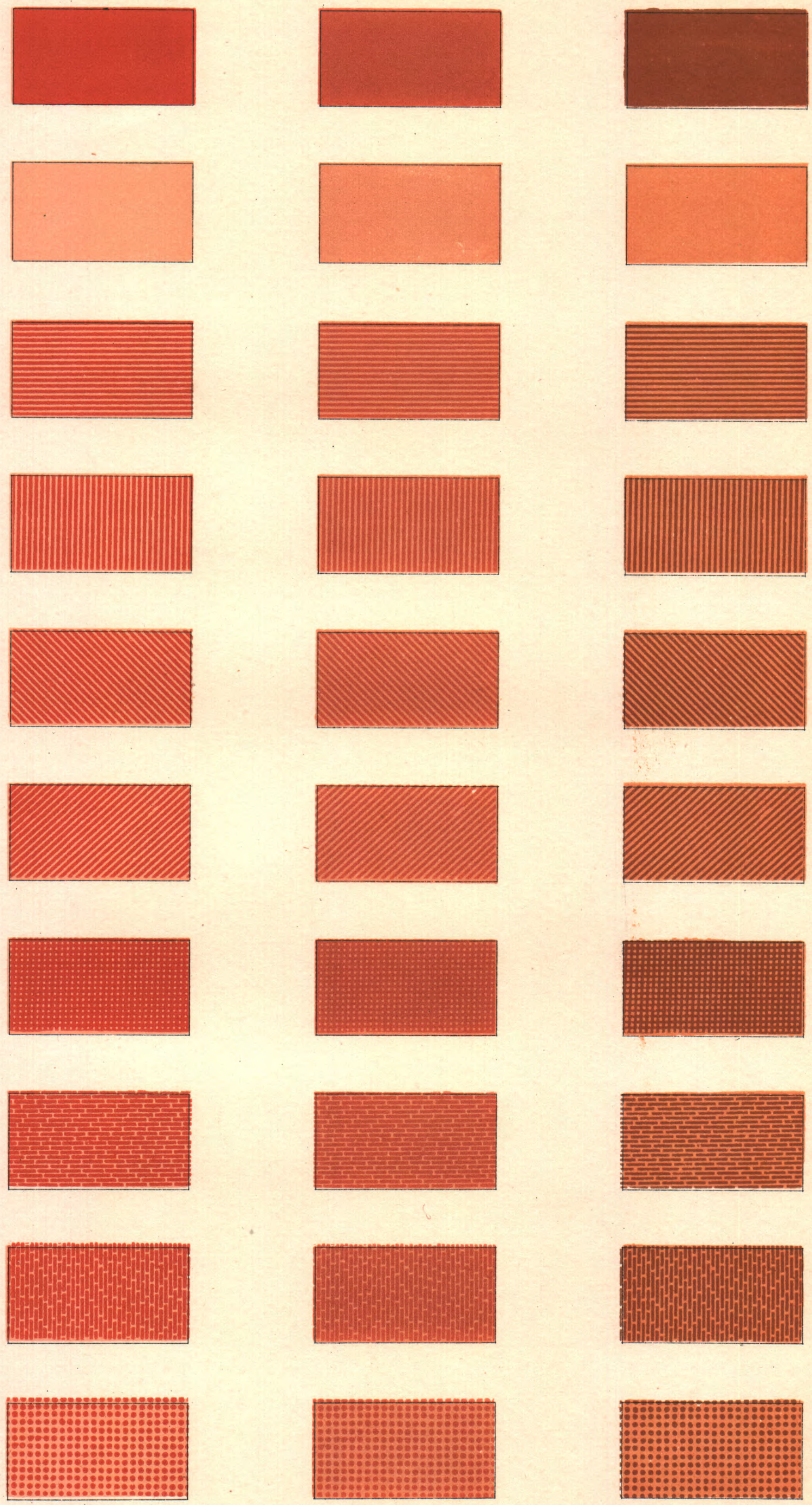
T. Sinclair & Son, Lith, Phila.

PALEOZOIC.
(LOWER PALEOZOIC)



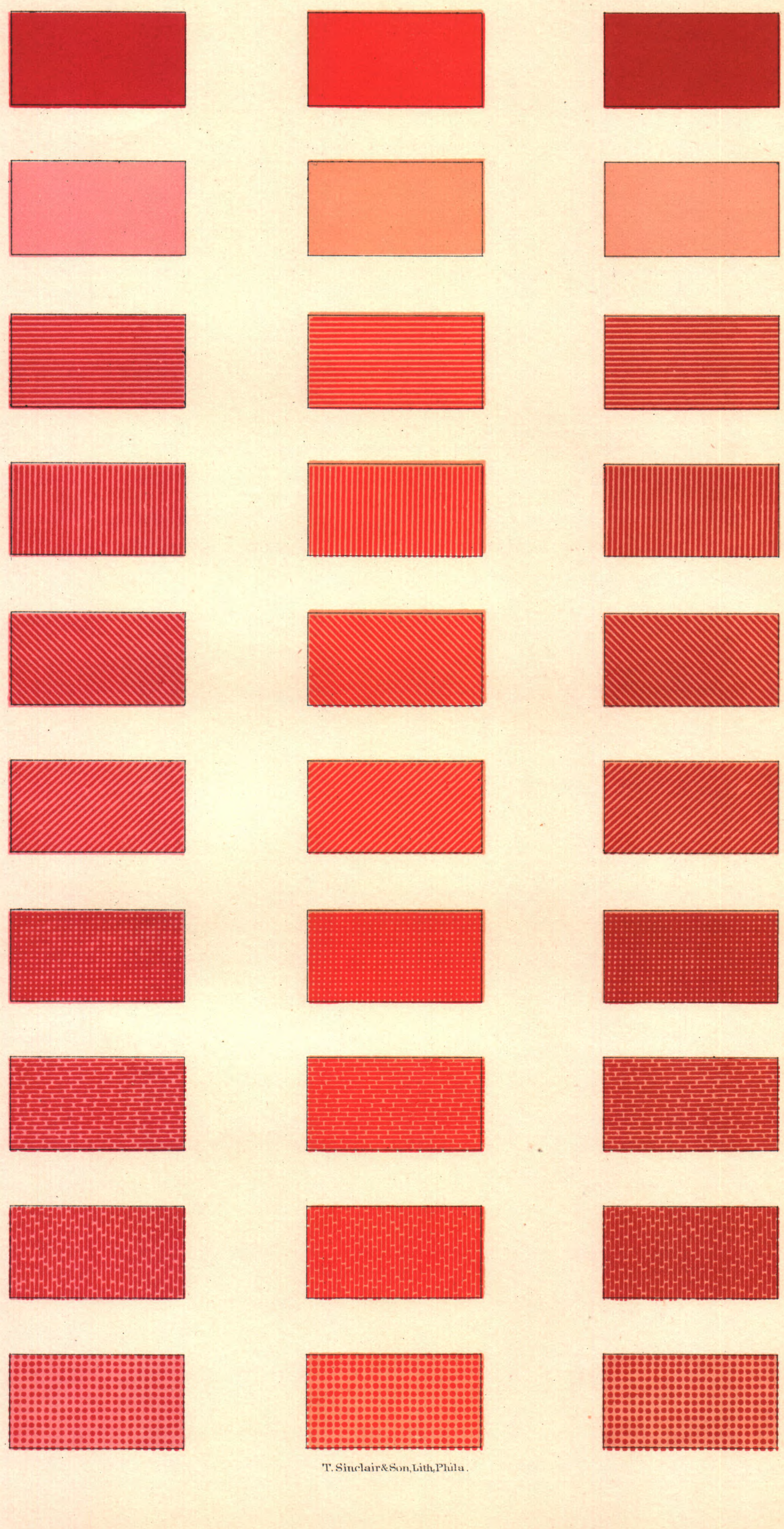
T. Sinclair & Son, Lith, Phila.

ARCHÆAN



T. Sinclair & Son, Lith, Phila.

IGNEOUS.



T. Sinclair & Son, Lith, Phila.

CONVENTIONAL CHARACTERS FOR DIAGRAMS

Another class of conventional characters is used by the Survey to express the more important lithologic characters.

Diagrammatic sections are of two classes, serial and regional. In the serial diagrams, Formations, Groups, and Systems are indicated by words and connecting lines; and lithologic characters by conventional signs, as follows:

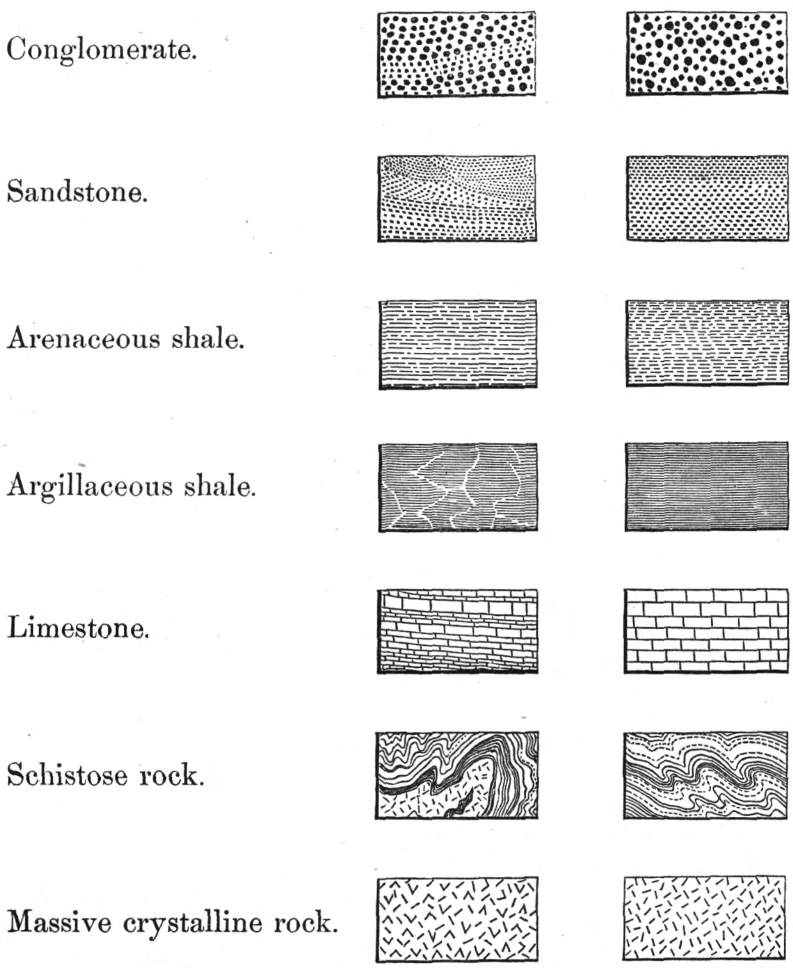


FIG. 1.—Conventional Characters for Diagrams.

In this scheme it will be observed that each conventional sign admits of many variations, which can be used when it is desirable to multiply such distinctions in order to discriminate the members of an extended series; and other characters may be superimposed for the expression of additional facts—for example, to indicate that the rock is dolomitic, gypsiferous, brecciated, geodiferous, etc.

In regional sections designed to express facts of general structure, it is found best to use formation colors rather than lithologic signs.

For general structural purposes stereograms are found useful and should often be constructed; to express relations of general structure to topographic formation, bird's-eye views are valuable, especially when constructed on sectional diagrams.

The general plan as set forth in the foregoing statement provides for the expression of geographic distribution of formations or epochs, groups or periods, and eras or systems, by the simple use of systematic color distinctions. It provides for the expression of the more important facts of lithology by the use of conventional signs in serial diagrams

Facts of general structure are expressed on charts by the relation of color distinctions, by regional diagrams constructed with the color distinctions of formations, and by stereograms. The relation of structure to topography is expressed by bird's-eye views constructed in combination with diagrammatic sections.

Cartographic colors and diagrammatic characters constitute the geologic alphabet, and its value will depend, first, on simplicity; second, on systematic consistency; third, on general usage.

FINANCIAL STATEMENT.

Amount appropriated by Congress for the use of the Geological Survey for the fiscal year ending June 30, 1881	$156,000 00
Expended during the fiscal year	150,948 47
Remaining on hand June 30, 1881 (required to meet outstanding liabilities)	5,051 53

The following is a classification of the expenditures:

	Amount.	
Salary of Director	$6,000	00
Services of assistants and employés	101,392	43
Rent of offices	3,760	93
Repairs of offices	101	35
Office furniture	2,495	52
Fuel	1,034	04
Gas	217	80
Ice	53	47
Telegrams	858	14
Rent of telephones	82	00
Rent of post-office boxes	50	00
Stationery	1,695	62
Drawing material	277	45
Books	171	35
Instruments purchased	1,171	03
Instruments repaired	285	30
Laboratory supplies	1,998	63
Photographic material	256	03
Publication of maps	175	00
Illustrations for reports	727	00
Job printing	36	00
Transportation of assistants and property	7,825	40
Traveling expenses	6,768	94
Purchase of horses	240	00
Purchase of mules	930	00
Camp and field equipage	1,190	51
Subsistence	6,626	90
Forage	2,338	83
Pasturage	597	94
Tollage	32	47
Storage	331	93
Apprehension and delivery of lost public property	95	00
Miscellaneous	1,131	46
Total	150,948	47

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, 1881.

ADMINISTRATIVE REPORTS

BY THE

HEADS OF DIVISIONS.

3-4

REPORTS OF THE HEADS OF DIVISIONS.

REPORT OF CAPT C. E. DUTTON.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE COLORADO,
Washington, October 3, 1881.

SIR: Conformably to the directions contained in your letter of July 8, 1881, calling upon me for a "report of the operations of your [my] Division of the United States Geological Survey for the fiscal year ending June 30, 1881," I have the honor to submit the following

PERSONAL REPORT.

On the 2d day of July, 1880, I left Washington and proceeded to Salt Lake City, Utah, accompanied by the following assistants:

Mr. Sumner H. Bodfish, topographer.

Mr. Richard U. Goode, topographer.

Mr. Robert E. Jones, assistant topographer.

Mr. Leonard H. Swett, assistant topographer.

Having purchased in Salt Lake City the necessary outfit and supplies, I proceeded by the Utah Southern Railroad to Juab station, 110 miles south of Salt Lake, meeting there eight hired men, with four freight wagons and animals. The entire party left the railroad on the morning of July 18, and journeyed slowly southward, ascending the valley of the Sevier River. The next day we reached the Mormon village Gunnison, which presents a distant and widely-extended view of the high plateaus of Utah, their battlements still flecked with patches of snow. These magnificent masses, which are exceedingly interesting alike in their topographical and geological features, have already been described by me in a former monograph. East of Gunnison, and 12 to 18 miles away, rises the Wasatch Plateau, composed of heavy masses of lower-Tertiary strata, which bend upwards from the valley below, and near the summit flex back to horizontality. Southward is a long stretch of level valley-plain, beyond which rise the dark, volcanic masses of the Sevier Plateau and Fish Lake Plateau, which attain altitudes of more than 11,000 feet above the sea. A day's journey from Gunnison over an easy road brought us opposite the north end of the Sevier Plateau and to the foot of the grand escarpment which forms its western flank. During five days this wall rose upon the left, while the still loftier heights of the Tushar towered above us on the right. At a distance of about 180 miles from the railroad we reached the divide which separates the drainage of the Sevier River from that of the Colorado. Descending thence to the southward through the great southern terraces of the High Plateaus, we reached the little village of Kanab on the 29th day of July.

Kanab is a Mormon settlement, lying upon the southern boundary of Utah, at the foot of the Vermilion Cliffs, and it has long been the base of operations of the exploring and surveying parties working in the district which drains into the Grand and Marble Cañons of the Colorado. Here the main bulk of supplies was deposited, and the pack and saddle animals prepared for active field work. The work contemplated was both topographical and geological.

TOPOGRAPHICAL WORK.

Two topographical parties were organized, the first under Mr. Bodfish, the second under Mr. Goode. The object of Mr. Bodfish's work was to complete the survey of that portion of the Grand Cañon of the Colorado which extends through the Kaibab Plateau, and also of the surface features of that plateau itself. To Mr. Goode was assigned the duty of making a survey of the San Francisco Mountains and their vicinity, lying 50 to 80 miles south of the cañon.

Mr. Bodfish's work was of more than ordinary difficulty. One group of determinations had not, up to the last year, been satisfactorily made, viz, the geographical co-ordinates (latitudes and longitudes) of the prominent points in the southwestern part of the Kaibab. This remarkable plateau has for several years been a difficult problem to the topographers. It is a lofty flat mass without a single peak or pronounced elevation anywhere upon its surface. It is densely forest-clad with gigantic pines and spruces. It is loftier by 1,500 to 4,000 feet than the surrounding regions, and to the eye and mind of the topograper, it is merely an obstruction which cannot be crossed by his lines of triangulation; and it is extremely difficult to circumvent, for it is nearly 100 miles long and from 15 to 40 miles wide. Being devoid of natural objects of sufficient definition to serve as targets for the theodolite, it was necessary to construct artificial ones; and the selection of stations within range of other well-determined stations, and readily distinguished, was not easy; for the nearest ascertained stations were from 50 to 80 miles away and even the most strongly individualized points were liable to be confused with others in their vicinity. It was at once concluded that none could be found except upon the brinks of the salients which project out into the broad chasm of the Colorado. From these it was known that unobstructed views could be obtained of the volcanic domes of the Uinkaret Plateau, 60 to 80 miles westward, and of the peaks of the San Francisco Mountains, 50 to 60 miles southward. It was desirable therefore, to build monuments upon these salients, which could be observed from those domes and peaks, and thus give the required data. I therefore left Kanab with Mr. Bodfish, taking also Mr. Goode, who was to observe these monuments, if possible, from the San Francisco Mountains, and proceeded to the brink of the cañon, about 80 miles south of Kanab. Two primary points were selected, one named Point Sublime, the other Cape Royal. The former is a headland, projecting far out into the chasm, about mid-length of the Kaibab division; the latter, a similar headland, situated about 20 miles east-southeast of the former. Here were built large monuments of timber, which we covered with white calico. From both points the well-determined stations and monuments on Mount Emma in the Uinkaret, and on the San Francisco Mountain, were discernible through the telescope, and satisfactory readings were made upon them from the large theodolite.

This being accomplished, Mr. Goode was dispatched to his field of labor, and I returned to Kanab, leaving Mr. Bodfish to pursue his work. This consisted of plane-table work checked by the theodolite. In the preceding season he had applied the plane-table to the Kaibab division, from the foot of the Marble Cañon to the head of the Kanab division of the Grand Cañon, and it was necessary to apply it to the lower portion of the Marble Cañon and the southern portion of the east wall of the Kaibab. The very extraordinary topography of the chasm and its accessories called for great skill and ingenuity on the part of the surveyor, but Mr. Bodfish proved equal to all emergencies, excepting a few which no skill can conquer, and which require wings rather than skill.

Believing that the study of the surface drainage of the Kaibab would throw light upon the larger geological problems which the district presents, I instructed Mr. Bodfish to make a careful reconnaissance or meander-survey of the plexus of ravines which constitute that drainage. These are almost innumerable, but they have, as the event proves, a systematic and intelligible character and grouping. With the assistance of Mr. R. E. Jones, he meandered these ravines, some of them repeatedly, carefully checking his courses and distances, and succeeded within the limits covered by his map in obtaining plots of all the principal ones and substantially of all their notable branches, with a degree of accuracy which is all that could be reasonably desired. He also visited Mount Emma, on the Uinkaret Plateau from which point he successfully observed the two monuments on the Kaibab already referred to, thus obtaining both forward and back sights between stations. With the data obtained in the seasons of 1879 and 1880, he has been able to complete his map of the Kaibab division of the Grand Cañon, and of the surface topography of the southern part of the plateau, upon a scale, as originally drawn, of about 1: 40,000 and with contours of 100 feet of vertical interval.

Mr. R. U. Goode left me on the 15th of August on the Kaibab Plateau, with instructions to proceed at once to the San Francisco Mountains. By previous arrangement, his hired men were to leave Kanab with animals, supplies, and equipments, and to meet him near the head of the Marble Cañon on a day appointed. The rendezvous was made as directed, and with his party he crossed the Colorado by "Lee's Ferry," at the head of the Marble Cañon, and in due time he reached the San Francisco Mountains, where he remained until about the 1st of November. The locality is a volcanic one, and an outlier of that very large volcanic district known sometimes as the Great Black Mesa, situated in eastern Arizona and western New Mexico. Upon this outlier are several large extinct volcanoes, surrounded and interspersed with a throng of recent cones, from which many sheets of lava have been outpoured. They stand upon one of the most elevated portions of that great Carboniferous platform which stretches northward without interruption to the abyss of the Grand Cañon, and thence further northward to the Utah boundary. Mr. Goode, by great diligence and industry, succeeded in obtaining data for the construction of a very good map of his field, upon the unusual scale of one mile to the inch, which map has already been drawn with 100 feet contours.

My own work for the season was the study of the geology of as much of the district as I could cover. As for problems to be solved, I went there to find them as well as to solve them. The great chasm, the faults and flexures of the strata, the vast erosion of the region, its cliffs and cañons, its strata and extravasated rocks, surely would furnish problems enough. But it seemed to me that whatever questions they might bring up and whatever answers they might suggest were merely subsidiary to one comprehensive inquiry: what have been the stages, the chief successive steps and the physical causes of the evolution of this strange region? The geologist seeks for facts in order to learn geological history and causation—in short, evolution. He picks up his facts much as the vagabond prospector picks up float ore or pans for a few colors in every gulch and when he finds them seeks to trace them back to their sources, dreaming always of bonanzas. Every accessible feature, therefore, was studied and pondered in the hope that it might be traced back to its origin, disclosing a common bond among them. My purpose was to seek for evidences of the geological history of the region; what success has attended the effort may appear in part in the chapters following this personal one. It has been less than might have been hoped, but greater than might have been feared.

On the 19th of August I left Kanab for the Uinkaret Plateau. Reaching Pipe Spring, 20 miles southwest of Kanab, I was rejoiced to find Mr. William H. Holmes, who had come to join me and co-operate in the work. Leaving Pipe Spring, we pushed across the desert to the southwestward, and in two days more made camp at the base of Mount Trumbull, on its southwest side. Preparations for a protracted camp were made and nearly four weeks were occupied in making excursions almost daily to all surrounding parts within one or two days' march. The Uinkaret Plateau was quite thoroughly examined. The principal facts which it presents are:

1. Its many basaltic cones and lava fields, none of any great dimensions, but thickly clustered together, and some so recent that it seems as if a century or two could hardly have passed since they became silent and inactive. Others are older, and some have been greatly ravaged and nearly effaced by secular erosion.

2. The Hurricane and Toroweap faults, which form excellent studies of displacement, especially in the vicinity of the chasm.

3. The Toroweap and Queantoweap valleys, which are remnants of lateral drainage channels of the Colorado, and represent a drainage system which has become extinct.

4. The Grand Cañon itself.

5. The remnants of Permian strata.

All these present matter of independent interest when considered apart from their relations to each other and apart from the broader problem of evolution. But each can be made to yield its quota of testimony, and when the story told by one group of features is compared with what is told by the others, the interest is greatly deepened. The study of the main problem is like trying to restore the newly discovered fragments of an antique vase which have been scattered and a portion of them recovered. Each fragment by itself is of minor importance and gives no definite idea of the shape and size of the vase. But when a number of them have been matched and the broken edges are seen to join, even though considerable portions be wanting, we may still perceive the original design and compute its dimensions. We were even more concerned with this method of analysis, comparison, and reconstruction, than with the concrete facts themselves; and diligently studied the latter in the hope of finding out something about the former. How these various observations, so incoherent and disjointed on the first view, become congruous through analysis and comparison, I shall endeavor to show in the monograph, now nearly completed, on the Tertiary History of the Grand Cañon District. It would be impossible to explain it briefly here.

During our stay at Mount Trumbull Mr. Holmes's magical pencil was was ever busy. Large and elaborate sketches of the panoramas presented from Mounts Trumbull, Logan, and Emma; of the splendid vista of the Toroweap Valley, and of the superlative spectacle of the Grand Cañon as seen from Vulcan's Throne, were made in rapid succession.

From the Uinkaret we returned to Kanab and proceeded thence to the Kaibab. I went there to visit those portions of it which I had not hitherto seen, and to review portions seen but not appreciated years before. Mr. Holmes devoted himself to making sketches of the chasm. Among them is a panorama of the cañon from Point Sublime. The studies on the Kaibab were of the same general nature as those of the

Uinkaret, and had their bearing on the geological history and evolution of the district.

Returning to Kanab, Mr. Bodfish and his assistants were sent northward to Salt Lake City, with instructions to return at once to Washington. I remained with Mr. Holmes in order to make another journey along the front of the Vermilion Cliffs, northwestward as far as the Valley of the Virgen, and thence southwestward to view the country in the vicinity of the Hurricane fault, and to the west of it. Thence we journeyed northward, along the western or dropped side of the Hurricane fault, and on the 23d of October, we reached Fort Cameron, at the town of Beaver in Utah. Here the laborers of my immediate party were discharged, and I returned without delay to Washington.

During the past winter and up to the close of the fiscal year ending June 30, 1881, I have been occupied in the preparation of a monograph on the Tertiary History of the Grand Cañon District. The maps have been completed by Mr. Bodfish and Mr. Renshawe, the former having delineated the Kaibab division of the Grand Cañon and the surface topography of the southern part of the Kaibab Plateau, while the latter has drawn the map of the Uinkaret Plateau. Mr. Holmes has redrawn the sketches of the cañon and adjoining regions, and the materials are now in the engraver's hands, as are also the maps. The manuscript of the monograph, is very nearly completed.

All of which is very respectfully submitted.

C. E. DUTTON,
Captain of Ordnance, in charge Division of the Colorado.

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

REPORT OF MR. G. K. GILBERT.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE GREAT BASIN,
Washington, D. C., October 27, 1881.

SIR: I have the honor to present the following report of operations in the Division of the Great Basin during the year ending June 30, 1881.

In the organization of the Survey in the year 1879 the territory subject to the investigation of the corps was apportioned in a number of Divisions which it was designed to make somewhat independent in administration. The Division of the Great Basin, as then defined by the Director, was exceedingly large, and a subdivision of the work within it was therefore made on the basis of its subject matter, the economic geology being assigned to the direction of Mr. G. F. Becker, and the general geology to myself. An exigency soon arose, however, which made it expedient to establish a third organization within the same geographic district, and the work of this organization was afterward placed in the charge of Mr. Arnold Hague, to whom had been assigned the Division of the Pacific. These innovations upon the original plan were partly in accordance with my request and wholly in accordance with my desire, and they have had the effect of enabling me to restrict my attention to a series of special investigations, in which I had already made some progress before the organization of the Survey. Mention is here made of them only because it is necessary to distinguish between the geographic Division of the Great Basin and the administrative Division of the Great Basin. The accompanying report applies only to that portion of the work in general geology the conduct and administration of which have been committed to me.

During the summer of 1880 two parties were in the field, and on their return an office was organized in Salt Lake City. The winter was spent in the elaboration of the field notes, and the majority of the corps continued in office work until the close of the fiscal year; but a small party was sent to the field in the spring of 1881.

This report will contain, first, a description of the field organization and an account of the field movements, and, second, a statement of the scope of the office work.

FIELD WORK.

Preparations for the field were begun at Washington, D. C., and completed at Salt Lake City, Utah. The plan of the work demanded that many points should be visited which were not only distant from any line of public conveyance but were even remote from all settlements, and it was necessary to make independent provision for the transportation and subsistence of the field parties. Each party was therefore furnished with a four-mule wagon, three pack mules, and a quota of saddle mules, and upon the wagons were loaded all the paraphernalia of camp life. Supplies were sent by rail to a number of different points where they could conveniently be taken up during the progress of the work.

On the sixteenth of July, 1880, the corps left Salt Lake City in two parties. The geological party was in my own charge, and contained Messrs. Israel C. Russell and H. A. Wheeler, geological assistants, and Mr. Frederick D. Owen, artist. The topographic party comprised Mr. Gilbert Thompson, topographer in charge, Mr. Albert L. Webster, assistant topographer, and Mr. R. I. Gill, barometer observer. Each party had three camp hands, and the topographic party was accompanied for a few days by Mr. R. H. Smith, who was then left at Fillmore, Utah, where he maintained a barometric base station throughout the summer.

The work planned for the geological party was to trace more thoroughly than has heretofore been done in southern Utah, the outline of Lake Bonneville, the great lake which formerly occupied all the lowlands of that region, and to make special examinations of the relations among themselves of the series of shorelines left by the water at its many stages of level. The first point visited was the mouth of Little

Cottonwood Cañon, a gorge of the Wasatch Range which opens out into the valley traversed by the Jordan River, and which at one time was filled by a glacier to its very mouth. Climatic considerations of a very general character had given rise to a belief that the ancient lake was coincident in time with the system of glaciers of the Wasatch and other mountains of the western territories, but up to that time no geologist had studied the phenomena produced by the two agencies in juxtaposition. The shore marks and lacustrine deposits formed by the lake occupy the valleys and merely touch the bases of the mountains, while the moraines and other vestiges of glacial action are for the most part confined to the higher mountain gorges. Here, however, was a locality where the moraines were known to extend into the region of the lake, and it was hoped that the theory of contemporaneity could be tested by an investigation of the locality.

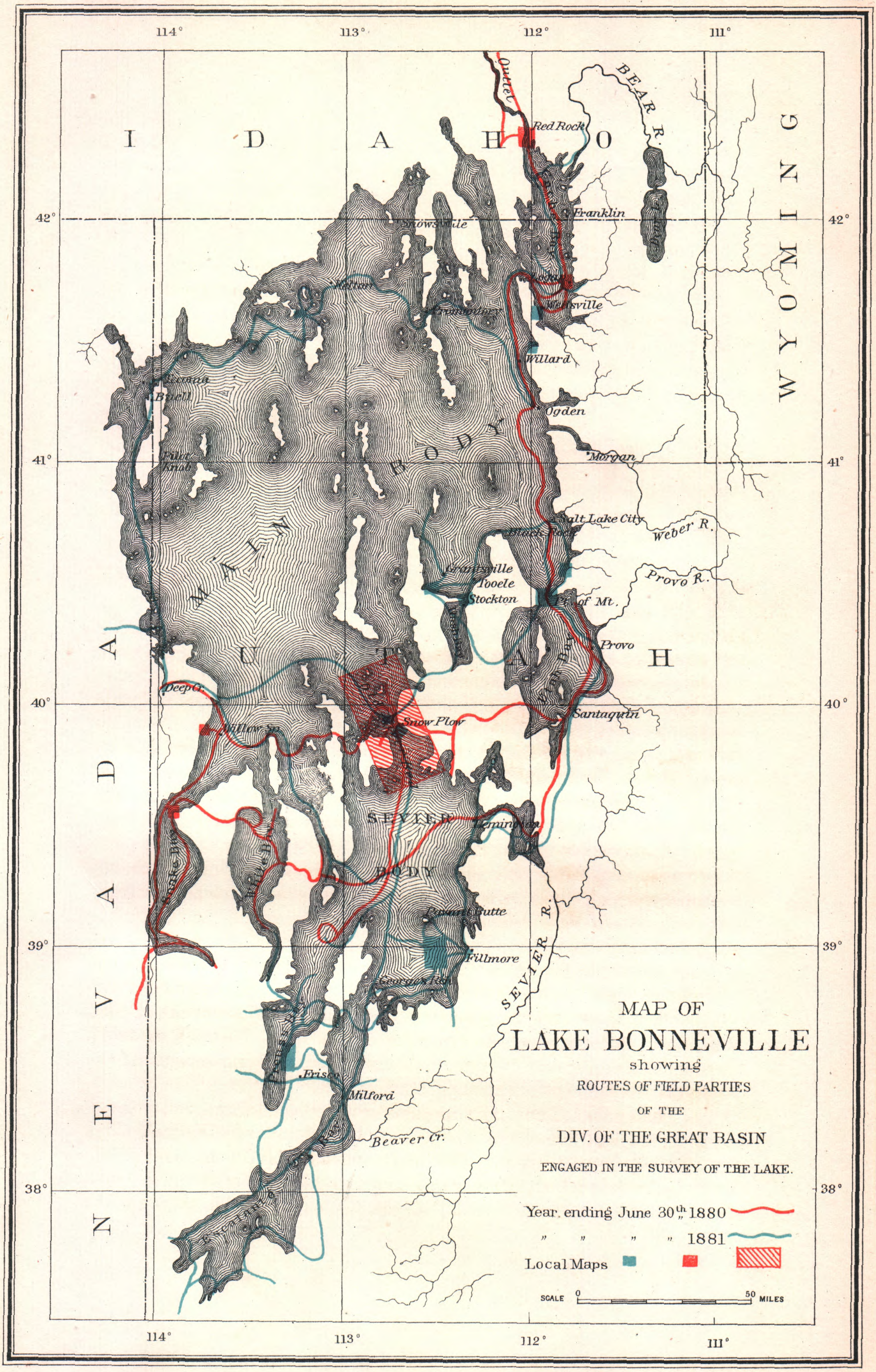
The next point of lingering was at the Point of the Mountain, a place where a low spur from the Wasatch Range stretches across the Jordan Valley to the Oquirrh Range beyond, but is cut through by the river midway. The gap was partly closed during the existence of the lake by embankments of gravel thrown into it by the action of the waves, and the recutting by the river after the lake had subsided has exposed the gravels to view in an instructive section.

The party then took its way across the lower end of Utah Valley, and through Cedar and Rush Valleys, to the north end of Tooele Valley, where the monuments of wave work are of the most imposing character. At the Point of the Mountain, and at two points in Tooele Valley, local maps were made of areas of interest a few miles in extent, and the differences of altitude of the various water lines were determined by means of the spirit level.

At this time the party suffered the loss of its artist, Mr. Owen, who turned back on account of sickness and was, unfortunately, not afterward able to resume his work.

From Tooele Valley the old overland stage road which skirts the southern edge of the Great Salt Lake Desert was followed for three days, when another and more protracted halt was made at the Old River Bed, a locality where the attention of every traveler and frontiersman is arrested by the presence of the desiccated channel of a river of some size in the midst of one of the most arid deserts of the continent. The history of this old river is intimately associated with that of the ancient lake, and nearly two weeks were spent in making a thorough examination of its features and of numerous objects of geologic interest in the vicinity.

The next point of special examination was the north shore of Sevier Lake, a saline of the desert, lying one hundred miles to the south. In 1872 the lake was thirty miles in length and had a depth of about fifteen feet. In the winter of 1879 it was found to have completely dried away, leaving its salt in the form of a heavy crust covering a large area of the


MAP OF
LAKE BONNEVILLE
showing
ROUTES OF FIELD PARTIES
OF THE
DIV. OF THE GREAT BASIN
ENGAGED IN THE SURVEY OF THE LAKE.
Year ending June 30th, 1880
" " " " 1881
Local Maps
SCALE 0 50 MILES
IDAHO
WYOMING
NEVADA
UTAH
MAIN BODY
SEVIER BODY
BEAR R.
Weber R.
Provo R.
SEVIER R.
Beaver Cr.
Outlet
Red Rock
Franklin
Snowsville
Promontory
Wellsville
Willard
Ogden
Morgan
Salt Lake City
Grantsville
Tooele
Stockton
Pt. of Mt.
Provo
Santaquin
Snow Plow
Deep Cr.
Willow Sp.
Fillmore
Frisco
Milford
114°
113°
112°
111°
42°
41°
40°
39°
38°

muddy bottom near the northern end. At the time of our visit a few inches of water covered the crust, and it was so far softened as to be traversed with difficulty. A carefully selected series of specimens was collected with a view of ascertaining the economic value of the deposit, and these have since been placed in the hands of a chemist for analysis.

From Sevier Lake the party traveled to Preuss Valley, being compelled to a circuitous route partly by the absence of a direct road but chiefly by the lack of water on the direct line. Here three most interesting groups of gravel embankments formed by the waves at different water stages were studied and mapped, and valuable data were gathered for the compilation of the history of the oscillations of the lake. The road was then taken southward to the Escalante Desert, the most southerly of the plains submerged by the ancient flood, and from there the party turned northward to Milford, a station on the Utah Southern Railroad which had been selected as a rendezvous and supply point for the field parties. It was reached on the twelfth of September.

The work of the topographic party was partly geographic and partly geologic. Before leaving Washington an attempt had been made to compile a map of the region to be visited from the material furnished by the government surveys of previous years, but it was found that the data pertaining to a district lying along the northern edge of the Escalante Desert were not sufficiently accurate for the purposes of the work, and it was determined to replace them by new material gathered during the summer. Selection was therefore made of a series of peaks overlooking the desert from the east and which had been determined in position by the work of the Survey of the Rocky Mountain Region, and a triangulation was planned which should use them as initial points and extend over the region to be mapped. This triangulation and the complementary topographic work were carried forward by Mr. Thompson and his assistant as one of their chief duties. Their other duty consisted of the tracing of the ancient shoreline from the vicinity of the town of Fillmore southward to its southern limit, so as to correct the existing map of the lake in that region, and especially so as to set at rest a question which had been raised as to the mode of connection between the body of water in the Escalante Desert and that in the deserts at the north. This work carried him along the eastern margin of the Sevier Desert, through the lower valley of Beaver Creek, and thence to the extreme southern and western limits of the Escalante Desert, and made it necessary to ascend many of the highest peaks of the region. Under his direction a series of barometric observations was made, not only upon the topographic stations but upon many points of the ancient shoreline, especially in the remoter parts of the Sevier Desert where the extension of railroads has not yet rendered other means of determination possible. The triangulation was far advanced and the survey of the shoreline of the Escalante Bay was completed at the time of the rendezvous at Milford.

For the remainder of the field season the force was redivided, Mr. Thompson being sent with a picked company of camp hands upon a long and rapid march across one of the most inhospitable portions of the desert, and the remainder of the corps traveling slowly toward Salt Lake City.

The principal halt of the main party was at White Mountain Spring, a few miles south of the town of Fillmore, and camp was maintained there for nearly two weeks. From this place excursions were made in various directions for the examination of a series of volcanic craters and lava beds spread upon the desert in the vicinity, the especial subject of investigation being the history of the relation of the volcanic eruptions to the several water stages of the ancient lake. A visit was also made by Mr. Russell to the sulphur deposits at Cove Creek, and attention was given to a peculiar recent local accumulation of gypsum.

A second halt was made at Lemington Station, where the Sevier River issues in a narrow valley from the mountainous district which contains its upper course and enters the desert. The locality is of interest by reason of the fine section there displayed of deposits of the ancient lake, and was made the point of departure for the excursions necessary to map the extensions of the lake in Tintic Valley and along the upper course of the Sevier. Here the field party was disbanded, and the professional assistants took the cars for Salt Lake City, where they arrived on the twelfth of October.

The field work was not stopped, however, but after a few days spent in preparation, a party consisting of Messrs. Russell, Wheeler, and Webster went by rail to Cache Valley, where they made some supplementary investigations at localities visited the previous winter. The map of the ancient delta of the Logan River, which had been made by Mr. Willard Johnson, was slightly extended, and a new map was made of a series of shore terraces near the town of Wellsville. Mr. Russell also paid a visit to the outlet of the ancient lake at Red Rock Pass, and in returning to Salt Lake City the party stopped to make examinations of the ancient deltas of Box Elder Creek and the Ogden River.

After leaving Milford, Mr. Thompson first ascended Frisco Peak for the purpose of completing his triangulation, and then proceeded to determine the position of the ancient shoreline in a district lying just west of Sevier Lake and which had been passed by in previous exploration by reason of the inhospitable character of the country. He was so fortunate as to find water in some rock pockets which had been filled by recent showers, and was thus enabled to accomplish in an entirely satisfactory manner that which would else have been a very difficult task. He then went to a point between Drum Mountain and the House Range where previous work had left a doubt as to the ancient configuration of the shore, and ascertained that a narrow strait had there joined the two bodies of water occupying severally the Sevier and Great Salt Lake deserts.

His course was then directed to the northwest, skirting the margin of the Great Salt Lake Desert, to Deep Creek Settlement, where it turned northward to the Central Pacific Railroad at Tecoma. Through nearly the whole of this distance he was enabled to follow a wagon road, and by the aid of short, lateral excursions succeeded in mapping all of the western margin of the ancient lake which had not been previously well determined. At Tecoma he connected the ancient shoreline with the roadbed of the Central Pacific Railroad by a line of levels, thus determining its altitude. He then proceeded eastward, following the line of the railroad. At Terrace Station he was, by previous arrangement, joined by myself, and we continued the investigation of the shorelines in company as far as the town of Kelton, stopping at Dove Creek and Ombe to make special examinations, measurements, and maps. In this region the work of the Survey was greatly facilitated through the courtesy of the officers of the Central Pacific Railroad, who permitted the party to supply itself with water from the tanks maintained by the railroad at their stations. The region is devoid of fresh-water springs, and it would have been a matter of great difficulty to have conducted the investigations there without the assistance afforded by the railroad.

From Kelton the writer and Mr. Thompson made a trip to Cache Valley by rail, while the wagon and material were taken by the camp men to Salt Lake City. It had been suggested by Mr. Thompson that certain puzzling phenomena connected with the shoreline would find their explanation in the hypothesis that an outlet of the lake had once existed from Cache Valley through Gentile Valley and what is known as Basalt Valley, northward to the basin of the Columbia, and had been afterward closed by the volcanic eruptions of Basalt Valley; and the excursion to Cache Valley and Gentile Valley was for the purpose of testing that hypothesis. It was found, however, to be untenable and only a brief stay was made. The terraces of Gentile Valley, although not produced by the waves of the ancient lake, offered an attractive field of study to which time and attention would have been devoted but for a fall of snow which covered the ground to the depth of several inches and effectually prevented all detailed observation.

By the thirteenth of November all the professional assistants were gathered in Salt Lake City, and, with the exception of a few short excursions, no further field work was performed that year.

In the following spring (1881) Mr. Russell again took the field, beginning his preparations at Salt Lake City and completing them at the town of Deseret, from which point he set out on the tenth day of April. The work intrusted to him was a reconnaissance of the ancient lake which in western Nevada formed a companion to Lake Bonneville—the lake to which King has given the name "Lahontan." His route for the first week lay within the basin of Bonneville, and before reaching the shores of Lahontan he crossed several valleys which had contained (doubtless at the same epoch of geologic time) small lakes. It was anticipated that he would continue his work through the entire season, and at the time of the present writing he is still in the field. His reports of progress show that before the close of the fiscal year he had completed his examination of the southern shore of the lake, making a preliminary map of it and ascertaining definitely that there was no outlet of the water in that direction. He made also a preliminary examination of the vestiges of a lake of some magnitude, of which Mono Lake is the shrunken modern representative, and discovered a number of localities in which glaciers from the Sierra Nevada had descended to points below the level of its waters. His studies of these localities, although brief and as yet incomplete, have already afforded valuable contributions toward the co-ordination of the glacial and lacustrine histories.

OFFICE WORK.

Immediately on the completion of the field work, the initiatory steps were taken for the establishment of an office. It was the purpose of the Director that the principal labor of the reduction and discussion of the field notes and field material gathered by the Division should be performed at Salt Lake City, and great care was therefore taken in the selection of an office site and in its equipment and organization. This duty necessarily consumed a large share of time and attention, and several weeks passed before the professional office work was fairly undertaken. In due time, however, a suitable building was leased, the necessary furniture was placed in it, and the material of the Survey was put in order. A thorough system of cataloguing by means of cards was inaugurated, not only for the maps and books of the office, but for all matters of record and for the numerous articles of camp equipage and other field material, which were stored in the same building.

In a frontier town there was, of course, no library suited to the needs of the professional work in hand, but the want was very fairly met by combining the technical works contained in the private libraries of the members of the Survey, which were loaned for the purpose. To the collection thus brought together a few works were added by purchase, and as soon as practicable it was furnished with a card catalogue.

The office force comprised at first Messrs. Thompson, Russell, Wheeler, Webster, and the writer, and a small amount of clerical work was performed by the janitor, Mr. Gill. In December the force was reduced by the resignation of Mr. Wheeler, in March by my departure for Washington, where I was ordered for the completion of the preparation of my report, and in April by the departure of Mr. Russell for field duty; so that at the close of the fiscal year it consisted of Messrs. Thompson and Webster only.

The work of the office consisted chiefly in the elaboration and discussion of the geologic and geographic material gathered in the field. Computations were made of the geographic positions of points determined by the triangulation, maps were compiled and prepared for the engraver, barometric altitudes were computed, and the numerous altitudes determined by spirit level were combined by means of connecting railroad surveys so as to be referred to a common zero. The geologic observations were classified and discussed, and in a few instances short excursions were made to settle matters of doubt by supplementary observations. In one of these excursions a new tide-gauge was established at Garfield Landing for observations on the rise and fall of Great Salt Lake, and series of synchronous readings were taken upon the new gauge and upon the old one at Lake Shore for the purpose of ascertaining the relation of their zeros. In another excursion a level was run from the tide-gauge at Lake Shore to a number of benches in Salt Lake City, and in yet another the altitude of the ancient shoreline in the neighborhood of Camp Douglass was redetermined by level.

A series of experiments was made for the determination of the influence which the presence of salt in water has upon sedimentation, and a series of computations was begun for the purpose of testing a new method of barometric hypsometry, which forms the subject of an essay in this volume.

In the equipment of the office no provision was practicable for chemical work, and the analyses called for by the investigations of the corps were therefore put in the hands of chemists not otherwise connected with the Survey.

In Washington the study of the geologic material was continued by the writer, and with clerical assistance the computations in barometric hypsometry were carried forward. Field sketches designed to illustrate the report on Lake Bonneville were placed in the hands of Mr. W. H. Holmes, under whose supervision the work of redrawing for the engraver was most auspiciously begun.

The field and office labors of my assistants have, without exception, been characterized by zeal and efficiency. The mapped outline of the lake, which constitutes the most tangible of our results, is a joint work to which each has contributed his quota. Drawn upon a larger scale by Mr. Thompson, it will be issued with the monograph of Lake Bonneville, now in preparation. The same volume will contain numerous local maps by Messrs. Wheeler, Thompson, Webster, and Johnson, and a report on the hypsometric work by Mr. Webster. These will speak for themselves in due time and need no commendation here. There can be no better place than this, however, to express my appreciation of the never failing promptitude with which all wants of the Division have been met, or even anticipated, by Mr. McChesney on behalf of the central office, and by yourself.

I am, with great respect, your obedient servant,

G. K. GILBERT,
Geologist in Charge.

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

REPORT OF MR. S. F. EMMONS.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE ROCKY MOUNTAINS,
New York, October 20, 1881.

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

In my report submitted to your predecessor, Hon. Clarence King, a year since, I stated that I hoped to have my memoir upon the Geology and Mining Industry of Leadville ready for publication during the spring of 1881. I regret to say that these hopes have not been fulfilled, and that even at this late date there still remains considerable work to be done before it can be put in the hands of the printer.

The delays arise in large part from the inherent difficulties of the work, which requires for its illustration a most extensive and elaborate set of maps, sections and diagrams, the preparation of which necessitated much greater labor, both in field and office, than had been foreseen. The natural difficulties of the work were moreover greatly enhanced by a combination of adverse circumstances.

The season for out of door work, when the ground is comparatively free from snow, always very short at Leadville, was during the summer of 1880 unusually so, snow having fallen permanently before the 1st of October, where on the year previous it was possible to do outside geology up to the middle of November.

Again, the want of funds consequent upon insufficient appropriation by Congress for the use of the Survey, rendered the desired increase of my corps of assistants impossible, and a portion of my map work had to be intrusted to private engineers. Thus the completion of our maps was in a measure dependent upon the greater or less press of other business, in consequence of which, in one instance, work which in summer might have been completed in six weeks, was only accomplished after five months of intensely laborious field work, during the winter, with snow covering the ground in places to a depth of 15 or 20 feet.

The chemical examinations, which constitute a most essential part of the investigation, and without which the study would have been deprived of a great part of its practical as well as scientific value, were much delayed by the necessity of having a laboratory building expressly erected, and the difficulty of procuring pure reagents, so that this work was not fairly under way before winter set in.

Owing to the small salaries our pecuniary necessities compelled us to pay, our draughtsmen were constantly changing, being offered larger salaries elsewhere, and much time was thus lost in familiarizing newcomers with the peculiar character of the work.

All these delays have been annoying to all engaged in the work, for the imperative necessity of publishing a memoir of such practical bearing upon mining industry at the earliest possible date, before its results had been discounted by the rapidly advancing developments of mines, was felt by the entire corps, and I feel it my duty to bear testimony to the cheerful alacrity with which these gentlemen have volunteered to work out of hours, and on Sundays even, when necessary for the completion of special parts for the engraver.

Field-work was finished, and the Leadville office discontinued on the 1st of April, 1881. The whole corps, with the addition of temporary draughtsmen, was then employed in the Denver office upon the final preparation of our numerous maps and illustrations for the engraver, until which were completed the actual memoir and final results of the investigation could not be written.

On the 15th of August I proceeded to New York to give my personal supervision to the preparation of the illustrations in the hands of Mr. Julius Bien, which are now in an advanced stage; the great labor involved, however, which will readily be appreciated by one perusing the list of maps and plats, given below, renders it impossible to give a definite date for their completion.

In addition to the work upon the Leadville memoir, no inconsiderable portion of my time has been occupied in supervising the compilation, and preparation for publication, of the statistics of precious metals which have been collected in my division during the year for the Tenth Census, and are now being printed.

All the members of my corps were busily occupied during the entire summer either in finishing up the investigations commenced in their individual specialties or assisting in the preparations of the numerous maps, sections, and diagrams for publication. No new work could consequently be undertaken until they were relieved from these duties.

About the middle of August Mr. C. W. Cross took the field at Golden, Colo., and in the middle of September Mr. E. Jacob proceeded to Kokomo to complete some insufficient data along the northern border of the general map of the Leadville atlas, and to commence a report upon the Ten-mile District of Summit County.

The two small monographs which these gentlemen are engaged upon are all that could safely be undertaken with the means at our command, and for which the necessary maps are available, for experience in the case of the Leadville report has shown that the commencing of such work without accurate maps already prepared, results in great loss of time, and renders one liable to annoying misconceptions and delays.

The plan of the work upon which Mr. Cross is engaged at Golden, Colo., comprises the following investigations:

1. A study of the basaltic flows, of which the mesas or table mountains at Golden are the relics.

a. Their lithology and mineral constituents, including an examination and determination of the numerous and interesting zeolites which abound in them.

b. Their relations to the inclosing Tertiary and Cretaceous beds, with special reference to deciding the vexed question of the age of the coal rocks of Colorado.

2. As a sequence of the above, which may be considered rather of purely scientific interest, the following investigations of more directly practical and economic bearing will receive especial attention.

a. Careful study of the coal horizons, as developed along the foot-hills of the range for some 10 to 20 miles in either direction, with special reference to the extent, thickness, and composition of the beds of coal, fire-clay, building stone, and other materials of economic value contained in them.

b. The construction of underground sections of the country to the east of the foot-hills for about 20 miles, and the determination, in as accurate a manner as the present developments will admit, of the depths at which coal may be found throughout the Denver basin.

In the prosecution of this work the chemical examination of rocks, minerals, and economic products will be conducted, as hitherto, by Mr. W. F. Hillebrand in the laboratory of the division at Denver.

This report will be illustrated by two geological maps, with explanatory sections and diagrams.

1st. Map of the Golden mesas, on a scale of 1,500 feet to the inch, to form one single atlas sheet, and include an area of about four by five miles.

2d. General map of the Denver coal basin, on a scale of two miles to the inch, to cover an area of about 25 by 30 miles, also to form one single atlas sheet.

In the present early stage of the work it is impossible to foresee the extent of the investigations which may be found necessary, or to fix a time for its completion. It is to be hoped, however, that the field-work may be practically finished before winter, and the publication of the results ensue in the coming summer or autumn.

The report upon the Ten-mile District, which was originally intended to be included in the report upon Leadville, will form, as it were, an appendix to this report, the map joining directly the northern border of its general map, and the geology and character of its ore-deposits being similar, and yet sufficiently distinct to present an interesting sequence to the study presented in the latter report. This report will be illustrated by a geological map of the district on a scale of two inches to the mile, covering an area of about 7 by 9 miles, to form a single atlas sheet, accompanied by illustrative sections and diagrams.

It is expected, unless want of funds renders it necessary to reduce my corps still further, that this report will be completed and ready for publication in the coming spring.

I have the honor to submit herewith a brief synopsis of my memoir upon the Geology and Mining Industry of Leadville, Colo., accompanied by a double-page geological map of Leadville and vicinity, with three colored sections illustrative of underground structure, on a scale of one-half mile to the inch, the same being a portion of the general map of the Musquito Range, which will accompany the final report.

Very respectfully, your obedient servant,

S. F. EMMONS,
Geologist in charge.

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

REPORT OF MR. ARNOLD HAGUE.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE PACIFIC,
New York, October 1, 1881.

SIR: I have the honor to submit the following report of operations conducted by the Division of the Pacific for the year ending September 30, 1881:

In accordance with the instructions of your predecessor, Hon. Clarence King, I proceeded in July of last year to Eureka, Nev., for the purpose of making a geological survey of a tract of country embracing not only the very productive mines of the Eureka mining district, but all those which occur in the same broad mass of mountains, including the Secret Cañon District to the south, and the Silverado to the southwest.

For the accomplishment of this work I was accompanied by two geological assistants, Mr. Charles D. Walcott and Mr. Joseph P. Iddings, and while they both rendered efficient aid in all departments of field work, Mr. Walcott devoted most of his time to paleontological questions, and Mr. Iddings was kept busy with the mapping of volcanic rocks.

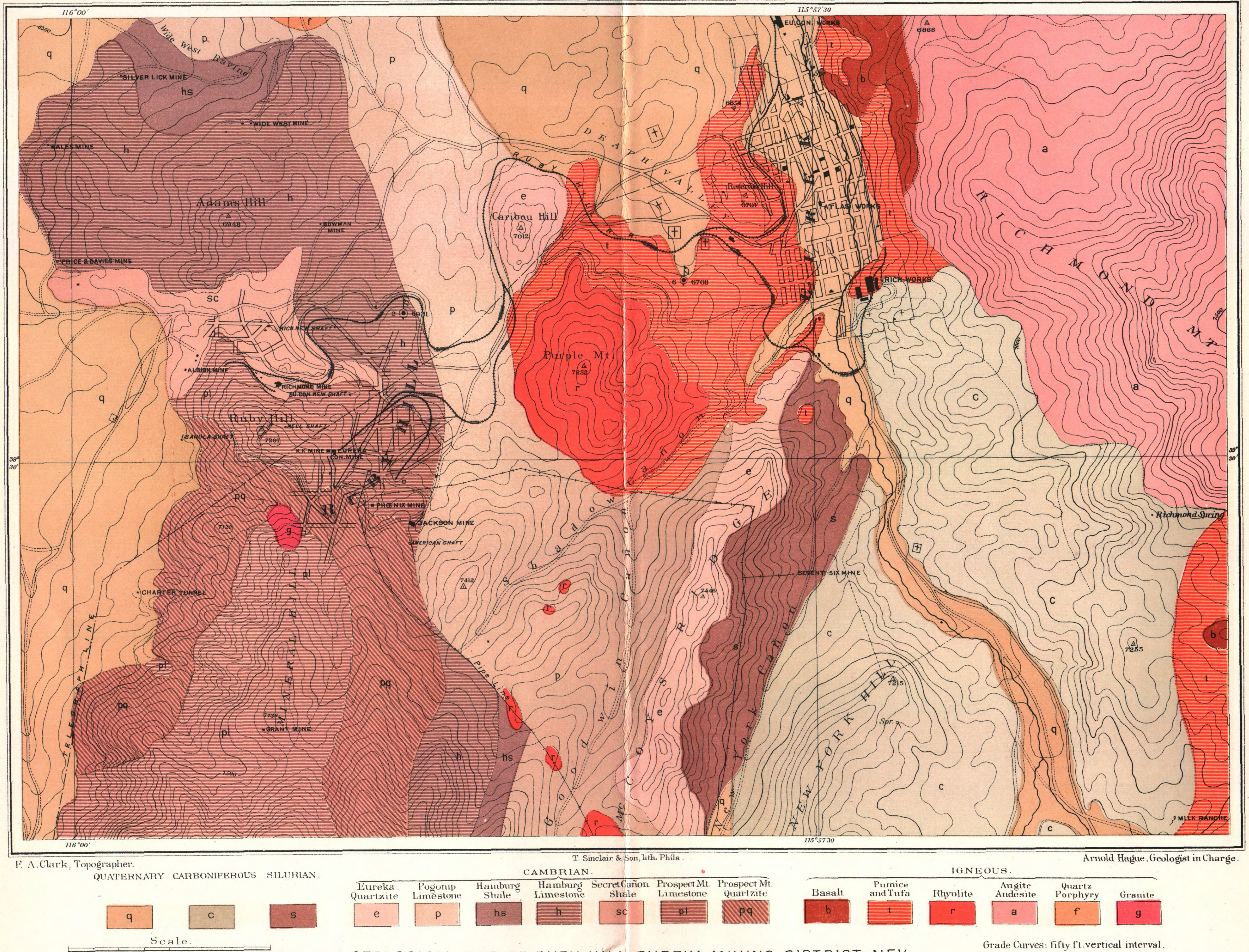
As a basis for geological work, an admirable topographical map was then in course of construction by Mr. F. A. Clark and his assistants. They had taken the field in August the previous season, working as long as the weather would permit, and only occupied winter quarters long after the ground was covered with snow. In early spring, as soon as the season was favorable, the topographical party again commenced operations and pushed the work rapidly forward. Nevertheless on my arrival I found the area of country intended to be covered but little more than half surveyed. As rapidly, however, as the plane-table sheets were completed, copies were made on tracing linen, and photographic duplicates prepared by the "blue process" were placed in the hands of the geological worker.

For purposes of accurate geological work, it seems to me indispensable for the geologist, on taking the field, that he should be furnished with completed maps of the district to be surveyed. It not only gives him clearer ideas of the main structural features of the country, and consequently the problems presented to him, but saves much time in his own instrumental work. Geological structure is so intimately connected with and dependent upon topographical features that the better the geologist sees the mutual relations of every hill, ridge, and ravine, the better equipped is he for the work placed before him. Moreover, no matter how painstaking he may be, he can never lay down with precision the boundaries of formations as well as when provided with a properly constructed map.

The Eureka Mining District, with Ruby Hill as a center of mining activity, stands pre-eminent in the United States as a district producing rich argentiferous lead ores. Its great economic importance, the highly interesting mode of occurrence of the ore deposits, not only in the great ore chambers of the leading mines but those of lesser value scattered through the hills, and the singularly complicated geological structure of this broad mountain mass with its profound faults and varied outbursts of volcanic material, made the selection of this tract of country a most judicious one for a thorough survey accompanied with elaborate maps.

The region covered by the present survey embraces a tract of country nearly twenty miles square. It is situated on the Nevada Plateau in Central Nevada, being midway between the Carson Basin to the westward and the Salt Lake Basin to the eastward. The 116th meridian west from Greenwich passes just to the westward of the center of the map, and the 39° 30′ parallel of north latitude crosses Ruby Hill. It lies partly in the county of Eureka and partly in the county of White Pine. It forms a rough, broken, mountainous region surrounded on all sides by the well-known Quaternary valleys of Nevada, presenting topographically and geologically a nearly isolated block connected by narrow ridges with two of the principal ranges which cross the State. To the north Diamond Valley is inclosed by two parallel longitudinal ranges, the Diamond and Piñon, which in the neighborhood of Eureka lose their distinctive features of narrow sedimentary uplifts, becoming lower and broader, and, uniting with Prospect Mountain ridge and large outbursts of igneous rocks, present a complicated mass of mountains and hills. This region may be designated as the Eureka District.

It is doubtful if any area of equal extent in Nevada possesses more varied topographical features, with strongly marked contrasts, capable of producing, when properly delineated, a beautiful map. Most areas in the State present long longitudinal ranges, with short lateral cañons stretching out on both sides of the main axis, the ridge being too narrow to offer any diversity of structure. Here, however, the coming together of several mountain uplifts, connected and penetrated by numerous volcanic outflows, admits of sharp contrasts in the physical features of the country. In close proximity may be found long, serrated ridges, broad,



GEOLOGICAL MAP OF RUBY HILL, EUREKA MINING DISTRICT, NEV.

flat summits, gently sloping tables of nearly horizontal sedimentary beds, and highly inclined strata with abrupt escarpments. Many of the more prominent mountains are characterized by the high angle of their long, uniform slopes—notably Diamond and Prospect Peaks. Broad, shallow basins, narrow, deep cañons, with perpendicular walls, and open, winding valleys connect the higher summits with the lowlands.

Among volcanic rocks, broad, gently inclined fields of basalt, with their abrupt cliff-like walls, are easily recognized. Rough, irregular outflows of rhyolite and crumbling, easily-eroding pumices add their full share to the diversity of outline. In many cases the igneous outbursts have changed previous water channels, making the earlier and somewhat intricate drainage still more complex.

On the Nevada Plateau the broad Quaternary valleys have an average height of 6,000 feet above sea-level. This is about the altitude of Diamond Valley. The lowest contour lines on the map of the Eureka District, both in Diamond and Fish Creek Valleys, taking the Eureka and Palisade Railroad as a base, are exactly 6,000 feet above sea level. Above the level of these sage-brush valleys many prominent peaks rise from 2,500 to 4,500 feet. Diamond Peak, in the northeast corner of the map and at the southern end of the Diamond Range, measures 10,637 feet above sea-level. Prospect Peak, a central station and the second point in the district, measures 9,604 feet, and Atrypa Peak, to the southwest, in the same ridge, has an altitude of 9,063 feet above sea-level. In the Fish Creek Mountains, White Cloud Peak, near the southern limit of the map, the highest point on a broad plateau-like ridge, reaches 8,950 feet above sea-level.

The active field season for geological operations occupied four months and ten days, from July 25 till December 5, a period far too short for the district, when we consider either its great economical importance as a silver-lead producing region or its complicated geological structure, and bearing upon the geology of the Great Basin.

After organizing the party for field work, I took a rapid survey of the entire district, to obtain, as far as possible, correct opinions as to the nature of the country to be examined, and the best way of accomplishing the survey with the least loss of time and labor; at the same time to learn, as far as it might be possible, the problems presented in its study. In attacking a new and unknown geological field, much depends on going to work not only in the right way, but in the right place. Many problems in field work, which in one locality may seem almost impossible to solve, may within a mile, or even within a few hundred feet, be answered at a glance, and the true relations of rock masses, when once correctly understood, save much valuable time in future work.

The first camp was made in the broad basin of New York Cañon, on the eastern side of Prospect Peak, and our first systematic work began along the western base of the mountain. This proved to be a fortunate selection, as it was afterward discovered that here were the oldest beds, and, of course, the base of the entire sedimentary series of rocks exposed at Eureka. The construction of the first cross-section was begun at this point.

From this time we were highly favored with good weather, never forced to stop work for a day, and surveys pushed forward without interruption through summer and autumn. Before the close of the season mapping was all completed and several cross-sections made. Large collections of sedimentary rocks were obtained, illustrating the entire series of Paleozoic beds found at Eureka. In crystalline rocks the collection is quite large, showing not only every variety to be found in the district, but specimens from nearly every locality represented on the map. Much time was devoted to paleontological work, and collecting carried on with energy, which was rewarded with success.

Field operations were only brought to a close by continued low temperature of winter, accompanied by high winds and violent snow-storms. During the last three weeks of the season the thermometer in camp registered in the region of zero every night, and on one occasion fell as low as —16° Fahr. I afterwards learned that the most severe weather of the winter occurred during our last weeks of work. Upon leaving Eureka, Mr. Walcott, under instructions, proceeded to New Mexico to study the formation and make a collection of plant-remains from Triassic rocks in the neighborhood of Santa Fé, and Mr. Iddings went to Virginia City, Nev., for a short time, to do some work under Mr. G. F. Becker's direction.

The topographical party, although working under great difficulties, the mountains being covered with snow, were obliged to remain in camp to complete their field surveys till December 12. Upon the completion of the work, Mr. Clark, with his assistants, proceeded immediately to San Francisco, and began the compilation of the map from the sixty-four plane-table sheets prepared in the field.

The instructions issued to Mr. Clark were to prepare a grade-curve survey of twenty miles square, adopting a scale of 1:10,000, with 50 feet vertical interval between contours, this scale being deemed ample to furnish sufficient detail to lay down all desired geological formations with precision, and to express geological structure in its relation to the varied and characteristic topography of mountain and valley. Upon this map may be accurately located all the mines of the district. By close application to office work, the map, covering a broad, handsome sheet nearly eleven feet square, was compiled by the first of March, 1881, and immediately forwarded by express to the Washington office.

Work upon the material gathered during the season was greatly hindered by vexatious delays in the delivery of freight; the boxes sent from Eureka not reaching their destination till February 1. Immediately upon their arrival the collections were unpacked, properly labeled and catalogued, and arranged for purposes of study, after which the preparation of reports was begun by writing out and carefully arranging in a systematic manner the results of the season's field notes. From this time forward the work has progressed steadily without interruption.

In the month of July, under your instructions, I again visited Eureka for the purpose of examining some unsettled points in its geology, brought out by a study and comparison of observations and sections at different localities after leaving the field. Pressed as I was for time to push forward for publication the geological maps, although many interesting questions presented themselves, I remained only two weeks in Eureka, returning immediately to New York.

The scale of the map finally adopted for publication as best suited to show the geology and topography of the Eureka District is 1,600 feet to the inch, a little more than one-half the size of the original field sheets.

This large map, while it permits of amply expressing most of the minor details of geology, including the smaller outbursts of igneous masses, is on too large a scale to present a comprehensive view of either the topographical or geological structure. This is especially true where the map is published on several detached sheets, which are not readily placed together without considerable space. To obviate this difficulty, and to give the advantages of a small map as well as of a large one, the map has been reduced to proportions which permit of its being published as a single atlas sheet, easily held in the hand. This presents a bird's-eye view of the topography and the mutual relations of the different mountain systems. On this smaller scale, the publication, while it possesses much less value as a working map, is much more effective in bringing out the orographic structure and marked contrast of mountain forms. Where the contours are thrown closely together, the sharp ridges and steep cliffs present the advantages of light and shadow. In a region where the mutual dependence between topographical features and geological structure are so well shown as at Eureka, and as in so many places the boundaries between geological formations are marked by prominent physical features, it is of the first importance to possess a comprehensive sketch-map, which gives the entire field at a glance. The small map is an exceedingly fine specimen of engraving.

Most of the atlas sheets are engraved, and those requiring color distinctions for geological purposes are nearly ready for the printer.

The atlas accompanying the report will contain twelve sheets:—

Sheet I, title page.

Sheet II, map of Eureka District; a single atlas sheet 14 by 15 inches, scale 7,200 feet to the inch. On this map will be shown locations of all important mines, principal wagon-roads, and elevation above sea-level of prominent mountains and well-known land-marks.

Sheet III, geological map of Eureka District; a single atlas sheet. This is the same map as Sheet II, with the geological formations printed over it in color, and the boundaries of the large geological sheets laid down.

Sheets IV to XI, inclusive, eight double atlas sheets, geological maps of Eureka District. The scale is 1,600 feet to the inch. The area covered by these maps is precisely the same as that of Sheet III. They are numbered consecutively from left to right, No. IV being in the upper left-hand corner of the general map. Two maps cover the area from west to east.

Sheet XII, geological cross-sections, drawn to a natural scale, across the map from west to east, showing the structure of the different sedimentary uplifts and their relations to the igneous outbursts.

Upon the general geological map (Atlas Sheet III) the geological features of the district are expressed in twenty-five color distinctions, sixteen of which belong to sedimentary formations, and nine to igneous rocks. In the sedimentary series the Cambrian, Silurian, Devonian, Carboniferous, and Quaternary are represented. In crystalline rocks, granite, granite-porphyry, and quartz-porphyry represent the pre-Tertiary masses, while Tertiary volcanic outbursts are classed as hornblende-andesite, augite-andesite, dacite, rhyolite, rhyolitic pumice, and basalt.

The number of formations delineated upon each of the eight larger maps varies from eight to twenty-one, Sheet IV requiring twenty-one color distinctions to express properly the geological features. The four formations unrepresented are the pre-Tertiary crystalline rocks and dacite, a highly acidic quartzose form of andesite, which only appears in the southern and western areas of the map, removed from the great center of volcanic activity.

These details of formation serve to show the complicated geological structure of the country surveyed, which, like most regions made up of a great thickness of sedimentary beds, accompanied by volcanic activity, is one of profound faulting and displacement, and the continuity of strata broken and obscured by masses of lava.

In the report upon the Eureka District my wish is to present as concisely as possible an account of its geological structure and history, and its relations to adjacent parts of the Great Basin.

The main features of the work will be as follows:

First. A description of each mountain ridge or block, giving a detailed account of each formation as outlined on the map and their relations to each other as shown in a comparison of cross-sections.

Second. A detailed description of the great series of Paleozoic sediments, whose 20,000 feet of strata, from the base of the Middle Cambrian well up into the Upper Coal Measure limestone, present excellent opportunities for geological and paleontological study.

Third. An account of some of the more important dynamical events which have produced the present physical features of the country, and broken the sedimentary beds up into great blocks, such as we now find.

Fourth. A history of Tertiary volcanic activity with its variety of geological phenomena—an activity which probably prevailed through a long period of time, during which every type of Tertiary volcanic rock, except trachyte, found its way to the surface, although in very varying proportions. The relations of the sedimentary beds to the volcanic rocks will be discussed, and the connection between the great north and south lines of faulting and lines of igneous outbursts will be shown. Investigations as to the sequence of volcanic rocks are always of great interest, and the Eureka District can, I think, add something to our stock of knowledge in this direction. The rhyolitic pumices and tufas cover so large a tract of country, extending with nearly unbroken exposures from Diamond Valley on the north, southward across the "Pinto Divide" and Pinto Basin until buried beneath the mountain *débris* of Fish Creek Valley, that they furnish much interesting evidence as to their age and relations to other volcanic rocks.

Fifth. Both for economic and purely scientific purposes, the position and geological horizon of all the more important mining properties of the several mining districts will be given, and some observations recorded as to the relations of the ore deposits to both Tertiary and pre-Tertiary crystalline rocks.

In the Cambrian rocks alone, which form the principal body of Prospect Mountain ridge, there is a very wide vertical range in geological position between ore deposits lying near the base of the lower limestone and deposits like the Page and Corwin in the Pogonip limestone, on the east side of Secret Cañon, just north of Roundtop Mountain.

Prospect Mountain ridge forms the most prominent feature in the Eureka District, extending from Diamond Valley southward for nearly nine miles. South of Prospect Peak it is intricately connected with the Fish Creek Mountains, which trend off to the southwest, stretching out beyond the limits of our map. Prospect Mountain presents a sharp broken outline with abrupt slopes to the westward, and long irregular ridges and hills to the eastward. The strata are everywhere inclined at a high angle. On the other hand, Fish Creek Mountains exhibit a broad table with horizontal or gently inclined strata. Taken together they form the greater part of the Cambrian exposures.

In the Cambrian period both the Middle Cambrian and Upper Cambrian are well exposed. There have been recognized seven well-defined formations, beginning with the lower, as follows: Prospect Mountain quartzite, Prospect Mountain limestone, Secret Cañon shale, Hamburg limestone, Hamburg shale, Pogonip limestone, Eureka quartzite.

All these formations are designated by local names, with the exception of the Pogonip limestone, which is so called from Pogonip Mountain, in the White Pine mining region, where the horizon is well developed.

From the base to the top of the group the Cambrian presents a conformable series of beds. The Eureka quartzite, while it carries no paleontological evidence of its age, is, on account of its conformability with the Pogonip limestone, placed at the summit of the upper Cambrian. Between the Eureka quartzite and the next overlying limestone there is a non-conformity of deposition, and the true Silurian beds come in with a marked change in fauna. This non-conformity, which has never before been recognized in the Great Basin, is, I think, of very considerable importance in stratigraphical geology, and some facts in relation to it I propose, in my report, to bring out in detail.

On the map, the Silurian period is designated by one color, as no well defined horizons have as yet been determined, and the boundary line between it and the Devonian by no means sharply ascertained. In the Devonian two color distinctions are given: one for the great limestone belt, which is not only one of the marked geological features of the district, but one of the highest importance in studying the series of palæozoic sediments in the Great Basin; and the other for the black argillaceous and arenaceous shales which overlie the limestone.

These beds have been named the White Pine shales, from the locality where they were first recognized, in Eberhardt Cañon, and underlying the town of Hamilton. The characters of the two groups are quite similar, although at Eureka they attain a much greater development than at White Pine.

For the Carboniferous period four geological divisions are well marked and require as many color distinctions. They are designated as Diamond Peak quartzite, Lower Coal Measure limestone, Weber conglomerate, and Upper Coal Measure limestone, and reach their highest development in the northeast corner of the district, where they form the southern termination of the Diamond Range. The lowest members form the slopes of Diamond Peak.

Among the most interesting and important results of the season's survey to geologists and paleontologists will be the invertebrate fauna collected from the paleozoic beds. Before the systematic survey was undertaken, the Eureka District was regarded as a very poor one for organic remains. Indeed, with the exception of a small collection of fossils, made by the writer during a two days' visit to the mines on Ruby Hill several years previous, and described in the volumes of the Geological Exploration of the Fortieth Parallel, I believe very little has been brought in. The collection made at that time was from the Pogonip beds of the Upper Cambrian, east of Adams Hill, and from the Carboniferous limestones, on the hill south of the Richmond furnaces.

The collections made by the Eureka District survey number about 4,500 specimens. While this is by no means a large number as compared with well-known and thoroughly-explored regions in the Eastern States and Mississippi Valley, it is, so far as I know, very much the largest collection of paleozoic fossils ever brought in from any equally limited area in the Far West. Its value, however, does not consist in its size, or in the number of new species found, mention of which will be made further on, but from the systematic collection obtained in one geological district, extending through more than 20,000 feet of paleozoic sediments formed of limestones, shales, clays, quartzites, sandstones, conglomerates, and grits, extending from the base of the Middle Cambrian well up into the Upper Coal Measure limestone. No attempt was made, owing to the limited time at our disposal, to gather large collections. Even in those localities which offered the most favorable opportunities, there was never more than a part of a day devoted to collecting. The time was not occupied in examining well-defined horizons, but in carefully searching through hundreds of feet of limestone and arenaceous beds, mainly barren or with poorly preserved forms, for evidences of organic remains to fill up the gap in the great series of beds. Much time was also given to obtaining paleontological evidences of horizons in complicated structural regions and regions showing considerable faulting and disturbance from outbursts of volcanic masses. In many such cases stratigraphical and lithological evidences fail entirely, and it is necessary to rely almost exclusively on organic remains.

In the *Olenellus* beds, a narrow belt of arenaceous shales, lying at the base of the Prospect Mountain limestone, occur the lowest fossiliferous strata found in the district. It is probable, from the association of forms found here, that the *Olenellus* beds are near the base of the Middle Cambrian strata. Unfortunately, no beds came to the surface below the Prospect Mountain quartzite, which immediately underlies the Prospect Mountain limestone. If the district anywhere exposed a lower group of fossiliferous strata, they would probably belong to the *Paradoxides* beds of the Lower Cambrian.

Here at Eureka we have a good section of the Middle and Upper Cambrian rocks. Now, one of the most desired points in the stratigraphy of the Great Basin of Utah and Nevada is a good exposure across the Lower and Middle Cambrian, which would connect the lower rocks with those of Prospect Mountain. Above the shale, which is a transition band between the quartzite and limestone, the beds pass into a true limestone, which forms the greater part of both slopes of Prospect Mountain ridge. This limestone, poor in fossil remains, passes at its base into beds yielding Potsdam forms. Allied species occur through the Hamburg limestone and Hamburg shales.

East of the Hamburg mine, at the base of the Pogonip or Upper Cambrian limestone, there is a decided mingling of species, but passing upwards we gradually find higher forms, and at the top the fauna indicates the horizons of the Calciferous and Chazy. Conformably overlying the Pogonip limestone occurs the Eureka quartzite, which is without any recognized organic remains, and which, as already mentioned, owing to its stratigraphical position, is placed at the summit of the Cambrian series.

Between the Eureka quartzite at the base and Diamond Peak quartzite, which is regarded as the base of the Carboniferous period, at the summit, the beds yield ample paleontological proof to confirm the stratigraphical evidences of their Silurian and Devonian age. The Silurian is represented by characteristic but poorly-preserved fragmentary remains, but identical with or closely allied to forms common to the Trenton of New York. On the other hand, the massive beds of Devonian limestone have yielded a rich and varied fauna.

From the two great belts of Carboniferous limestone separated by the Weber conglomerate, valuable additions have been made to our knowledge of their life. As the limestones are, in general, favorable for the preservation of organic remains, fossil-bearing horizons occur throughout the series, and geologists are not so dependent upon favored localities as in the Lower Paleozoic rocks.

Accompanying my report upon the "Geology of Eureka District" will be Mr. Charles D. Wolcott's report upon the paleontology of the district. It will, I think, be accepted as a valuable contribution to our knowledge of the geology of the Great Basin.

Mr. Walcott's detailed study of the paleontological material shows three hundred and fifty-nine species in the collection. Of these three hundred and fifty-nine species, two hundred and ninety-nine have been specifically determined, the remaining sixty receiving only a generic name, as they are either imperfectly represented, or, as in the case of the Trenton fauna and Devonian corals, it appeared best to await the collecting of more complete material before attempting to illustrate them.

The Cambrian fauna, embracing both the Middle and Upper divisions, contains one hundred and nineteen species, of which no less than sixty-three have been indentified as new. An unusually large brachiopodous fauna for this age is represented by twenty-four species. The *Trilobita* are represented by fifty-nine species, a percentage of the entire fauna, rather below the average. The genus *Receptaculites* is distinguished by the presence of three species and an immense number of individual specimens of one of them, *Receptaculites Gumbeli*, occurs in the upper portion of the Pogonip limestone.

The Silurian fauna is but slightly developed, and the material obtained mainly from the Trenton formation. The thirteen species found are sufficient to indentify the geological horizons, but are too poor and fragmentary for detailed study.

From the Devonian rocks the fauna includes one hundred and forty-four species, thirty-eight of which are new, and 50 per cent. are identical with species occurring east of the Mississippi River.

The accompanying lists show the varied character of the fauna:

	Genera.	Species.
Porifera	3	3
Actinozoa	10	18
Brachiopoda	16	63
Lamellibranchiata	14	15
Gasteropoda	10	24
Pteropoda	3	6
Cephalopoda	4	8
Crustacea	2	2
Pœcilopoda	4	5

From the Carboniferous rocks the fauna afforded eighty-three species, twenty-four of which are new and interesting forms. One of the most striking features is the occurrence of twenty-eight species of lamellibranchiate shells, a class that heretofore has been but sparingly represented in the collections of Carboniferous fossils from the Rocky Mountains and the Great Basin.

During the preparation of Mr. Walcott's report he has written descriptions of one hundred and twenty-three new species, and made notes, more or less full, upon one hundred and sixty species, which presented in their characters or geographical distribution information not heretofore published.

It will be seen, therefore, that the report embraces a fauna from the Cambrian, Devonian, and Carboniferous. It will be illustrated by over three hundred accurate drawings of fossils, arranged on twelve plates. Four plates represent the fauna of the Cambrian, five that of the Devonian, and three that of the Carboniferous.

A second special monograph, to accompany the geological report, is by Mr. Joseph P. Iddings, upon the microscopic petrography of the crystalline rocks of the Eureka District. From every characteristic and important specimen of crystalline rock, whether from a geological or mineralogical point of view, a thin section for microscopical examination has been prepared. An investigation of these sections has been of great value, not only as an aid in a proper classification of the rocks, but in determining their mutual relations, and in pointing out striking differences in their internal structure, which have a direct bearing upon many geological questions connected with eruptive masses. In this branch of geological investigation Mr. Iddings has made a systematic study of all the thin sections in the collection, and from a mass of notes has prepared a condensed and concise statement of the results of his work.

His report is divided into two parts or chapters. The first treats of pre-Tertiary crystalline rocks, granite, granite-porphyry, and quartz-porphyry; and the second treats of Tertiary crystalline rocks, augite-andesite, hornblende andesite, andesitic pearlites, dacites, rhyolite, pumice, and basalt. This report will have several illustrations showing some interesting features in the structure of fine ground mass in volcanic rock, and the micro-granitic structure observed in granite-porphyry. A number of curious products of decomposition will also be illustrated.

Accompanying my report is a geological map of Ruby Hill, in the Eureka mining district, which is prepared from one of the larger atlas sheets of which it forms a part. It is presented here for the purpose of showing the principal physical features of the adjacent country, as well as the position of the different mines situated on Ruby Hill, where all the more important mining interests center. By reference to the map it will be seen that the intersection of the 116th meridian west of Greenwich and the 39° 30′ parallel of north latitude occurs in the valley just west of the Isandula shaft, the latitude line crossing Ruby Hill about 200 feet south of the shaft of the Eureka Consolidated Mine. Eureka is connected by the Eureka and Palisade Railway, 88 miles in length, with the Central Pacific Road at Palisade. The railway station is situated just north of the town, in Eureka Cañon, about a quarter of a mile below the Eureka Consolidated furnaces. Branch tracks connect with the Eureka Consolidated and Richmond furnaces, and these again by a somewhat sinuous course with the ore-dumps on Ruby Hill. Eureka, a long narrow town, lies in the main northern drainage channel of a large area of country, as the inhabitants know only too well during the season of violent storms of summer. It has a mean altitude of 6,500 feet above sea-level, and is the center of population and trade for this part of the State.

Ruby Hill is situated a little to the south of west of Eureka. It stands out as a bold termination to the long ridge of Prospect Mountain; its prominence being largely due to its somewhat isolated position, erosion having worn out deep ravines on its southern slope, leaving it connected with the main ridge by a low saddle of quartzite. The highest point on the hill has an altitude of 7,291 feet above sea-level and about 500 feet above the neighboring valley. On Ruby Hill are located the two principal mining properties of the district, those of the Eureka Consolidated and Richmond Companies, and to the west of the latter property, and about 200 feet lower down, is the Albion shaft. The Phœnix and the Jackson properties lie to the southeast of the Eureka Consolidated, but separated from Ruby Hill by a narrow deep ravine.

It is not my purpose within the limits of this letter to discuss the geological features of Ruby Hill and the adjacent formations, reserving such discussions for my final report, but I desire in a few paragraphs to explain its structure sufficiently to make the map intelligible and to point out the relations of the beds to the main body of Prospect Mountain. As previously mentioned, Prospect Mountain is mainly a sedimentary uplift of Cambrian rocks. Along the eastern slopes the beds dip to the eastward, and from the entrance of Secret Cañon, where they rise above the volcanic rocks, they present, for more than six miles, a nearly uniform north and south strike. To the north, where the ridge begins to descend rapidly toward the valley, that is, just to the south of Ruby Hill, the strata bend around to the westward with a broad swinging curve, as is so often seen in the structure of many anticlinal ridges. Naturally in such cases, the lower rocks near the axis of the curve have undergone more crushing and faulting and lie in a disturbed and broken condition, causing a frequent change in strike and dip. This is the case with the Prospect Mountain quartzite; in general the structure is simple, but owing to minor faults and local disturbances, it becomes very complicated in detail.

Directly in the axis of the curve, and on the south side of the ravine which separates Ruby Hill from Mineral Hill, occurs an obscure outcrop of granite. It is so insignificant and so covered with *débris* from the hill-slope that it is scarcely recognizable; and, although the region has been examined thoroughly by seekers after ore, it has probably been observed by few persons. There are probably very few ranges, or any considerable group of hills in Central Utah or Nevada, between the Wahsatch and the Sierra Nevada Ranges, that do not present a body of granite of greater or less extent. It crops out either at the base of the sedimentary series, is found in the low passes, or is associated with volcanic rocks. At Eureka, although the lower sedimentary beds are well exposed, this small outcrop of granite is, I believe, the only one in the district. All outcrops of granite-porphyry and quartz-porphyry at Eureka present abundant proof of their having broken through the surrounding sedimentary rocks, but in the case of the granite the evidence is quite obscure. The overlying sedimentary beds wrap around the granite mass, and everywhere dip away from it. Although this exposure is quite limited, there is reason to suppose that it represents a much larger body, and has exerted a very considerable influence on the geological structure of adjacent rock-masses. The granite is best observed in coming up the ravine from the west, and is exposed just above the path where some miners have cut into it, attracted by the red color of the decomposed rock. It extends from the foot-path up to within fifty feet of the top of the hill. There are no good exposures of the rock, and it is so much decomposed that fresh specimens are obtained with difficulty. It presents the true granitic habit. The essential minerals are quartz, feldspar, hornblende, and mica, the latter being very abundant. The quartz is grayish-white in color, in irregular pellucid grains.

The upper beds of Prospect Mountain quartzite, in their northern extension, form the southern side of Ruby Hill. Its surface outline is an irregular one, and underground workings in the mines show an equally broken line. Conformably overlying this quartzite occurs a broad belt of limestone, which has been named Prospect Mountain limestone, as it forms the most prominent geological formation of the mountain. It everywhere forms the summit of Ruby Hill and its northern slope. In its structural features and chemical composition it is quite identical with the main body of limestone, presenting the same crushed and broken character that is seen in so many places on the mountain. All the ore deposits of Ruby Hill occur at this horizon, many of them lying close to the quartzite and never reaching the overlying shale, while others near the shale are far removed from the quartzite; but in no instance is either the underlying or overlying formation penetrated by ore bodies. Both the Eureka Consolidated old shaft and their new shaft, which is now in process of construction, and will be ready for hoisting early in the spring of 1882, are located in the limestone, but the Richmond and Albion shafts are in the overlying shale near the contact of the two formations. By means of old workings it is quite possible to pass from the Jackson Mine through the Phœnix, Eureka Consolidated, K. K., Richmond, and on to the Albion, reaching the surface through the latter shaft.

Overlying the Prospect Mountain limestone occurs the Secret Cañon shale, the horizon being identical with the great argillaceous shale formation that occupies the bottom of Secret Cañon.

The ravine between Ruby and Adams Hill has been worn out of this formation by erosion. Conformably overlying the Secret Cañon shale comes the Hamburg limestone, which forms Adams Hill, extending northward as far as the Wide West ravine. It is the same limestone as the prominent ridge in which the Hamburg and Dunderberg mines are located. On Adams Hill are situated the Price & Davies, Wales, Silver Lick, Wide West, and Bowman mines. The limestone of Adams Hill has undergone less local disturbance than that of Ruby Hill; the strata lie inclined at a much lower angle, and on the south side of the hill have curved around to a due east and west course.

A second shale body occupies Wide West ravine, which erosion has worn out in a similar manner to the ravine lying south of Adams Hill. This shale body belongs to the horizon of the Hamburg shale, which may be seen east of the Hamburg Mine, but which is still better developed east of the Dunderberg Mine. North of the Wide West ravine comes in the Pogonip limestone, the upper limestone of the Cambrian system, which extends northward beyond the limits of the small map.

In my report, in addition to the stratigraphical and lithological evidences of the position of these beds and their relations to those of Prospect Mountain, will be the evidence of paleontology, organic remains having been secured from Ruby Hill, Adams Hill, and the overlying Pogonip limestone which correlate the formations with similar beds to the south. On Ruby Hill an interesting discovery was made of fossils in a well-defined stratified limestone on the seventh level of the Richmond Mine, which without doubt identify the formation with that of the Prospect Mountain limestone. The reason it is so difficult to connect this northern series of beds with those upon the east side of Prospect Mountain, is that they cannot be traced continuously, owing to a north and south line of faulting which cuts off the Prospect Mountain limestone, Secret Cañon shale, Hamburg limestone, and Hamburg shale, and brings up the Pogonip limestone as a continuous body extending northward beyond the limits of the map.

East of Adams Hill the Pogonip limestone dips to the eastward, and passes under Cariboo Hill, which is capped with Eureka quartzite, and the same structure is again seen on the east side of Goodwin Cañon, where the limestone conformably underlies the quartzite of McCoy's ridge. Overlying the quartzite of McCoy's ridge occurs a narrow belt of grayish-black silicious limestone, referred to the Silurian period, in which the Seventy-six Mine is located. It is, I believe, the only mine in the district found at this horizon.

In closing this letter I wish to express my indebtedness to the trustees of the American Museum of Natural History for the generous facilities which they have afforded us, not only in offering the use of their valuable library and collections, but in placing the most desirable and agreeable of working rooms at our disposal during the preparation of the report and maps.

Very respectfully, your obedient servant,

ARNOLD HAGUE,
Geologist-in-charge.

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

REPORT OF MR. RAPHAEL PUMPELLY.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF MINING GEOLOGY,
Newport, R. I., November 10, 1881.

SIR: I have the honor to forward the following report of the work under my charge.

The field covered by my division has been:

1st. The gathering of statistics of mines and mining east of the Missouri River.

2d. The tracing out, and the study of the extent, structure, and character of the copper-bearing rocks, bordering the northern and southern shores of Lake Superior.

In gathering for the census the statistics of mines and mining, I have attempted, in accordance with the desire of the Superintendent of Census, to gather the statistical information in such a manner as to throw as many side lights as possible upon the correlation of the different branches of the industry and of the industry itself (as a whole), with other industries and with society at large.

To do this required the framing of schedules adapted to the various branches of mining and metallurgy and containing a large number of of questions capable of being understood by the mining community, and to most of which the answers could be summed up to give totals for the whole country.

Although the questions asked varied according to the branch of the industry, the most important of those intended to foot with totals are contained in the following scheme:

QUESTIONS OF LOCALITY.

State.
County.
Number of mines.

QUESTIONS RELATING TO PRODUCTION.

Maximum capacity of yearly product in commercial units of the substance mined.

Product during the census year in tons of the material hoisted.

Product during the census year in the commercial units of merchantable product.

QUESTIONS RELATING TO MATERIALS AND POWER EXPENDED.

Value of product.
Value of materials, or supplies used.
Wages.
Men employed above ground.
Men employed below ground.
Boys employed above ground.
Boys employed below ground.
Total employés.
Miners.
Laborers.
Administrative force.
Number of horses, mules, and oxen.
Number of steam-engines, horse power and steam engines.
Value of all machinery.
Value of explosives.
Cords of wood used for fuel.
Value of wood.
Lineal feet of timber used.
Value of timber.
Board measure and sawed lumber used.
Value of lumber.

QUESTIONS RELATING TO CAPITAL.

Amount of working capital.
Value of plant.
Value of real estate.
Total capital.

In addition to the above questions, to which answers were required from all establishments, there were asked a large number of other questions, the answers to which, from a considerable number of establishments, would give the necessary data for estimating the totals for the whole industry.

It was decided, with the sanction of the Superintendent of Census and of the Director of the Geological Survey, to carry the investigation, in so far as it related to the production of iron ores for the census year, into an exhaustive study of the various iron ores of the United States, with a view to determining:

1st. Their classification.

2d. The distribution, geographically and geologically, of the different varieties of iron ore.

3d. The manner of occurrence of the different varieties.

4th. The chemical character of the varieties.

This involved the visiting of a large proportion of the mines operated during the census year by experts, who studied the deposits and took commercial samples of the product. In doing this they were instructed to take strictly "average commercial samples" of the ore as ready for shipment, and in all cases where desirable to take average samples of the different varieties occurring in the mine in order to determine the influence of the separate varieties upon the chemical character of the whole product.

These samples weighing 10 to 15 pounds each, and consisting each of several thousand chips, were forwarded to the laboratory at this office, accompanied by hand specimens taken to illustrate each variety of ore contained in the sample, and by triplicate specimens illustrating the ore and its associated rocks.

Special pains has been taken in determining the amount of phosphorus throughout the whole series of iron ores.

The number of schedules filled out at establishments of productive mining industries amounts to 10,440; of these many single schedules represent several establishments.

In the census of 1870 only 2,254 establishments were canvassed within the same field.

These statistics have all been tabulated, and bulletins of several, showing the results of various branches of the mining industry, have been forwarded to the Superintendent of Census, while others are in course of preparation.

There remains now in this department to be finished only the generalization and graphic representation of these returns.

I present, in the accompanying table, an abbreviated tabulation of the most essential results of the statistical inquiry into the mining industries.

The returns are given in separate columns for the eastern and western districts. Those of the eastern district were collected by my Division, and are believed to be both complete and accurate.

Those from the western district (that is, west of the one hundredth meridian) were transferred to me from other divisions of the Survey, but are still incomplete.

Mineral production of the United States from June 1, 1879, to June 1, 1880.

[Ton=2,000 pounds.]

	Anthracite coal. *	Bituminous coal.		Iron ore. §	Copper. ‖		Lead. ‖	Zinc. ‖
		Eastern district. †	Western district. ‡		Eastern district. †	Western district. ‡	Eastern district. †	Eastern district. ‡
Number of counties	8	314	20	135	12	13	29	....
Number of establishments	280	2,943	46	805	32	38	234	....
Product of establishments ....tons	28,361,043	40,311,459	1,477,736	7,061,829	lbs. 51,091,188	lbs. 6,244,702	tons 54,766	tons 127,648
Value of said product	$41,723,700	$49,044,498	$3,272,470	$20,470,756	$8,842,961	....	$2,113,592	$2,128,877
Irregular product ¶ ....tons	28,224	628,569	....	909,877	....	....	....	....
Total product ....do	28,378,267	40,940,028	1,477,736	7,971,706	lbs. 51,091,188	lbs. 6,244,702	tons 54,766	tons 127,648
Value of total product	$41,780,148	$49,733,603	$3,272,470	$23,167,007	$8,842,961	....	$2,113,592	$2,113,592
Number of men employed above ground	15,964	13,842	621	16,345	2,755	80	3,097	....
Number of men employed below ground	38,235	76,512	2,812	13,735	3,069	50	4,526	....
Number of boys employed above ground	12,193	755	....	1,339	202	....	107	....
Number of boys employed below ground	3,979	5,366	8	249	90	....	57	....
Total employés	70,371	96,475	3,442	31,668	6,016	130	7,787	....
Value of machinery	$13,690,415	$2,403,211	$265,650	$3,210,558	$2,632,800	....	$521,268	....
Total capital	$153,038,196	$93,517,464	$8,480,573	$61,782,287	$31,675,096	$111,500	$7,565,672	....
Total materials used	$6,648,277	$4,661,662	$189,431	$2,896,011	$1,391,101	$90	$347,807	....
Number of animals	8,373	9,018	221	3,993	251	2	263	....
Number of steam engines	1,652	812	42	821	134	1	173	....
Horse-power of steam engines	105,412	24,696	1,447	24,838	13,491	30	7,083	....
Total wages paid	$22,417,055	$30,707,059	$1,828,401	$9,538,117	$2,915,103	$94,128	$2,716,219	....
Tons paying royalty	14,485,891	13,689,864	....	2,266,510	....	....	....	....
Amount paid as royalty	$3,357,372	$1,964,076	....	$981,170	....	....	....	....

* These returns will be increased by two collieries yet to be heard from, producing about 75,000 tons each.
† East of one hundredth meridian.
‡ West of one hundredth meridian.
§ During the census year no iron ore was mined west of the one hundredth meridian for the manufacture of iron, excepting 6,972 tons in Oregon, which is included in this table.
‖ The returns from west of the one hundredth meridian are incomplete for copper, lead, and zinc.
¶ Mined by unorganized industry (as by farmers) and to extent of less than $500, and without special plant or equipment.

In the work of determining by chemical analysis the economic value of the iron ores of the United States, the collecting of average commercial samples of the ores has been finished, and the following table will show the number of samples collected in each State.

Total number of samples received up to November 1, 1881, 1,388.

Apportioned as follows:

Alabama	78	New York	159
British Columbia	1	North Carolina	73
California	4	Ohio	93
Colorado	31	Oregon	3
Connecticut	18	Pennsylvania	133
Georgia	61	Rhode Island	1
Kentucky	34	Tennessee	154
Lake Superior	139	Utah	29
Maine	3	Vermont	10
Maryland	55	Virginia	100
Massachusetts	11	Washington Territory	1
Minnesota	8	West Virginia	19
Missouri	49	Wisconsin	6
Nevada	1	Wyoming Territory	2
New Hampshire	1		
New Jersey	109	Total	1,388
New Mexico	2		

Of these samples there have been analyzed the aggregate numbers set down opposite the names of the respective districts in the following table.

Analyses made up to November 1, 1881, 807.

Apportioned as follows:

	Partials.	Complete.	Total.
Alabama	71	5	76
Connecticut	16		16
Georgia	41	4	45
Kentucky	32	1	33
Lake Superior	113	28	141
Maine	2	1	3
Massachusetts	10		10
Missouri	43	5	48
New Hampshire	1		1
New Jersey	44	5	49
New York	63	3	66
North Carolina	54	10	64
Rhode Island	1		1
Tennessee	130	14	144
Vermont	9	1	10
Virginia	88	12	100
Total	718	89	807

Professor Irving has finished his study of the copper rocks of Lake Superior, having followed them from the end of Keweenaw Point through Wisconsin, across the Mississippi, and northeast along the north shore of Lake Superior into the British territory, to connect with the work of the Canadian geologists. The report, containing elaborate, instructive, and valuable results, is already in my hands, and will be forwarded to you in a few days.

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

RAPHAEL PUMPELLY,
Geologist in charge.

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

REPORT OF MR. G. F. BECKER.

DIVISION OF MINING GEOLOGY,
DISTRICT OF THE GREAT BASIN,
New York, October 27, 1881.

SIR: At the date of the last annual report I had been engaged since the preceding April in investigating the geology of the Comstock lode, and at the same time in conducting the census examination of the mineral industry west of the Rocky Mountains. The detailed report of the latter work belongs elsewhere, and it is sufficient to state in this place that throughout the past year it has continued to occupy, and still occupies a portion of my time.

The field work on the Comstock was continued through the winter months, and was not completed until March, 1881, eleven months from its commencement. So extended an examination was rendered necessary in part by the geological difficulties, but largely also by the fact that the district had previously been examined by a number of eminent geologists, with not altogether accordant results. In this, perhaps final examination, it was therefore needful to accumulate a vast amount of evidence of the most precise and detailed character as a means of deciding disputed points. At the close of my field work on the Comstock, I was ordered to New York, and have since been engaged in working up the material collected and in preparing the observations made, for publication. The resulting paper is now nearly completed.

Mr. R. H. Stretch, whom I engaged to assist me in mapping the underground geology of the Comstock, completed his contract about April first. Mr. Stretch's familiarity with the inaccessible upper portion of the lode, which he had mapped for the Exploration of the Fortieth Parallel, made him an especially valuable assistant in the very complicated operation of bringing to bear the maximum amount of evidence on the structure of the sections chosen.

On May first, Mr. F. R. Reade resigned his position as assistant geologist. The collections of the Washoe District owe much to his efforts, as well as the computation of the increase of temperature below the surface at Virginia.

On July first, Dr. Carl Barus, a digest of whose work as physicist on my staff will appear elsewhere, having completed, more than satisfac torily, the investigations I required, was assigned the prosecution of in quiries not connected with my duties.

From the first of April Mr. J. S. Curtis, who during the previous year had served as census expert under my direction, was appointed geologist, and ordered to report to me. He was directed to undertake an examination of the mine geology of the Eureka District, which forms a necessary complement to Mr. Hague's examination of the general geology of the region. The Eureka ore deposits are of a somewhat remarkable character, consisting in masses of ore distributed in limestone. The nature of the connection existing between these bodies has formed the question at issue in several of the most important mining lawsuits which have ever been tried in the United States. Several of the most noted geologists of the continent, and a large number of well-known mining experts have made public their views regarding the nature of these deposits, but neither geologists nor experts have been able to agree upon an opinion. Mr. Curtis will continue his examination until he has accumulated as much evidence as is obtainable upon the following points:

1. The structural nature of the deposits; that is to say, whether they have any direct communication with one another, and are to be regarded as forming an irregular vein, or are entirely isolated, and share only a common origin, &c.

2. The peculiar physical and chemical conditions which have brought about the actual distribution of the ore-bodies.

3. The changes which the ore has undergone in place.

4. The probable origin of the ore, and the method of its deposition.

5. The dependence of these features upon the lithological character and the structural phenomena of the surrounding region.

A very large amount of laboratory work is a necessary concomitant of the study of the subjects mentioned; and as on the Comstock, the disputed indications of the phenomena necessitate the accumulation of an unusual amount of evidence. Mr. Curtis's examination is still in active progress. Its results will be ready for publication in about a year.

Very respectfully, your obedient servant,

GEO. F. BECKER,
Geologist-in-charge.

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

REPORT OF DR. F. V. HAYDEN.

PHILADELPHIA, PA., *November* 19, 1881.

SIR: I have the honor to submit herewith a brief abstract of my operations under your direction for the past fiscal year. The work has been a continuation of that noticed briefly in the first annual report of the survey, on page 50, namely, a digest of the field notes and various reports which have been prepared by me or under my direction for several years past, embracing that portion of the Rocky Mountain region that lies north of New Mexico and west of the 94th meridian.

No field work has been performed by me during the past year. My studies during that time have been mostly confined to the region drained by the Missouri River and its tributaries. The early explorations, which really comprise its history, have been examined. The physical geography as well as the geology of this vast region is full of interest, much of which remains to be written. The country lying more immediately along the main Missouri and Yellowstone Rivers was the scene of my early explorations, from 1853 to 1860, when the region was mostly unknown and almost inaccessible. Traveling was then necessarily slow across the broad area between the Missouri River and the Rocky Mountains, enabling the geologist to study with considerable detail the simple but interesting geological structure of what is usually termed the plain country. At the present time the railroads are so numerous that the tendency to pass rapidly over this great intermediate belt is universal, so that this vast area of nearly or quite horizontal strata receives very little study except from the window of a railroad car. In the plains of Kansas, Nebraska, Dakota, and Montana the geology is very simple and the work can be performed with great rapidity, as extended areas of the strata are horizontal or nearly so. Though much is known, there remains still a good deal of work to be done before we can affirm that we have a critical knowledge of the geology. The period of pioneering has passed away, and at the present time the completion of our knowledge of the geological structure of the plains can be greatly facilitated by using the thoroughfares as base lines, radiating from them in every direction.

During the past summer I have spent some time in digesting the history and results of the exploration of the Black Hills of Dakota. The publication of the excellent monographic study of this mountain range by Messrs. Newton and Jenney, under the auspices of the Director of the United States Geological Survey, has stimulated the interest anew. I have made a careful examination of the geological portion of the report prepared by Mr. Newton, and I am glad to bear testimony to its great value, conscientious accuracy, and fairmindedness throughout. The report is so exhaustive that it must form a datum point for the future study of the geology of the Northwest. Similar monographic studies of greater or less importance might be made of other isolated ranges east of the main Rocky Mountains, as the Big Horn, Bear's Paw, Little Rocky, Girdle Mountains, &c.

The writer visited a portion of the Black Hills in the winter of 1854; in 1856 he acted as geologist to the exploration of this region, conducted by General Warren, United States Engineers, and in 1859 he examined the northeastern portion as geologist to the expedition commanded by Colonel Raynolds, United States Engineers. All these examinations were mere reconnaissances, and no time was permitted for those mature, detailed studies of which Mr. Newton's report is a type.

The problems connected with the Coal or Lignitic groups of the Northwest have been still further examined. The reports of the Canadian Geological Survey, and particularly those of Dr. Hector and Mr. G. M. Dawson, of the Northwest Boundary Survey, have been of the greatest aid. The great Lignitic group, as well as other formations known in the Upper Missouri region, are extended northward far into British America, so that the labors of the Canadian surveyors become of great importance to the United States geologists. Although many geologists may affirm with much positiveness that the precise age of the Lignitic is fixed in the geological scale, the difference of opinion among certain eminent geologists in this country and in Europe and the conflicting evidence of the organic remains shows that much remains to be done before the problem can be regarded as clearly solved. The term Laramie group was established by the study of certain coal strata in eastern Colorado and along the line of the Union Pacific Railroad in Wyoming Territory. These coal strata continue northward, without interruption, far past our northern boundary into British America. At the south the organic contents indicate that nearly the entire group of strata is of brackish-water origin, while northward along the Yellowstone and Missouri Rivers, the great thickness of coal or Lignitic beds are brackish at the base, but soon become purely fresh water. The plant remains are similar and in many cases of identical species. On the Missouri River the coal beds were designated many years ago as the Fort Union group. So far as we now know, there is no distinct line of demarcation between the Fort Union and Laramie groups. Are they identical in part or entirely? With the data before me, I am unable to determine this question. I would respectfully suggest that a critical examination of a belt of country from a point on the Union Pacific Railroad where the Laramie group is well shown, fifty to one hundred miles in width, northward, passing up between the Black Hills of Dakota and the Big Horn range to the northern boundary of the United States, would furnish a vast mass of material toward the settlement of this question. A continuous section should be made and the organic remains of each layer, however thin or apparently unimportant, should be preserved and kept separate. So far as we know at this time, there is no well-defined break in the continuity of the strata in the plains from the base of the Cretaceous to the summit of the latest Tertiary, and yet, along the borders of the mountain ranges some unconformability has been observed. In the examination of the belt of country suggested, the eastern base of the Big Horn range and the western side of the Black Hills would show the entire series of sedimentary strata known in the Northwest.

The material relating to the Yellowstone Park now under my control has been put in shape for publication. Should the survey under your charge be hereafter extended into this interesting region, the reports, maps, charts, &c., must be important.

A geological map on a scale of 12 miles to one inch, covering the entire area examined by me, or under my direction, from 1853 to the close of the season of 1878, is nearly completed. This map can be improved from year to year as additional material is collected, and thus made useful in connection with the more extended enterprises of the survey.

In presenting this brief report, I beg permission to thank you cordially for much courtesy and personal kindness.

Very respectfully, your obedient servant,

F. V. HAYDEN.

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

REPORT OF MR. CLARENCE KING.

NEW YORK, *November* 1, 1881.

SIR: I have the honor to submit the following brief statement of the executive direction for the fiscal year ending June 30, 1881, of an investigation concerning the production of the precious metals in the United States for the census year ending May 31, 1880, and incidentally for the fiscal year ending June 30, 1880.

As no investigation of the production of the precious metals for a given period could be intelligently undertaken until the close of that period, active operations were not commenced until the end of the above-mentioned census year.

On the 1st of June, 1880, I effected an organization, employed a corps of special experts, and dispatched them to the field, charging them with the duty of personally visiting all the important precious-metal districts of the United States, and with the investigation of the total output of gold and silver.

For purposes of convenience and easy executive control, the whole country was divided into the following three general divisions:

(1.) Division of the Pacific, consisting of California, Washington, Oregon, Idaho, Utah, Nevada, and Arizona, under the immediate charge of George F. Becker, geologist, United States Geological Survey, whose headquarters were at San Francisco, Cal.

(2.) Division of the Rocky Mountains, consisting of Montana, Dakota, Wyoming, Colorado, and New Mexico, under S. F. Emmons, geologist, United States Geological Survey, having headquarters at Denver, Colo.

(3.) Eastern Division comprising all the States and Territories east of the Rocky Mountains, under the charge of Raphael Pumpelly, geologist, United States Geological Survey, with headquarters at Newport, R. I.

Each of these three Chiefs of Division were directed to employ the necessary special experts, who upon my nomination were duly appointed by the Hon. Francis A. Walker, Superintendent of Census.

The members of the staff and their territorial assignment were as follows:

PACIFIC DIVISION.

Mr. J. M. Cunningham, for the eastern portions of Washington and Oregon and the northeastern part of California;

Mr. J. S. Curtis: Nevada, south of the line of the Central Pacific Railway;

Mr. J. H. Hammond: Central and eastern counties of California.

Mr. D. B. Huntly: Utah, Southwestern Nevada, and portions of California;

Mr. H. W. Leavens: The tract lying west of the Cascade and Coast ranges in Washington, Oregon, and Northern California;

Mr. Walter Nordhoff: Southwestern and Middle Arizona;

Mr. W. H. Sander: Western Arizona;

Mr. Luther Wagoner: Southern California;

Mr. Albert Williams, jr.: Idaho, Nevada, north of the Central Pacific Railway, and the Comstock Lode.

DIVISION OF THE ROCKY MOUNTAINS.

Mr. W. B. Fisher: Portions of Lake, Chaffee, Clear Creek, and Gilpin Counties, in Colorado, and Beaverhead County, in Montana;

Mr. William Foster: Montana and Wyoming;

Mr. J. E. Hardman: The smelting works in Lake County, Park and Summit Counties, and portions of Clear Creek and Gilpin Counties, in Colorado;

Mr. Charles Potter: Mew Mexico;

Mr. E. H. Schaeffle: Dakota and portions of Colorado;

Mr. W. G. Sharp: San Juan, Hinsdale, Gunnison, La Plata, Huerfano, Ouray, and Rio Grande Counties, in Colorado, and portions of New Mexico.

In addition to the census experts, the following-named gentlemen acted as temporary assistants: Messrs. Herman Garlichs, J. C. Hines, H. B. Price, H. L. Simmons, and W. H. Whittlesey, in Colorado, and W. F. Wheeler, in Montana.

EASTERN DIVISION.

Mr. George H. Eldridge: Southern States and reduction works east of the Missouri River;

Prof. N. S. Shaler, with the assistance of Messrs. Joseph M. Wilson and J. E. Wolff: New England States.

The above organization was completed and in the field by June 30, 1880, and continued the active prosecution of field work to the close of the fiscal year, at which time the field investigation was, as far as practicable, completed.

The assistants rendered their detailed reports to the three Chiefs of Division, and were then all discharged with the exception of three experts who were retained for the office work in the compilation and tabulation of the statistical results.

The field investigations were conducted upon a series of elaborate schedules, embracing not merely the questions of total output of ores and total yield of gold and silver bullion, but comprehending as well a close analysis of all the methods of production, mechanical and metallurgical, together with a detailed study of the character and cost of the labor, power, and material consumed in the industry.

The returns from the field investigation comprise reports from 1,967 deep mines, 325 placer mines, 327 amalgamating mills, concentration works, chlorination and leaching establishments, 86 smelting works, and 25 arrastras, making in all 2,730 detailed reports.

The close of the fiscal year, June 30, 1881, marked the close of the field investigation and the beginning of the office compilation and tabulation.

Very respectfully, your obedient servant,

CLARENCE KING.

Hon. J. W. POWELL,

Director United States Geological Survey.

THE

PHYSICAL GEOLOGY

OF THE

GRAND CAÑON DISTRICT.

BY

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

THE PHYSICAL GEOLOGY OF THE GRAND CAÑON DISTRICT.

BY CLARENCE E. DUTTON.

CHAPTER I.

THE PLATEAU PROVINCE.

The investigations made by this division of the Geological Survey during the last two years have been pursued with the object of increasing our knowledge of the physical and historical geology of the West and have had little relation to economic interests. The field of labor is one of the most impressive and instructive in the world—impressive by reason of the magnificent scale on which certain processes of nature have operated, and instructive because the causes, methods, and results of those processes are revealed with a distinctness which is unparalleled. This field comprises the Grand and Marble Cañons of the Colorado and the regions which drain into them. To the entire tract, comprising an area of more than 13,000 square miles, I have given the name of the GRAND CAÑON DISTRICT.

The lessons which the geologist finds in this district are many, but the most conspicuous one embraces those subjects which are included under the nearly synonymous names "LAND SCULPTURE," "DENUDATION," "EROSION." These processes operate upon the land unceasingly, carving out mountains and valleys and giving shape and character to the earth's surface. They represent the work done upon the land by the winds and rains, by flowing water, by the chemical reactions of the atmosphere and of organic life. These processes are operative almost everywhere, and their results in the lapse of immense periods of time attain magnitudes, the statement of which may astonish the ordinary reader and perhaps excite his incredulity, but which at length appear veritable when tested by geological research and deduction. In no other portion of the world are the natural laws governing the processes of land sculpture exemplified so grandly; nowhere else are their results set forth so clearly. The interest excited by the grandeur of the subjects is intensified, and the value of the lessons enhanced, by the exceptionally intelligible manner in which their materials are presented for study.

For convenience of geological discussion Professor Powell has divided that belt of country which lies between the meridian of Denver, Colo., and the Pacific and between the 34th and 43d parallels into provinces, each of which possesses topographical features which distinguish it from the others. The easternmost he has named the Park Province. It is situated in the central and western parts of Colorado and extends north of that state into Wyoming and south of it into New Mexico. It is preeminently a mountain region, having several long ranges of the second order of magnitude. The structure and forms of these mountains are not exactly similar to those of any other region now well known, but possess some resemblance to the Alps, though not a very close one.

As we pass westward of these ranges in Colorado we enter, near the western boundary of that state, a region having a very different topography. The mountains disappear almost wholly, and in their stead we find platforms and terraces nearly or quite horizontal on their summits or floors and abruptly terminated by long lines of cliffs. They lie at greatly varying altitudes, some as high as 11,000 feet above the sea, others no higher than 5,000, and with still others occupying intermediate levels. Seldom does the surface of the land rise into conical peaks or into long narrow crested ridges; but the profiles are long, horizontal lines suddenly dropping down many hundreds or even two thousand feet upon another flat plain below. This region has been very appropriately named, by Powell, the Plateau Province. It occupies a narrow strip in the extreme western part of Colorado, a similar strip of western New Mexico, a large part of southern Wyoming, and rather more than half of Utah and Arizona.

West of the Plateau Province is the Great Basin, so named by Fremont because it has no drainage to the ocean. Its topography is wholly peculiar and bears no resemblance to either of the two just alluded to. It contains a large number of ranges, all of which are very narrow and short, and separated from each other by wide intervals of smooth, barren plains. The mountains are of a low order of magnitude for the most part, though some of the ranges and peaks attain considerable dimensions. Their appearance is strikingly different from the noble and picturesque outlines displayed in Colorado. They are jagged, wild, and ungraceful in their aspect, and, whether viewed from far or near, repel rather than invite the imagination.

The Wasatch, however, is an exception. This noble range is properly a part of the Basin Province, and is one of the finest and most picturesque of the West, but so completely does it contrast with the other Basin ranges that it may be regarded as an anomaly among them. The topographical features of this region are also found outside of the limits which Frémont assigned to the Great Basin, and reach southward into Arizona and northward into Idaho and Oregon. The Basin proper covers the western part of Utah, nearly the whole of Nevada, and a small portion of southern Oregon and Idaho. Its western boundary is the base of the Sierra Nevada.

No attempt will be made here to characterize the Sierra Nevada, partly because it is not thoroughly understood, but especially because it is remote from the region here to be discussed, and presents few considerations essential to that discussion. The Grand Cañon District is a part of the Plateau Province, and to this province as a whole we may now devote our attention.

As already indicated, it lies between the Park and Basin Provinces, and its topography differs in the extreme from those found on either side of it. It is the land of tables and terraces, of buttes and mesas, of cliffs and cañons. Standing upon any elevated spot where the radius of vision reaches out fifty or a hundred miles, the observer beholds a strange spectacle. The most conspicuous objects are the lofty and brilliantly colored

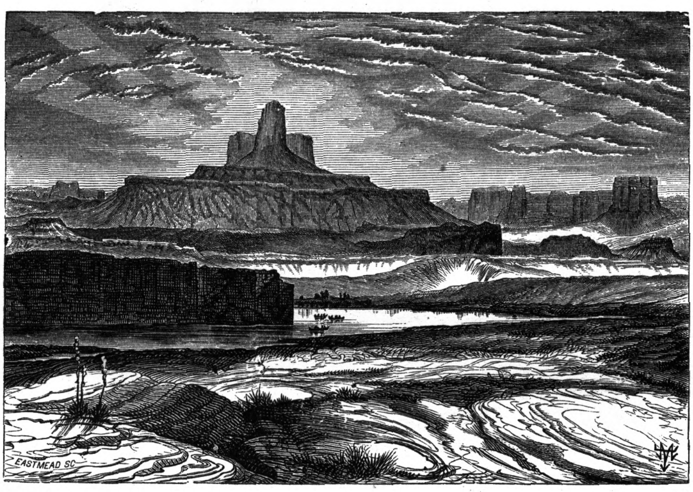


FIG. 2.—Butte of the Cross. Trias.

cliffs. They stretch their tortuous courses across the land in all directions, yet not without system; here throwing out a great promontory, there receding in a deep bay, and continuing on and on until they sink below the horizon or swing behind some loftier mass or fade out in the distant haze. Each cliff marks the boundary of a geographical terrace and marks also the termination of some geological series of strata, the edges of which are exposed like courses of masonry in the scarp-walls of the palisades. In the distance may be seen the spectacle of cliff rising above and beyond cliff, like a colossal stairway leading from the torrid plains below to the domain of the clouds above. Very wonderful at times is the sculpture of these majestic walls. There is an architectural style about it which must be seen to be appreciated. The resemblances to architecture are not fanciful or metaphorical, but are real and vivid; so much so that the unaccustomed tourist often feels a vague skepticism whether these are truly the works of the blind forces of nature or of some intelligence akin to the human, but far mightier; and even

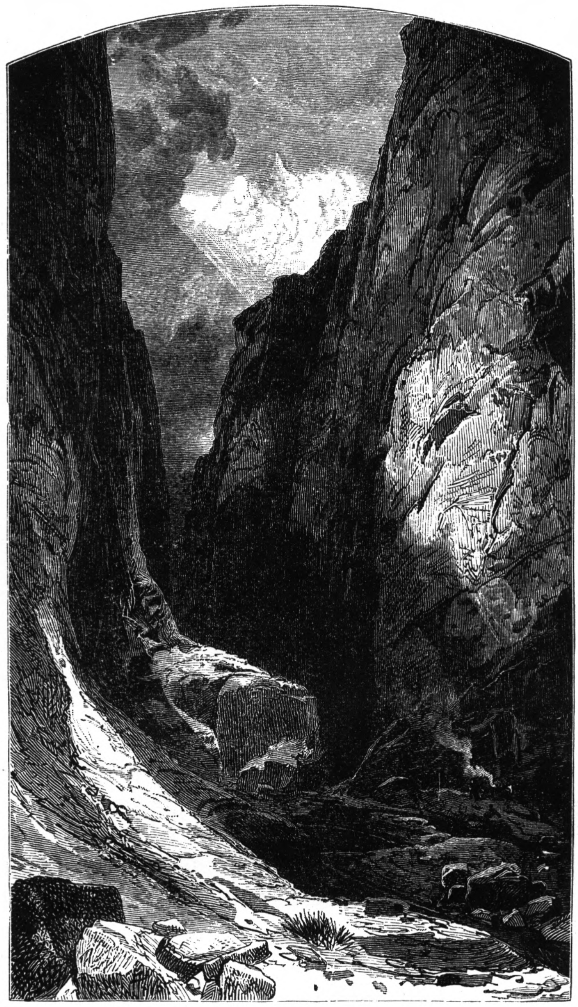
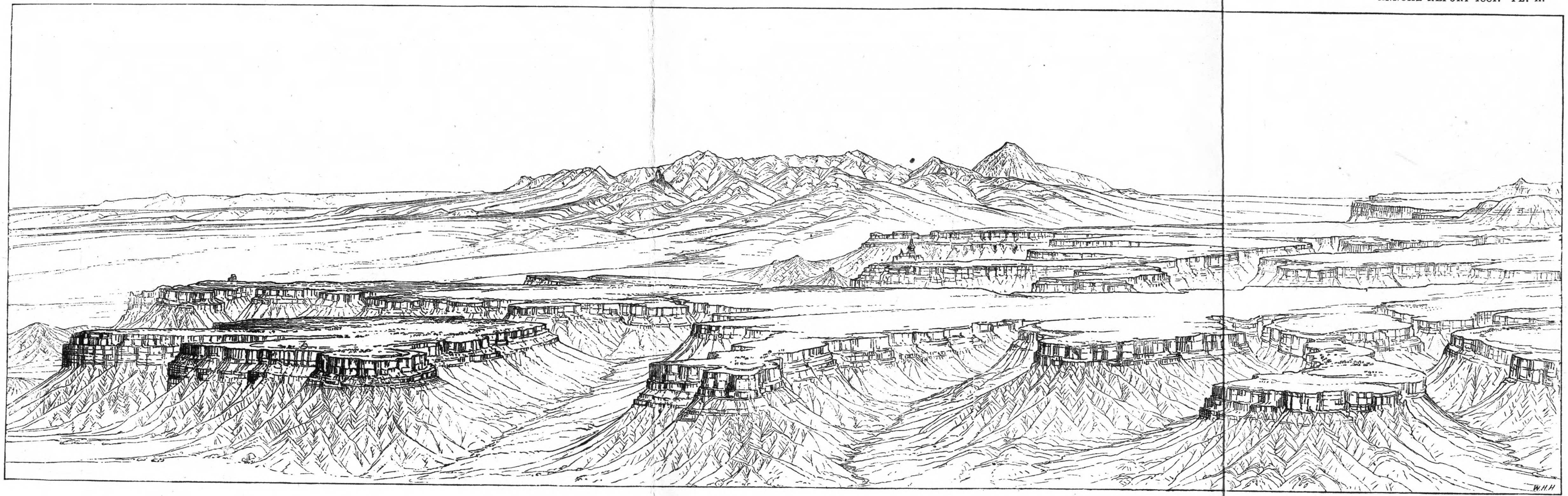


FIG. 3.—A lateral cañon. Escalante.

the experienced explorer is sometimes brought to a sudden halt and filled with amazement by the apparition of forms as definite and eloquent as those of art. Each geological formation exhibits in its cliffs a distinct style of architecture which is not reproduced among the cliffs of other formations, and these several styles differ as much as those which are cultivated by different races of men.

The character which appeals most strongly to the eye is the coloring. The gentle tints of an eastern landscape, the pale blue of distant mountains, the green of vernal or summer vegetation, the subdued colors of hillside and meadow, are wholly wanting here, and in their place we behold belts of brilliant red, yellow, and white, which are intensified rather than alleviated by alternating belts of gray. Like the architect-



PLATEAU SCENERY—THE MESA VERDE—CRETACEOUS.

Reproduced from Hayden's Ninth Annual Report.

ure, the colors are characteristic of the geological formations, each series having its own group and range of colors. They culminate in intensity in the Permian and Lower Trias, where dark, brownish reds alternate with bands of chocolate, purple, and lavender, so deep, rich, and resplendent that a painter would need to be a bold man to venture to portray them as they are.

The Plateau country is also the land of cañons, in the strictest meaning of that term. Gorges, ravines, cañadas are found and are more or less impressive in every high region; and in the vernacular of the West all such features are termed cañons, indiscriminately. But those long, narrow, profound trenches in the rocks, with inaccessible walls, to which the early Spaniards gave the name of *cajon* or *cañon*, are seldom found outside the plateaus. There they are innumerable and the almost universal form of drainage channels. Large areas of the Plateau country are so minutely dissected by them that they are almost inaccessible, and some limited though considerable tracts seem wholly so. Almost everywhere the drainage channels are cut from 500 to 3,000 feet below the general platform of the immediate country. They are abundantly ramified and every branch is a cañon. The explorer upon the mesas above must take heed to his course in such a place, for once caught in the labyrinth of interlacing side gorges, he must possess rare craft and self-control to extricate himself. All these drainage channels lead down to one great trunk channel cleft through the heart of the Plateau Province for eight hundred miles—*the chasm of the Colorado*, and the cañons of its principal fork, the Green River. By far the greater part of these tributaries are dry during most of the year, and carry water only at the melting of the snow and during the brief periods of autumnal and vernal rains. A very few hold small, perennial streams, coming from the highlands around the borders of the province, and swelling to mad torrents in times of spasmodic floods.

The region is for the most part a desert of the barrenest kind. At levels below 7,000 feet the heat is intense and the air is dry in the extreme. The vegetation is very scanty, and even the ubiquitous sage (*Artemisia tridentata*) is sparse and stunted. Here and there the cedar (*Juniperus occidentalis*)* is seen, the hardiest of arborescent plants, but it is dwarfed and sickly and seeks the shadiest nooks. At higher levels the vegetation becomes more abundant and varied. Above 8,000 feet the plateaus are forest-clad and the ground is carpeted with rank grass and an exuberant growth of beautiful summer flowers. The summers there are cool and moist; the winters severe and attended with heavy snow-fall.

* Botanists inform me that the predominant upland juniper of the Plateau Province, as the species are now distributed according to Dr. Engelmann's revision published in 1877, would be *Juniperus Californica*, var. *Utahensis*, rather than *J. occidentalis*, some of the varieties of which may, however, occur there. Until that revision was made the western junipers were little known, and several distinct species were indiscriminately classed as *J. occidentalis*.

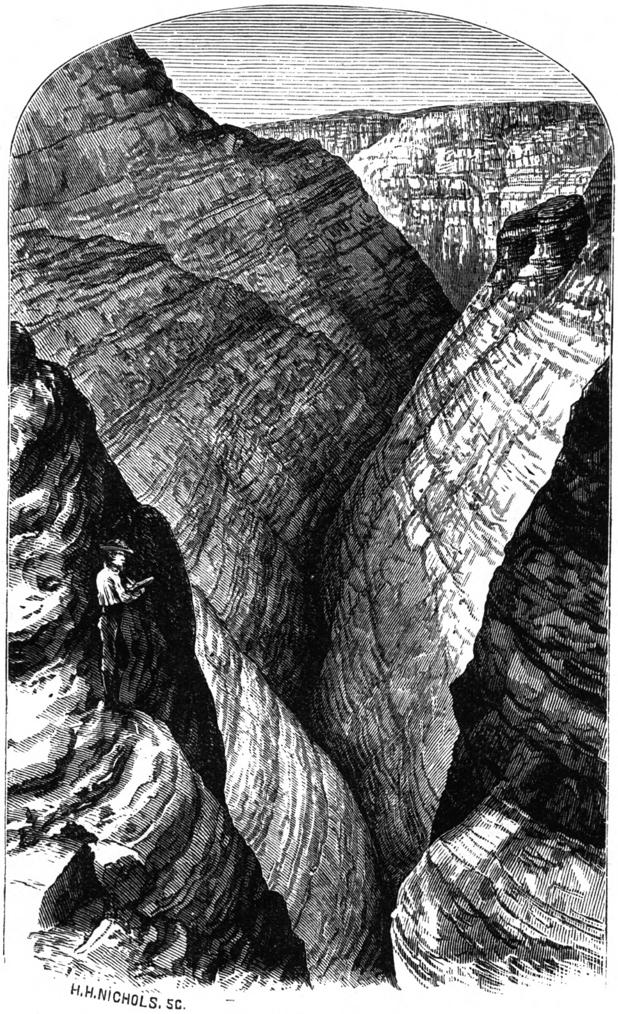


FIG. 4.—The Water Pocket Canon.

The Plateau Province is naturally divided into two portions, a northern and a southern. The dividing barrier is the Uinta range. This fine mountain platform is, in one respect, an anomaly among the western ranges. It is the only important one which trends east and west. Starting from the eastern flank of the Wasatch, the Uintas project eastward more than 150 miles, and nearly join perpendicularly the Park ranges of Colorado. Of the two portions into which the Plateau Province is thus divided, the southern is much the larger. Both have in common the plateau features; their topographies, climates, and physical features in general, are of similar types, and their geological features and history appear to be closely related. But each has also its peculiarities. The northern portion is an interesting and already celebrated field for the study of the Cretaceous strata and the Tertiary lacustrine beds. The subjects which it presents to the geologist are most notably those which are embraced under the department of stratigraphy—the study of the succession of strata and co-related succession of organic life. Otherwise the region is tame, monotonous, and unattractive. The southern portion, while presenting an abundance of material for stratigraphical study, and in this respect fully rivaling, and perhaps surpassing, the northern portion, also abounds in the grandest and most fascinating themes for the student of physical geology. In respect to scenery, the northern portion is almost trivial, while the southern is the sublimest on the continent. With the former we shall have little to do; it is the latter which claims here our exclusive attention.

The southern part of the Plateau Province may be regarded as a vast basin everywhere bounded by highlands, except at the southwest, where it opens wide and passes suddenly into a region having all the characteristics of the Great Basin of Nevada. The northern half of its eastern rim consists of the Park ranges of Colorado. Its northern rim lies upon the slopes of the Uintas. At the point where the Uintas join the Wasatch, the boundary turns sharply to the south, and for 200 miles the High Plateaus of Utah constitute the elevated western margin of the Province.

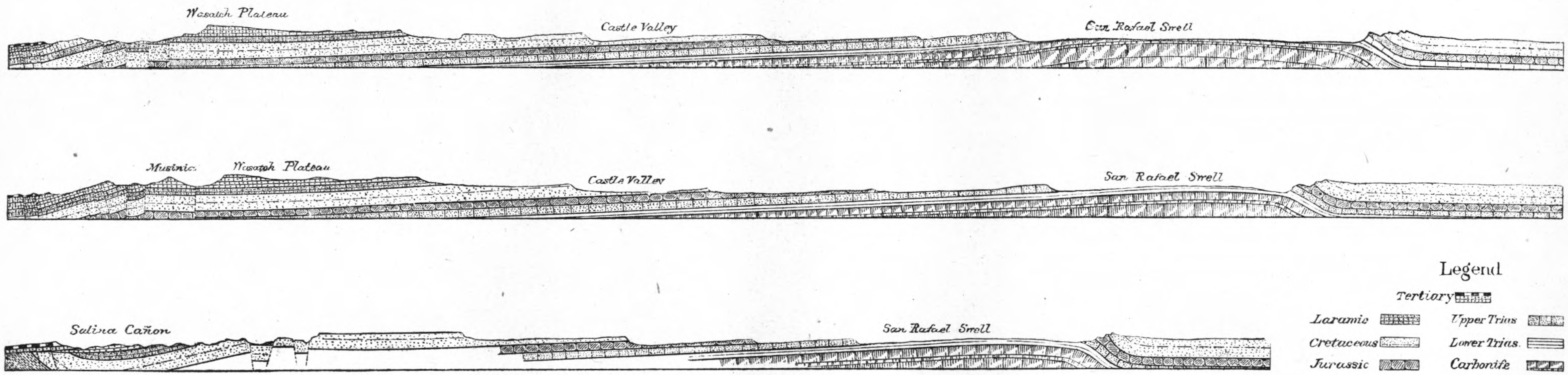
It is from the summits of the High Plateaus that we gain our first comprehensive view of those grand facts which are the principal subjects of this discourse. But let me first ask the reader to endeavor to frame some conception, however crude, of three lines, each 200 miles long, placed in the positions of three sides of a square; the fourth side being for the moment neglected. Upon the eastern side conceive the Park ranges of Colorado; upon the northern, the Uintas; and upon the western side the southern portion of the Wasatch and the High Plateaus of Utah; and all these highlands having altitudes ranging from 9,000 to 12,000 feet above the sea, while the included area varies from 5,000 to 7,000 feet high. The space thus partially bounded may represent the northern part of the southern Plateau Province. Along the line required for the fourth and south side of the complete square there is no boundary. The topography continues on beyond it to the southward, and also widens out both west and east and overspreads an additional area more than twice as great as that already defined. From the eastern crests of the High Plateaus we may obtain an instructive overlook of the northern portion of the southern Plateau country.

The easiest line of approach is from Salt Lake City. Proceeding south from that town along the western base of the Wasatch, we reach the southern end of that fine range about 90 miles from Salt Lake. The last mountain pile is Mount Nebo, and skirting around its southern flank we soon perceive to the southeastward a long and very lofty ridge 20 to 30 miles distant. This is the Wasatch Plateau, the northernmost member of the group of High Plateaus. It has nothing in common with the

Wasatch Mountain range, being wholly disconnected from it and standing with a wide interval *en échelon* to the southeastward of it. The Wasatch Plateau presents a long, straight, horizontal summit projected against the sky without peaks or domes, resembling somewhat the ridges of Pennsylvania and Virginia, but on a grander scale. We perceive along its entire western front a rapid slope, descending to the bottom of the San Pete Valley at its foot. It is not deeply incised with ravines and amphitheaters, nor notched with profound transverse gorges, as are ordinary mountain ranges, but shows a slightly diversified slope in every part. As we draw nearer we begin to see the attitudes of the strata composing its mass, or, as the geologists say, its "structure." The strata are inclined at the same angle as the slope of its flank. In the valley below, the beds are horizontal; as they approach the base of the plateau they flex upwards and ascend the slope; as they reach the summit they flex back to horizontality. If we ascend the plateau and ride eastward a very few miles, there suddenly breaks upon the view a vast and impressive panorama. From an altitude of more than 11,000 feet the eye can sweep a semicircle with a radius of more than 70 miles, and reach far out into the heart of the Plateau country. We stand upon strata of Lower Tertiary age, and beneath our feet is a precipice leaping down across the level edges of the beds upon a terrace 1,200 feet below. The cliff on which we stand stretches far northward into the hazy distance, gradually swinging eastward and then southward through a course of more than a hundred miles, and vanishing below the horizon. It describes, as we well know, a rude semicircle, around a center about 40 miles east of our standpoint. At the foot of this cliff is a terrace of greatly varying width, rarely less than 5 miles, consisting of Upper Cretaceous beds nearly but not quite horizontal. They incline upwards towards the east at angles rarely so great as 3°, and are soon cut off by a second cliff plunging down 1,800 feet upon Middle Cretaceous beds. This second cliff describes a semicircle like the first, but smaller and concentric with it. From its foot the strata still rise gently towards the east, through a distance of about 10 miles, and are cut off as before by a third series of cliffs concentric with the first and second. For the fourth and fifth time this process is repeated. In the center of these girdling walls is an elliptical area about 40 miles long and 12 to 20 miles broad, completely surrounded by mural escarpments more than a thousand feet high. This central spot is called the SAN RAFAEL SWELL, and it is full of interest and suggestion to the geologist. From its central point the strata dip away in all directions, the inclinations, however, being always very small.* This configuration of the strata (dipping away from a central point in all directions) is technically termed "quaquaversal."

The accompanying diagram (Plate XI) shows the relative masses and positions of the strata as they would appear in vertical sections cutting

*Upon the eastern margin of the swell is one of those great "monoclinal flexures" with a high inclination so characteristic of the Plateau Country. These will be adverted to hereafter.



Sections from San Pete and Sevier Valleys across the Wasatch Monoclinal to the San Rafael Swell.

east and west through the Wasatch Plateau to the San Rafael Swell. It will be observed that the lower Tertiary is found only on the summit and western flank of the plateau. The Cretaceous extends further out, but is at last cut off in turn; and as lower and lower beds are exposed to daylight, they too are similarly cut off until the summit of the Carboniferous is nearly or quite exposed within the swell itself. The approximate length of the section here given is about 55 miles, and the thickness of the strata from the summit of the Carboniferous to the top of the Lower Tertiary is nearly 11,000 feet.

The geologist who becomes aware through observation of the general facts thus set forth quickly reaches the following conclusion: The beds which are successively terminated in the terrace cliffs once reached further eastward, and in all probability every one of them extended in full volume and without a break entirely over the *locus* of the swell to regions far beyond it. Upon the eastern side of the swell, and at varying distances from it, the missing strata reappear in inverse order, with terminal cliffs facing the westward. From the intervening space they have been swept away by erosion.

In restricted localities of a few square miles, in a river valley, in the open glades of a hill-country, the most unscientific observer may be easily convinced that the waste of thousands of years has broken the continuity of the strata and quarried away large masses of rock. But in the wide expanse before us even the mind of the geologist may falter before accepting a conclusion so portentous. The magnitude of the work is oppressive, and cautious philosophers are reluctant to take up and carry the burden of unusually large figures. They prefer to cast about in order to see whether some easier conclusion may not be discovered. The one already stated is to the effect that a body of strata more than 10,000 feet thick and more than 500 square miles in area have been swept off from the surface of the swell; that nearly 9,000 feet have been removed from a much larger annular space around it; 7,000 feet from a still larger and remoter space; and so on with expanding annuli, from which successively decreasing amounts have been denuded. It is needless to define just here the limits of the denuded region, even if it were possible. It is sufficient to say that its extent is much more than 10,000 square miles, and that the thickness of the strata removed varies from a few hundreds to more than 10,000 feet. Nor does the conclusion stop here. The San Rafael region is only one of a considerable number of the subdivisions of the Plateau Province where the same enormous extent of erosion has taken place. It is not the largest of those subdivisions, nor is the thickness of the removed strata the greatest there. It is merely an example, and whatsoever it reveals in regard to erosion is but a group of events common to the entire southern province with its vast area of nearly 100,000 square miles. I have selected it for discussion because its array of facts in evidence is more easily handled and can be more lucidly presented than those of the other subdivisions. Let us, then, examine in detail the arguments upon which this deduction of a great denudation is based.

If we stand before one of the great marginal cliffs which bound the several terraces, we shall speedily detect abundant evidence that time and the elements are slowly robbing its face of the materials which compose its mass. Fragments have spawled off and fallen, and they now lie at its base in great quantities, forming a talus. Cliff and talus alike are seamed and scored with rain-gullies, and if we are fortunate enough to observe the effects of a shower we shall see the waters trickling, spouting, or rushing down through every seam and gully, carrying sand, mud, and small fragments with which they are charged to their utmost capacity. The meaning of this is that the cliff is wasting away, and its *locus* through the ages is farther and farther back. This backward movement of the line of frontage by slow waste is very happily named by Powell the *Recession of Cliffs*.

It may seem at first as if the rate of recession must be so exceedingly slow that when we are asked to consider the possibility of a recession of thirty or forty miles the argument would break down under the weight of its time-factor. But it will be shown hereafter that in the total process of denudation the rate of recession is rapid enough to satisfy the temper of such geologists as may be parsimonious or even very stingy in their allowances of time. It is sufficient here to advert to the very obvious fact that the cliffs are receding, and that at some former geological period they once stood nearer the center of the denuded district. Now, it is sufficiently obvious that if we allow the imagination to range back indefinitely into the past and reverse the process of recession, restoring the material which has been denuded, the continuity of argument will at length bring us to an epoch in which the cliffs which now face the center of the San Rafael Swell came together, and the strata which those cliffs now terminate stretched unbroken from west to east across the whole width of the Plateau Province. It is only a question of time and continuity of the process. The geologist may, however, raise a very pertinent inquiry. Admitting that the cliff-bound strata once reached out in advance of their present limits, may they not have grown thinner as they approached the center; may they not have attenuated rapidly so that their former thickness over the swell was but a small fraction of the aggregate thickness disclosed in the present escarpments? May not the higher beds have thinned out and disappeared entirely a few miles from their present boundaries? In all other well-studied regions it is a general and almost universal rule that the strata vary greatly in thickness when traced from place to place, and attenuate as they extend away from their shore-lines. May they not have done so here?

Answering the questions directly, it may be said that the Permian, Trias, and Cretaceous certainly did not grow perceptibly thinner as they approached the center of denudation. The Jurassic did thin out quite notably from west to east, and it is possible that the Tertiary may have thinned a little; but this loss of thickness in the Jurassic and Tertiary has been abundantly discounted in the estimate given of the mass of strata denuded. As regards the general rule that strata vary greatly in thickness, it may be stated that the Plateau country is a remarkable exception to it. One of the most striking features in its stratigraphy is the wonderful persistency with which its formations maintain their volumes and lithological features over great areas. In this respect the province has no parallel, not even in the calm and undisturbed *terrains* of the Mississippi Valley.

Further support of this conclusion may be found by reverting to the section (Plate XI). On the eastern side of the swell the section shows a great monoclinal flexure where the strata extending eastward rapidly bend downward and subsequently flex back to horizontality. Before this flexure began to form, the Cretaceous strata had already been deposited. Possibly, also, the Tertiary had been laid down, but of this we are not as yet certain. But we know that it was formed after the Cretaceous age, for the strata abundantly betray it. If we could bend back the strata now inclined upward in that flexure, we should have a wall about 8,000 feet high or more, looking down from the east upon the central amphitheater, and in that wall would appear the broken edges of the Permian and Mesozoic beds, though the upper part of the Cretaceous and Tertiary would be wanting at the summit. Thus nearly four-fifths of the denuded strata appear upon the eastern side of the swell, in very close proximity to it, and the remainder make their appearance at varying distances beyond. There is no appreciable loss of volume in the exposed beds of the monocline as compared with the corresponding beds to the westward.

But we may with advantage pursue the task of restoring the beds to the position they held during the period of their deposition by straightening out or bending back the strata in those parts where they have been tilted and flexed since their accumulation. This is readily done here. They were deposited originally in layers which were quite horizontal. We know this by reasoning upon the following facts. From the summit of the Permian, and I think we may say quite confidently from the summit of the Carboniferous upwards, the whole series was deposited in very shallow waters. The evidence of this is overwhelming. We find proof that the surfaces of deposition throughout Mesosoic time oscillated repeatedly a little below and a little above sea-level. The cross-bedded sandstones of the Trias and Jura, the sandy shales wonderfully ripple-marked, the occurrence of bands containing the silicified remains of forest trees, the occasional recurrence of contacts showing "unconformity by erosion" without any unconformity of dip,* the occurrence of brackish-water types of mollusca in the Jurassic, the

* There are throughout the series numerous instances of beds resting upon surfaces slightly eroded and channeled by streams without any discrepancy of dip in the apposed beds.

lignites, fossil leaves, and carbonaceous shales of the whole Cretaceous system, the brackish-water fossils of the lowest Tertiary, leave no doubt as to the verity of the foregoing inference. The final restoration, then, of the strata to their original positions leaves them horizontal.*

If we draw a section of the strata restored to horizontality, we shall find that the strata now remaining require, in order to perfect their continuity, the restitution of large masses fully equal to those which we have inferred to have been swept away by erosion. Any hesitation to do this would leave us without resource. Any other hypothesis, so far as I can conceive, would be not only without support in the facts presented, but in opposition to their entire tenor and purport.

The geologist who is familiar through long field-study with the physical problems presented in the West would not need further argument to become satisfied of the reality of the great erosion here inferred. Perhaps he would consider that too much has been said in support of it already; especially since the subject of this paper is not the San Rafael but the Grand Cañon district. But I have devoted so much discussion to the San Rafael district because it is a type of a congeries of districts which make up the Plateau Province, and because it exemplifies in the most intelligible, compact, and complete manner the broad facts and laws which are to engage our attention hereafter. These facts and laws apply to the Grand Cañon district; but to take the facts there presented and arrange them in a clear view before the mind of one who has never visited that region, and make them definite and convincing, would be extremely difficult without preparatory exercises on problems similar in kind but simpler in form. For this reason I propose, before leaving the San Rafael district, to bring out another category of facts which it exemplifies. They involve a generalization very interesting in itself, and of the greatest utility in solving many problems presented in all parts of the Plateau country. This generalization—or law in the sense of an observed order of facts—may be called the *Persistence of Rivers.*

The rivers of the Atlantic States, from the Hudson southward, cut through the Appalachian ridges by narrow gorges, or gaps, which seem to have been quarried out for the purpoes. Geology, however, does not

* It would be very instructive, if space permitted, to elaborate this discussion of the original horizontality, and I am tempted to point out in the hastiest manner some obvious consequences of the deduction. It appears that if this deduction be true the deposits must have settled or subsided as rapidly (in the long run) as they were accumulated. The surface of deposition appears never to have varied much from sea-level. But the total accumulation of Permian, Mesozoic, and Tertiary beds was nearly 11,000 feet, and when the deposition ended (supposing that it ended in the Middle Eocene, though I think it more probably continued here until the close of the Eocene) the Permian must have sunken more than two miles below sea-level. The gradual subsidence of large bodies of sediment as they accumulate in strata is a fact now generally recognized, and is of universal application. That it is caused by the gross weight of the enormous masses of deposited material sinking into the yielding earth seems a most natural explanation.

take account of "purposes" or "design," but seeks its explanations in "natural" causes alone. It asks by what natural processes were those gorges made?

The answer it finds is, that the rivers themselves scoured them out, and that secular decay has widened them somewhat. A reader not versed in geology might be led to ask a further question. How can a river attack a mountain wall, or even a gentle declivity, and quarry though it a pathway giving a continuous descent for the flow of its waters? The reply is that no river ever does that. To understand how it all came about we must go back to the beginning. The rivers were born with the country itself. The land emerged from the sea; and when it emerged the rains or melting snow sought whatever channels were determined by the slight inequalities of the newly-risen surface and flowed seawards. These lofty ridges, gashed with noble ravines, had then no existence. The rivers are older than the mountains. As time ran on the mountains grew upward, athwart the courses of the streams. But a flowing river has a power to fight for and maintain its right of way, which becomes apparent only when we have carefully studied and analyzed it. This power is inherent in the descent of its waters—is literal water-power. The weapons or tools are the sand, gravel, and silt which the waters carry, and which act after the manner of a sand-blast, except that in the sand-blast the grit is impelled by air or steam, while in the river it is impelled by water. This power, inherent in the fall, increases rapidly as the fall increases. When the declivity is feeble the power to grind down the channel—to "corrade," as Powell terms it—is correspondingly feeble, or even annihilated. When a barrier like a ridge rises across the track of a stream the declivity is increased at that point. Increased velocity and corrasive power is at once developed in the stream, and it cuts down the barrier. Perhaps a lake may be formed above the barrier, but its outlet will be cut down and the lake drained.

In a low country the slopes are, with rare exceptions, feeble, and this corrasive power by which the stream maintains its *locus* is in such countries correspondingly feeble. Here we may expect to find many cases where streams have been deflected largely from their courses; but in a high country the reverse is the case. In a region newly risen from the waters the positions of the streams may be very inconstant; but as the elevation increases they gradually fasten their grip upon the land and hold it.

It would be difficult to point out an instance where a great river has ever existed under conditions more favorable to stability of position than those of the Colorado and its tributaries. Since the epoch when it began to flow it has been situated in a rising area. Its springs and rills have been among high mountains, and its slope since the earliest period of its history has always been great. The relations of its larger tributaries have, in these respects, been the same; and indeed the river and its tributaries have been a system, and not a mere aggregate; for the latter are dependent upon and responsive to the physical conditions of the former. And now we come to the point. The Colorado and its tributaries run to-day just where they ran after the region emerged from the waters. Since that time mountains and plateaus have risen across their tracks, whose present summits mark less than half their total amounts of uplift. The rivers have cleft them to their foundations.

The Green River, passing the Pacific Railway, enters the Uinta platform by the Flaming Gorge, and after reaching the heart of the chain turns eastward parallel to its axis for 30 miles, and then southward, cutting its way out by the splendid cañon of Lodore. Then following the base of the range for a few miles a strange caprice seizes it. Not satisfied with the terrible gash it has inflicted upon this noble chain, it darts at it viciously once more, and entering it, cuts a horseshoe cañon in its flank 2,700 feet deep, and emerges near the point of entrance; thenceforward, through a tortuous course of 300 miles, it flows southward through gently inclined terraces, which rise slowly as the river descends. Along this stretch it runs almost constantly against the dip of the beds, cutting through one after another, beginning with the Upper Eocene until its channel is sunk deep in the Carboniferous. Further down, the Kaibab Plateau rose up to contest its passage, and a chasm 5,000 to 6,000 feet deep is the result. It is needless to multiply instances; the whole province is a vast category of instances of river channels cutting through plateaus, mesas, and terraces where the strata dip up stream. The courses of the cañons are everywhere laid independently of the topographical inequalities, whether these inequalities be due to the broader features of land sculpture or to displacement and unequal uplifting. On the north and west side of the Colorado the tributaries generally run counter to the structural slopes; on the east and south sides, they ran more nearly with them.

It is clear then that the structural deformations of the surface, the uplifts and downthrows had nothing to do with determining the present distribution of the plateau drainage. The rivers are where they are, in spite of them. As irregularities rose up, the streams turned neither to the right nor to the left, but cut their way through in the same old places. The process may be illustrated by a feeble analogy with the saw-mill. The river is the saw and the rising strata are the timber which is fed against it. The saw-log moves while the saw vibrates in its place. The river holds its place as rigidly, and the rising strata are dissevered by its ceaseless wear. What, then, did determine the situations of the present drainage channels? The answer is that they were determined by the configuration of the surface existing at, or very soon after, the epoch of emergence. Then, surely, the water-courses ran in conformity with the surface of the uppermost (Tertiary) stratum. Soon afterwards that surface began to be deformed by unequal displacement, but the rivers had fastened themselves to their places and have ever since refused to be diverted.

HORSESHOE CAÑON, GREEN RIVER.

From Powell's Exploration of the Colorado River.

This theorem is of great utility in the study of the Plateau Province, for it throws light upon many problems which would otherwise be obscure. The course of a river is the index of the slope, and, to a great extent, the configuration of the primitive unmodified surface of a tract. It betrays the amount of tilting or flexing which the strata have undergone, and also conveys information as to the amount of strata which have been denuded. This information, however, is in many cases incomplete, but when placed in relation with other facts it frequently becomes conclusive. The application of the theorem to the San Rafael district is a beautiful instance of its validity.

Across the San Rafael Swell extend two river channels, one crossing it near the northern and the other near the southern end. They head in the High Plateaus, and pass through the successive terraces in deep cañons; then crossing the swell, enter the high cliffs on the eastern side and flow on. The northern stream—the San Rafael River—ultimately joins the Green River; the southern one—Curtis Creek—enters the Frémont River, a tributary of the Colorado. A glance at the map and an interpretation of the topography as expressed by the contours will quickly show that these streams are quite independent of the existing topography and could not have had their situations determined by it. They must have been laid out upon some ancient surface differing widely from the present. To find that surface is not difficult. It must have had a continuous descent, though doubtless of slight declivity, from the western margin of the province to the line of the Green and Colorado Rivers. We shall obtain precisely that surface configuration by reducing or bending back the flexures, and depressing the tilted strata until the Cretaceous beds are everywhere horizontal, and then filling up the gaps made in the continuity of the strata by erosion. Thus we shall reach, by argument from the persistence of rivers, the same conclusion which we reached by studying the effects of the recession of cliffs, and by the independent study of the displacements.

The example of erosion thus given by the San Rafael Swell illustrates, as a sharply defined type, the denudation of the Plateau Province. The thickness of the strata removed varies greatly in different portions. In the High Plateaus it has amounted to only a few hundred feet. In large areas it amounts to two or three thousand feet and in others of considerable extent it reaches more than 10,000 feet. Preliminary comparisons of known facts derived from nearly the entire extent of the southern province lead to the conclusion that on the average 5,500 to 6,000 feet of strata have been removed from its entire expanse. Our knowledge of the geology of some portions of it is at present very imperfect. Still, enough is known to justify us in believing that this summary estimate will not be much affected by future investigation.

We may for special purposes of convenience regard the province as consisting of districts or spots of maximum erosion separated from each other by high mesas or dividing platforms where erosion has been at its minimum. The San Rafael district may be regarded as one of these areas of which the central part is an area of maximum erosion while its peripheral parts are areas of minimum erosion. The Grand Cañon district is another, and there are still others which we need not here specify.

Before concluding the introductory part of this paper it will be desirable to recite briefly the succession of geological events which the study of the region has thus far brought to light, selecting only such as will hereafter be of special utility.

Throughout the great Carboniferous age the entire area of the Plateau Province was submerged beneath the ocean. Deposition of strata went on continuously. The thickness of the strata accumulated in that age appears to have varied greatly, and the deposits were laid down unconformably over the surface of a country which had been ravaged by a great erosion. Such exposures of the Carboniferous as now exist, however, exhibit for the most part a remarkable evenness of stratification. In the interior spaces of the province the beds are either horizontal, or if disturbed, give full evidence that the disturbances took place long after their deposition. The close of this age evidently left a subaqueous surface, which was exceedingly flat, and, except around the borders of the province, quite free, so far as we now know, from any appreciable inequalities.

The thickness of the Carboniferous system is from 4,500 to 5,000 feet in the interior of the province, but around its borders, and in the Uinta Mountains, it is sometimes found in far greater volume. Its strata consist of impure limestones, occasionally of enormous thickness in the individual beds, and alternating with fine-grained homogeneous sandstones. Extensive beds of gypsum also occur.

After the Carboniferous came the Permian age, in which were laid down from 800 to 1,500 feet of sandy shales. The stratification was wonderfully even and everywhere horizontal. The Permian beds are often ripple-marked and betray many evidences that they accumulated in shallow waters. Among these evidences are the appearance at several horizons of indications that for a time the sea-bottom was laid bare by the recession of the waters, or by the elevation of the platform itself; for we may discern evidences of slight erosion at the contacts of the beds. But the horizontality of the beds appears never to have been notably disturbed.

The same state of affairs continued through the Trias. There, too, we find evidence of alternations of emergence and submergence in the shape of slight unconformities by erosion, and in the occurrence of extensive remains of silicified forests. The Triassic series is composed almost wholly of sandstones, the only calcareous matter being thin seams of gypsum. The sandstone beds are very numerous and often shaly. They are usually of no great thickness individually, but there is one very notable member of which we shall see more when we come to view the Vermilion Cliffs.

Directly upon the Trias rests the Jurassic. A wonderful bed of sandstone 800 to 1,200 feet thick, and very white and sugary in color represents the principal part of this series. It is a very notable formation because of its remarkable homogeneity, the persistent way in which it preserves its lithological characters through great distances, and the absence of divisional planes of stratification—the mass being solid from top to bottom. But most striking of all is its wonderful cross-bedding, far surpassing in beauty, extent, and systematic character, any similar phenomenon elsewhere, with which I am acquainted. The summit of the Jurassic suddenly changes to calcareous and sandy shales, abounding in fossils. This series, as well as the Trias, appears to have been laid down horizontally in shallow waters.

Next comes the Cretaceous system—a mass of yellow sandstones with clayey and marly shales, aggregating from 4,000 to 5,000 feet thick. In this series we find an abundance of plant remains, many beds of good coal, and much carbonaceous shale. The conditions during the Cretaceous appear to have been quite similar to those which prevailed in the Appalachian region during the Carboniferous. Perhaps the conditions which attended and rendered possible the accumulation of coal are not sufficiently well understood to enable us to say confidently just what they were, but there seems to be a general agreement that they involved a flat, low, moist country lying almost exactly at mean sea-level, and subject to alternate emergence and submergence. No other supposition seems to meet the requirements of the case, or to be capable of explaining how a mass of strata could be so accumulated, consisting of alternations of thin seams of coal and carbonaceous shale with layers of sandstone containing marine fossils.

We have now the following remarkable state of affairs. From the close of the Carboniferous to the close of the Cretaceous there is strong evidence that the surface of deposition was always very near to sea-level, sometimes a few feet above it, but for the most part a little below it. And yet in the interval about 9,000 feet of strata accumulated with remarkable uniformity over the entire province, and always in a horizontal position. From this it necessarily follows that the mass of material thus deposited sank or "subsided" at a rate which, in the long run, was exactly or sensibly equal to the rate of deposition.

At the close of the Cretaceous we find evidence that the long calm which had characterized the action of the physical processes was invaded. Some extensive disturbances took place, resulting at some places in the dislocation and flexing of the strata, and the elevation of some portions of the region to considerable altitudes. Erosion at once attacked the uplifted portions, and around the borders of the province we find numerous localities, usually not very extensive, which were greatly devastated. At some of these places the entire local Cretaceous series was denuded, and even a portion of the Jurassic; and the Tertiary is seen lying upon the Jurassic and across the beveled edges of the flexed Cretaceous strata. But even these localities were again submerged, as the presence of the Tertiary fully attests. These disturbances were not general—did not extend to the entire province, but appear to have occurred around, or a little within, its marginal portions.

The last period of deposition was marked by the accumulation of the Eocene beds, which form such a striking feature in the stratigraphy of the peripheral parts of the Plateau country. Around the southern flanks of the Uintas their aggregate thickness exceeds 5,000 feet, but southward the upper members disappear, and 80 miles north of the Grand Cañon only about 1,000 to 1,200 feet, representing the lowest portion of the series, make their appearance. It is highly probable that the middle and upper portions of the Eocene were never deposited there. But the lowest beds, most probably, once covered the entire province, while the middle and late Eocene were confined to its more northerly portions. The lowest members were deposited in brackish water, as their fossils amply attest; but in the succeeding beds the fossil forms are entirely those which live in fresh water. From that epoch to the present time there has been no recurrence of marine conditions.

We now reach a turning point in the history of this region. That long continuance of marine conditions lasting from the beginning of Carboniferous time to the close of the Cretaceous came gradually to an end. The waters became brackish and then fresh. During the prevalence of the marine condition it seems to be a necessary conclusion that the waters which covered it had abundant access to the ocean. Whether its waters were wide open to the ocean, like the Gulf of Mexico or Hudson's Bay, or whether they formed a broad expanse, with a comparatively narrow outlet, like the Mediterranean, we do not know, and it would be useless to conjecture at present. At all events the communication was sufficiently free to maintain a degree of saltness suitable to the existence of molluscan forms of the ordinary marine types. When the waters became brackish, we infer that the straits became greatly narrowed; when they became quite fresh, we infer that the access of the ocean to the area was wholly shut off, and that the water brought by the rivers and rains merely outflowed, and the region became an inland lake of vast proportions. For the deposition still went on. Through Eocene time from 1,000 to 5,000 feet of lacustrine beds, containing an abundance of fresh-water fossils, were deposited. Among them are also found layers of coal and carbonaceous shales, and sandstones thickly imprinted with the traces of arboreal vegetation.

But at length the deposition of lacustrine strata ceased; not, however, at one and the same time in all parts of the province. The evidence indicates that in the southern and southwestern portions it stopped after about one-fourth or one-third of the Eocene horizons had been laid down. In the central portions it appears to have ceased after about one-half to two-thirds of those horizons had been deposited. In the northern portions, in the vicinity of the Uintas, the entire system of Eocene strata is found in immense volume. These facts lead us to infer that the great Eocene lake, soon after its waters became quite fresh, began to shrink its area, and that its bottom became through a slow progression dry land. The southern and southwestern portions were the first to emerge; then the middle portions; the lake gradually retracting its boundary to the northward, until in the latter part of the Eocene it occupied a greatly diminished area in the vicinity of the San Rafaél country and the southern base of the Uinta Mountains. At the close of the Eocene this remnant of the lake also disappeared.

We now reach another turning point in the history of the region. Hitherto and for an immense stretch of geological time it had been an area of deposition and of subsidence. It now became an area of elevation and denudation, and these processes have been in operation ever since. In the periods of deposition and subsidence, from the Carboniferous to the Eocene, both inclusive, the thickness of the strata accumulated varied from 14,000 to 20,000 feet, and the subsidence of the base of the Carboniferous was of nearly equal extent. In the periods of elevation and denudation these vast masses of strata rose bodily up again; the amount of elevation varying according to locality from 6,000 to 18,000 feet. The havoc wrought by erosion has been, as already shown, stupendous; the thickness of strata removed exceeding 10,000 feet in some considerable areas, and averaging probably 5,500 to 6,000 feet over the entire province.

The points which it is desirable to notice in this chapter concerning the progress of the Tertiary and Quaternary erosion of the province, are few and of the broadest nature. In truth it is necessary to speak very guardedly. For while the most general features of the work have left well-marked traces which can be interpreted, yet when we come to details the vast erosion has swept away so much of its mass that a large portion of the evidence of the details has vanished with the rocks. There is reason to believe that the greater part of the denudation was accomplished in Miocene time. This was a period of slow but continuous uplifting, reaching a great amount in the aggregate, and it was most probably also a period of rapid erosion. The uplifting, however, was unequal in the different parts of the province. The comparatively even floor of the old lake was deformed by broad swells and plateaus rising above the surrounding country. As we shall see hereafter, the action of the denuding agents is much more vigorous and efficient upon the higher than upon the lower parts of a region; and consequently these up-swellings at once became the objects of special attention from the destroying forces and were wasted more rapidly than the lower regions around them. Here were formed centers or short limited axes, from which erosion proceeded radially outwards, and the strata rising gently towards them from all directions were beveled off. Thus were formed those areas of maximum erosion, already spoken of, and of which the San Rafael Swell is the most perfect and simplest type.

We have also reason to believe that the climate of the Miocene was moist and subtropical, conditions favorable under the circumstances to a rapid rate of erosion. We do not indeed find the proof of this in the province itself, for it contains no Miocene strata or fossils; but in surrounding regions the strata and fossils of that age are found in abundance, and they clearly indicate that the climate had that character; and it would be quite untenable to suppose that so limited a tract as the Plateau Province was an anomaly in respect to the climate of the broader regions of which it is a part, unless special reasons for it could be adduced. I know of no such special reasons. But near the close of the Miocene, or not long thereafter, the climate of almost the entire West underwent a change, becoming arid, as it is at present. In this change the Plateau country no doubt shared. The more important results of the Pliocene and Quaternary erosion, however, will be among the principal themes of the following chapters.

CHAPTER II.

GEOGRAPHY OF THE GRAND CAÑON DISTRICT.

The Grand Cañon District—the region draining into the Grand and Marble Cañons—is the westernmost division of the Plateau Province. Nearly four-fifths of its area are situated in Northern Arizona. The remaining fifth is situated in Southern Utah. Let us turn our attention for a moment to the portion situated in Utah. It consists of a series of terraces quite similar to those which we have already seen descending from the summit of the Wasatch Plateau to the San Rafael Swell like a colossal stairway. At the top of the stairs are the broad and lofty platforms of the High Plateaus of Utah; at the bottom is the inner expanse of the Grand Cañon District. The summits of the High Plateaus are beds of Lower Eocene age. Descending southward we cross, step by step, the terminal edges of the entire Mesozoic system and the Permian, and when we reach the inner floor of the Grand Cañon District we find that it consists of the summit beds of the Carboniferous series patched here and there with fading remnants of the Permian.

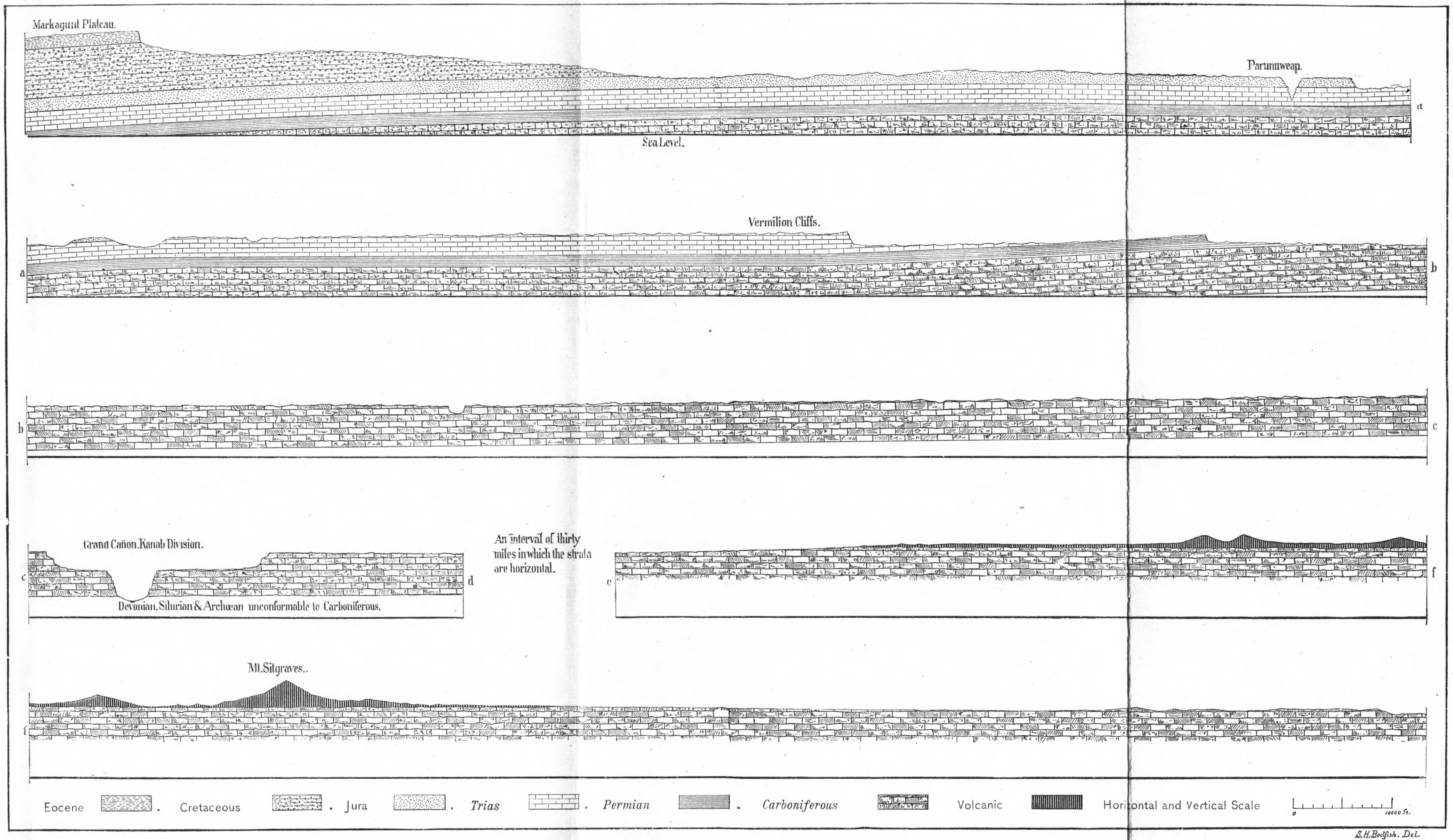
Far beyond the remotest limits of vision stretches the great expanse of Upper Carboniferous beds, flecked with Permian outliers, and rising or falling to form the broader inequalities of level in the surface of the region. The terraces of Southern Utah are the border land between the High Plateaus on the north and the Carboniferous platform of the Grand Cañon on the south, and may be regarded as the appanage of either district. Their nature and meaning may become clearer by glancing a moment at the District of the High Plateaus.

Let us conceive a right-angled triangle in which the acutest angle is regarded as the apex and the shortest side as the base. Place the apex about 25 miles east of Mount Nebo, the great mountain which marks the southern end of the true Wasatch Range; place the right angle 170 or 180 miles due south of the apex, and the other acute angle about 100 to 110 miles due west of the right angle. This figure would include pretty nearly all of the summit areas of the High Plateaus. Consider now the north-and-south side reaching from the apex to the right angle. It runs along the crest lines and terraces which look down eastwardly upon the San Rafael district and upon other enormously eroded districts further south. The base reaching westward from the right angle to the other acute angle runs among the terraces which descend from the southern termini of the High Plateaus to the Grand Cañon District. The hypothenuse looks northwestward over a portion of the Basin Province. The High Plateaus themselves are large remnants of Mesozoic and Tertiary strata which have been spared in the enormous denudation which has eaten out the heart of the Plateau Province. Their preservation has been largely due to extensive outpours of lavas, which have overspread most of their summits, and the energy of the eroding agencies has there spent itself upon the more obdurate materials of volcanic origin.

Starting from the right angle and reaching out south-southeast is a rather lofty mass, named the Kaiparowits Plateau. It reaches to the Colorado River, where it is cleft asunder by the mighty gorge of the Glen Cañon, but resumes its course on the other side, extending into Arizona, where it spreads out. It is composed of Cretaceous strata. Its western flank forms a part of the eastern boundary of the Grand Cañon, or more restrictedly of the Marble Cañon, district. Here again is the same old arrangement—terraces with their marginal cliffs rising from the Carboniferous platform step by step to the Middle Cretaceous—the cliffs all looking westward over the great region from which the former extensions of the strata they terminate have been swept away.

Thus we may note that the northern and eastern boundaries of the Grand Cañon District are cliff-bound terraces. Crossing the district either longitudinally from north to south, or transversely from east to west, we find as we approach the southern or western border that the Carboniferous platform ascends very gradually. There are broad and feebly marked (sometimes well marked) undulations, or ups and downs; but, on the whole, the country gains in altitude as we approach its western and southern limits. At last it terminates in a giant wall plunging down thousands of feet to the platform of a country quite similar to that of the Great Basin of Nevada. Those who have traveled on the Central Pacific Railway will recall the features of that very desolate region which lies between Great Salt Lake and the Sierra Nevada; and all those features are repeated and their desolation intensified in the dreadful region which lies west and south of the Grand Cañon District.

The district may be conveniently divided into parts. The northernmost portion is the area comprising the southern terraces of the High Plateaus. A description of these sufficient for preliminary purposes has already been given. At the foot of these terraces stretches away to the southward the great Carboniferous platform of the heart of the district. That portion of the platform which lies north of the Colorado River may be subdivided into five distinct plateaus. Naming them in regular order from west to east, they are: 1, the Sheavwits; 2, the Uinkaret; 3, the Kanab; 4, the Kaibab; 5, the Paria. These five plateaus are separated from each other by natural boundaries, which are for the most part quite distinct. These boundaries are great faults or dislocations of the main platform, which have produced cliffs by hoisting the platform on one side of the fault line or dropping it on the other. To show how these dislocations have affected the topography, the reader is referred to the east and west section delineated in the accompanying dia-



SECTION FROM NORTH TO SOUTH ACROSS THE GRAND CAÑON DISTRICT.

gram. (Pl. XIII.) Immediately south of the Paria Plateau extends the Marble Cañon, with a southwestward course. Directly across the remaining four plateaus winds the Grand Cañon of the Colorado. South of the river is a vast expanse of nearly flat surface, but little diversified, called the Colorado Plateau. Upon its southern borders rise abruptly a group of great volcanic piles called the San Francisco Mountains, the largest or dominant cone being of an impressive order of magnitude. There are still other portions beyond, but the entire region south of the Colorado has been reconnoitered rather than surveyed; and though we have a general knowledge of pretty nearly the whole of it, our knowledge of details is not as yet precise.

The entire expanse of the Grand Cañon platform within the terraces consists of a flat surface, interrupted at wide intervals by cliffs or sharp flexures produced by the great displacements which traverse the land in a prevailing north to south direction.* On the whole, it is a smooth country in comparison with the other districts of the Plateau Province. It is not dissected or honeycombed by the ramifications of innumerable side gorges, as is the case with most of the other districts, for the Grand Cañon has on the north side only one lateral or tributary cañon of any considerable length, and this tributary has but few branches. In truth, one of its remarkable features is the paucity of lateral chasms. The southern side is not more diversified than the northern, and I think we may say that it is somewhat less so. Between the great cliffs of displacement and between the foot of the terraces and the brink of the chasm the country is not more uneven than the Great Plains of Western Nebraska and Kansas, and not much more so than Indiana and Illinois. But the traveler is seldom out of sight of the palisades reared at the fault-lines, or of the gigantic and gorgeously colored walls which bound the terraces of the High Plateaus.

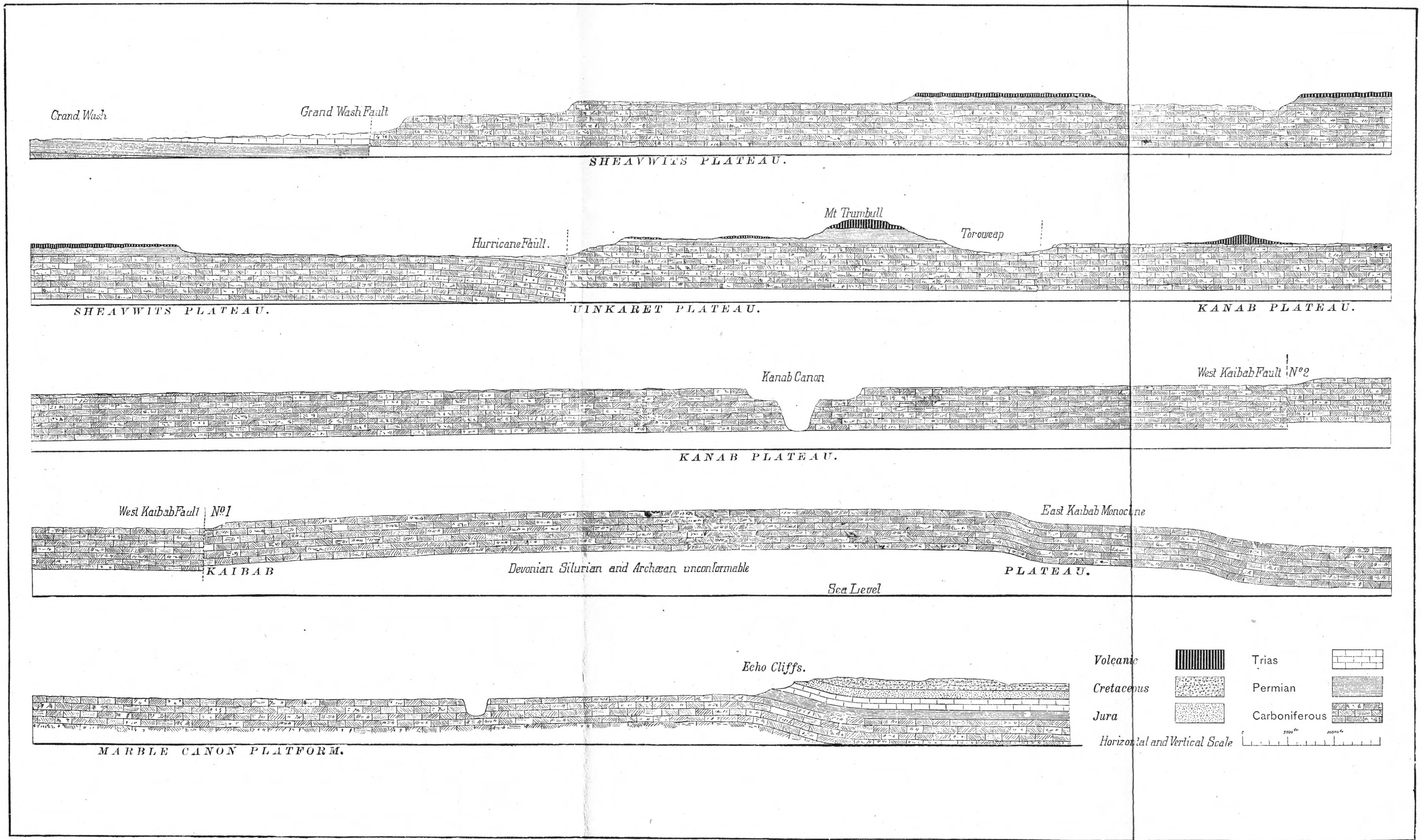
The Grand Cañon will be described at some length in subsequent chapters. Here will be noted only those more general features which may be made to appear on the map. It crosses transversely the four western plateaus of the district, while the Marble Cañon traverses the eastern or fifth plateau. The two cañons are only nominally separated, for there is no gap between them. The Marble Cañon begins at the base of the eastern terraces. The Colorado River, after traversing the central mesas of the Plateau country in a series of profound chasms, at length emerges from the Echo Cliffs of Triassic and Permian age. Here for an instant the river is in comparatively open country. But within a mile or two it begins to sink another chasm in the Carboniferous rocks, and in the course of 65 miles the depth steadily increases until it becomes about 3,500 to 4,000 feet. This is the Marble Cañon. It is

* It will be noted here that cliffs may be produced (1) by faults lifting the country on one side of the fault-line or depressing it on the other; (2) by the denudation of the strata in front of the cliff. The former are called *Cliffs of Displacement*; the latter, *Cliffs of Erosion*.

a gorge of very simple form, and its width is about twice as great as its depth. Its course is at first southwest, but gradually deflects to the southward. Its lower end is arbitrarily fixed at the junction of the Little Colorado or Colorado Chiquito, a stream coming in from the southeast and entering by a lateral chasm as deep as the main gorge itself. Below this junction the river turns westward, the walls grow rapidly higher, the great chasm widens out to six or eight times its width in the Marble Cañon, and the valley of the river is filled with buttes as large as mountains and wonderfully sculptured. Here the river enters the Kaibab, and its walls soon attain the altitude of about 6,000 feet. After a tortuous course of sixty miles in a prevailing northwest direction the river passes out of the Kaibab and at once changes its trend to west southwest. It passes without a break from the Kaibab to the Kanab Plateau. Here its depth diminishes to about 5,000 feet and its topography changes in character, becoming more simple. Preserving its new features and the direction of its course throughout the Kanab and Uinkaret plateaus, it at length crosses the Hurricane fault where the whole platform of the country suddenly drops more than a thousand feet, correspondingly diminishing the height of the walls. But the lost altitude is steadily and rather rapidly regained as the river enters the Sheavwits Plateau. Soon after crossing the fault the river turns abruptly to the south, and after describing a great curve in the heart of the Sheavwits platform it turns northwestward again. The great chasm suddenly terminates in the face of the giant wall which forms the western boundary of the Sheavwits Plateau. Here the river emerges through a mighty gateway a mile in depth, and is almost in open country, its banks dropping at once to altitudes of only a few hundred feet. This is the western bound, not only of the Grand Cañon District, but of the Plateau Province itself. Thenceforth the course of the Colorado to the ocean is through and across that dismal, torrid sierra region, which is the southward extension of the features of the Great Basin.

For convenience of discussion the Grand Cañon is divided into four divisions, (1) the Kaibab, (2) the Kanab, (3) the Uinkaret, (4) the Sheavwits, divisions. The last three are much alike in all their features and dimensions. The Kaibab division is a little deeper, notably wider, and very much grander and more diversified than the others. The total length of the Grand Cañon, as the river runs, is about 218 miles, and its depth varies from 4,500 to 6,000 feet, averaging 5,000. Its width, from crestline to crestline, varies from 4½ to 12 miles—the widest portions being always the grandest.

It is also necessary to advert to the tributaries of the Colorado lying within the district. Upon the northern side there is but one now entering the Grand Cañon; but there are on this side two others, one of which, named the Paria, enters at the head of the Marble Cañon, and the other, the Virgen, which enters it about 40 miles west of the lower end of the



SECTION FROM EAST TO WEST ACROSS THE GRAND CAÑON DISTRICT.

Grand Cañon. Kanab Creek joins the Colorado on the north side in the heart of the great chasm. These three streams, the Virgen on the west, Kanab Creek in the middle, and the Paria on the east, all have their sources in the terraces of the High Plateaus. They are very important factors in the problem of reconstructing the history of the region.

On the south side of the river are (1) the Colorado Chiquito or Little Colorado, entering at the foot of Marble Cañon, (2) Cataract Creek, entering near the middle of the Kanab division, (3) Diamond Creek, joining at the elbow of the great bend in the Sheavwits division. These, too, have their bearing upon the general problem.

CHAPTER III.

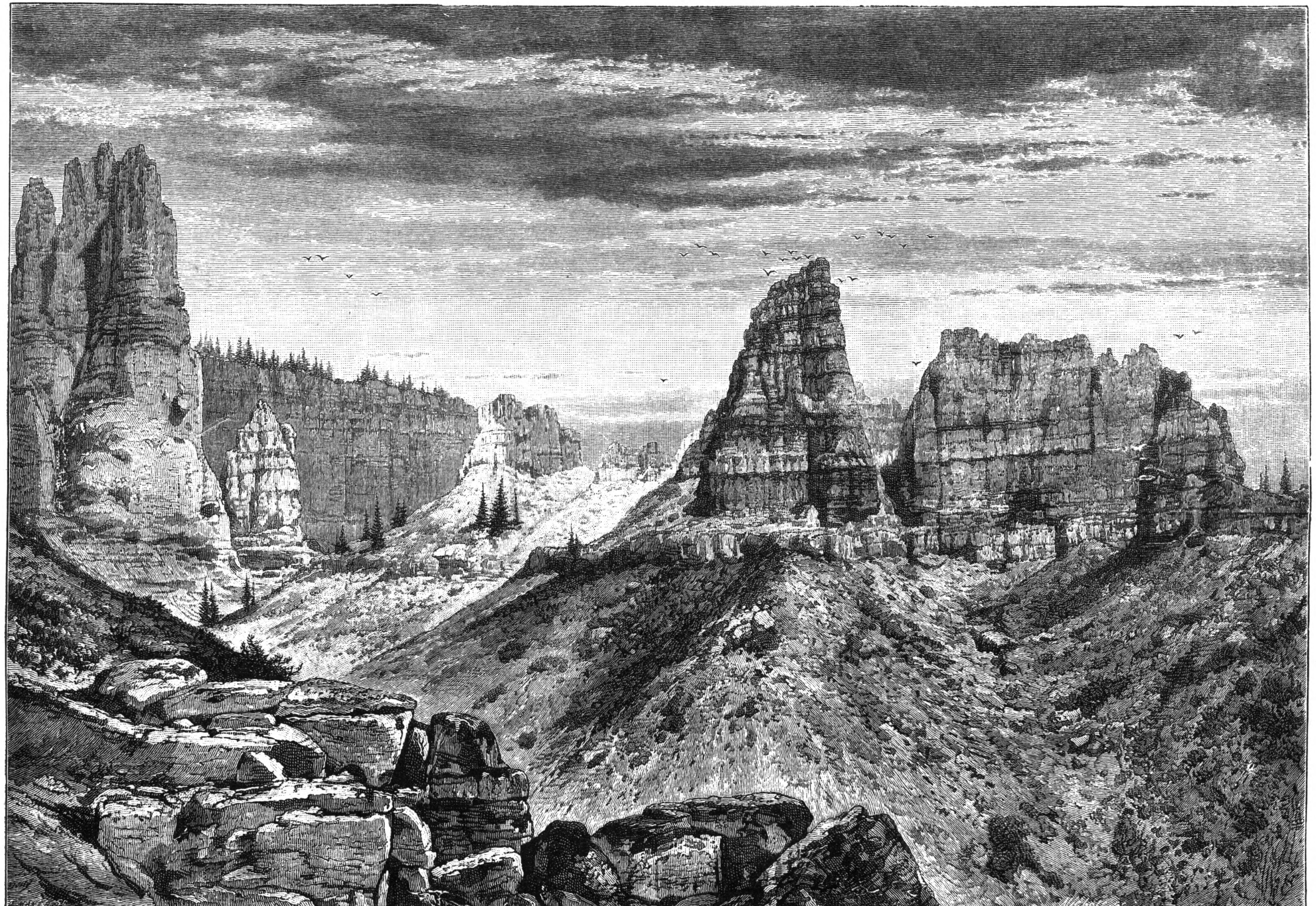
THE TERRACES.

In describing those subdivisions of the Grand Cañon district which are of greatest moment to the present discussion, I shall begin with the terraces terminating the High Plateaus.

Before the observer who stands upon a southern salient of the Markágunt Plateau is spread out a magnificent spectacle. The altitude is nearly 11000 feet above the sea, and the radius of vision reaches to the southward nearly a hundred miles. In the extreme distance is the calm of the desert platform, its surface mottled with indistinct lights and shades, too remote to disclose their meaning. Against the southeastern horizon is projected the pale-blue escarpment of the Kaibab, which stretches away to the south until the curvature of the earth carries it out of sight. To the southward rise in merest outline, and devoid of all visible details, the dark mass of Mount Trumbull and the waving cones of the Uinkaret. Between these and the Kaibab the limit of the prospect is a horizontal line, like that which separates the sea from the sky. To the southwestward are the Sierras of the Basin Province, and quite near to us there rises a short but quite lofty range of veritable mountains, contrasting powerfully with the flat crestlines and mesas which lie to the south and east. It is the Pine Valley range, and though its absolute altitude above the sea is smaller than many other ranges of the West, yet since their bases are comparatively low (3,000 to 3,500 feet above the sea), the mountain masses themselves are very high.

THE EOCENE.

The foreground of the picture is full of strength and animation. At our feet is the brink of a precipice where the profiles descend 800 feet upon rugged slopes which shelve away downwards and mingle with the inequalities of a broad platform deeply indented with picturesque valleys. The cliff on which we stand is of marvelous sculpture and color. The rains have carved out of it rows of square obelisks and pilasters of uniform pattern and dimensions, which decorate the front for many miles, giving the effect of a giantic colonnade from which the entablature has been removed or has fallen in ruins. The Plateau Country abounds in these close resemblances of natural carving to human architecture, and nowhere are these more conspicuous or more perfect than in the



PINK CLIFFS—EOCENE—PAUNSAGUNT.

scarps which terminate the summits of the Markágunt and Paunságunt Plateaus. Their color varies with the light and atmosphere. It is a pale red under ordinary lights, but as the sun sinks towards the horizon it deepens into a rich rose color, which is seen in no other rocks and is beautiful beyond description. These cliffs are of lower Eocene age, consisting of lake marls very uniformly bedded. At the base of this series the beds are coarser, and contain well-marked, brackish-water fossils; but as we ascend to the higher beds we find the great mass of the Eocene to consist of fresh-water deposits.

These beds are identical in age with the lower divisions of the Eocene which are seen in great volume both north and south of the Uinta Mountains, in the basins of the Green River, of Bitter Creek, and of the White and Uinta Rivers. Their geological relations and associations, too, are quite the same, for the same lake bottom received the deposits of the southern Uinta slopes and those of the Markágunt. Those of the Green River basin north of the Uintas appear to have accumulated in a separate lake basin communicating with the one which submerged the southern Plateau province. The interval separating the Markágunt from the Uinta region is 250 miles and more, but the lower Eocene is continuous between them. It occupies a marginal belt sometimes narrow, but more frequently wide, which was once the locus of the northwestern portion and shore line of the great lake. The summits of the High Plateaus, wherever the volcanic masses are absent, disclose this formation, and its presence is decisively inferred beneath the lavas and their débris. A common bond between the two regions is also indicated by the physical conditions attending the deposition of these strata. The lower Eocene rests upon the underlying formations, conformably in some places, unconformably in others. Where conformity prevails, both the upper and lower series were at the time of deposition sensibly horizontal. But in many places the Cretaceous, prior to the deposition of the Eocene, was greatly disturbed and greatly eroded. And in general the base of the Eocene marks an epoch in the geological history of the country, in which an old order of events was closing and a new order was making its advent. This revolution was the transition of the region from the oceanic condition to that of an estuary and lake, and subsequently to that of dry land. The Lower Eocene beds are brackish-water deposits in the basal members, while higher up they become fresh water. The basal members are coarse and even conglomeratic in their texture, while the middle and higher ones are fine and marly. Thus is indicated the complete severence of the lake from the access of oceanic waters. Both in the Uinta district and throughout the High Plateaus these events are recorded in the same order and their meaning is the same in both.

The beds now found in the southern extremities of the High Plateaus represent less than half of the duration of Eocene time. No middle and no upper Eocene strata are found there. But as we go northward towards the Uintas we find later and later formations successively appearing until upon the flanks of the Uintas we find the whole Eocene series in enormous volume, exceeding perhaps 5,000 feet. Could these middle and Upper Eocene masses once have existed upon the southern portion of the High Plateaus and been swept away by erosion? There is strong evidence to the contrary.* The facts, then, indicate that when the desiccation of the lake took place, the portion which first emerged was the southern and southwestern—or the Grand Cañon district; that its shore line gradually receded northward during middle and upper Eocene time, leaving dry land behind it; and the last remnant of the lake disappeared near the base of the Uintas. Wherever the physical geology and evolution of the Grand Cañon district touches the question of time, the earlier date of its emergence than that of other portions of the Plateau Province appears—sometimes dimly, sometimes forcibly.

The principal mass of the Eocene terminates at the "Pink Cliffs," as they are called, in the southern margins of the Markágunt and Paunságunt Plateaus. There are a few outliers beyond. Around the base of the Pine Valley Mountains to the southwest, and beyond them in the same direction, some remnants have escaped destruction. But this part of the country has not been sufficiently explored to indicate more than the bare fact of their existence. Far to the eastward a single outlier stands upon the summit of the great Kaiparowits Plateau, forming the apex of Kaiparowits Peak. But generally speaking, the Eocene is wholly absent, so far as known, from the country south of the terraces.

THE CRETACEOUS.

The platform immediately below the Pink Cliffs is picturesque rather than grand. Rough rolling ridges of yellow sandstone, long sloping hillsides, and rocky promontories clad with large pines and spruces, surround the valleys. These rocks are of Cretaceous age. Upon the southward slopes of the Paunságunt and Markágunt Plateaus, they nowhere present the serried fronts of cliffs, but break down into long irregular slopes much like those of common hill countries. In those superficial and merely scenic aspects which make the terraces so impressive, the Cretaceous is for the most part notably deficient; but in those deeper studies, which are of most significance to the geologist, it holds an importance not inferior to that of any other formation. It is never wanting at its proper place in the terraces, but always displays a vast series of sandstones and clay-shales, varying from 4,000 to 5,000 feet in thickness. Around the western and southern flanks of the Markágunt, and just beneath the summit platform, they occupy a belt varying in width from 4 to 10 miles. Around the Paunságunt their relative positions and re-

*This evidence will be fully discussed in my monograph on the Geology of the Grand Cañon district.—C. E. D.

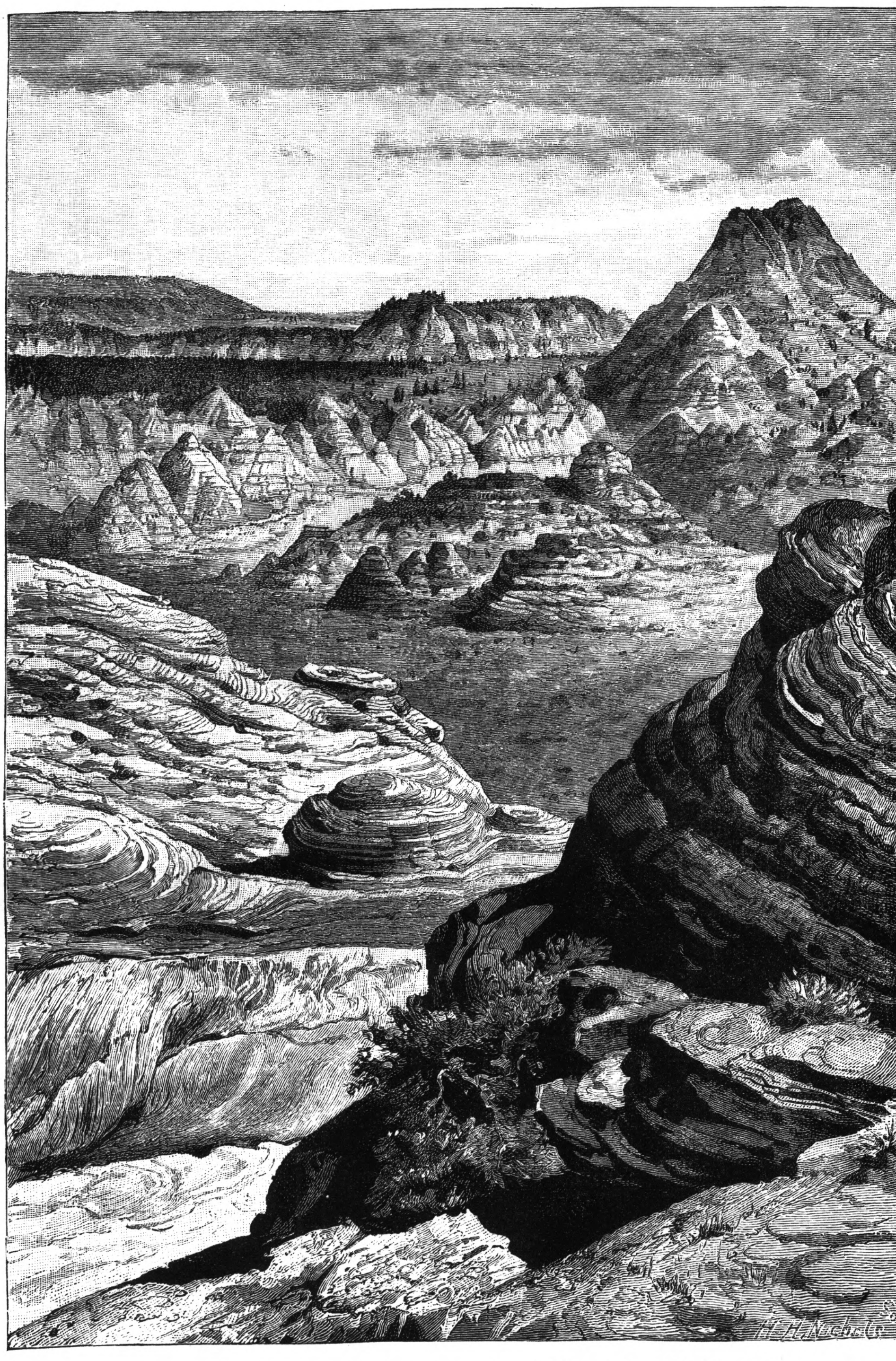
lations are quite the same. But as we pass eastward into the great amphitheater of the Paria Valley they at length take the form of cliffs of very striking aspect. The numerous ledges rise in quick succession, step by step from the valley bottom to the base of the Eocene mass of Table Cliff, which stands as a glorious Parthenon upon the summit of a vast Acropolis. The many superposed cliffs which constitute this stairway are severally of moderate dimensions, but their cumulative altitude is more than 4,000 feet, tier above tier, and their composite or multiple effect, intensified by the exceeding sharpness of the infinite details of repetitive sculpture, places it among the grander spectacles of the Plateau country. In their coloring, these cliffs are quite peculiar. There are no red, purple, orange, and chocolate hues, such as prevail in other formations, but pale yellow and light brown in the sandstones and blue-gray to dark iron-gray in the heavy belts of shale. The tones are very light and brilliant on the whole, the darker belts playing the part of a foil which augments rather than diminishes their luminosity.

THE JURASSIC.

Beyond the Cretaceous, as we descend the stairway of terraces, the Jurassic comes to daylight. It forms a belt encircling the Cretaceous and outside of the latter. It is composed of two groups of strata; the upper consisting of red sandy shales with belts of impure limestone; the lower a great mass of white sandstone, nearly a thousand feet thick. The red shales contain abundant fossils, strongly characteristic of their Jurassic age, while the sandstone below is wholly barren of organic remains. The sandstone, however, is full of interest on account of its remarkable lithological characters. From summit to base, it is apparently one indivisible stratum. Here and there signs of a division are suspected, but closer scrutiny shows that they are produced by the contact of one plexus of cross-bedding with another, or by some other cause not affecting the dominant fact. It is remarkably homogeneous throughout its whole mass. On a near view of the rock faces they are seen to be covered with a wonderful filagree of cross-bedding. On every cliff and headland, on every butte or rocky knoll where this huge stratum is exposed, the rock faces are etched with an arabesque as beautiful as frostwork. Along hundreds of miles of linear extent, and over thousands of square miles of surface of the country, this graceful waving of myriads of curves is displayed. Cross-bedding is common enough in other regions and other formations, but nowhere in the world, I fancy, can such a profusion of it be seen.

The Jurassic sandstone is also conspicuous for its cliffs. Here every formation has its own style of architecture and sculpture, which are as distinctive as the lithological constitution, for upon that constitution the style depends. The Jurassic forms are characterized by a peculiar massiveness and boldness and by an extreme simplicity which is even severe. Its walls are quite plain, without horizontal or vertical mouldings, and the only decoration is the cross-bedding which becomes invisible at distances sufficient to render a general view of the fronts effective. A notable feature also is the absence of talus—or, if it be present, its small proportions. This simplicitly usually gives a dull slumberous aspect to the escarpments, suggesting on a vast scale the structures of the Peruvian Incas. But it is not always so. Occasionally the austerity of these forms is relaxed or replaced by a strange kind of animation which sometimes becomes amusing. Looking southward from the brink of the Markágunt the eye is attracted to the features of a broad middle terrace upon its southwestern flank, named The Colob. It is a veritable wonderland. It lies beyond the Cretaceous belt and is far enough away to be obscure in its details, yet exciting curiosity. If we descend to it we shall perceive numberless rock-forms of nameless shapes, but often grotesque and ludicrous, starting up from the earth as isolated freaks of carving or standing in clusters and rows along the white walls of sandstone. They bear little likeness to anything we can think of, and yet they tease the imagination to find something whereunto they may be likened. Yet the forms are in a certain sense very definite, and many of them look merry and farcical. The land here is full of comedy. It is a singular display of Nature's art mingled with nonsense. It is well named the Colob, for the word has no ascertainable meaning and yet sounds as if it ought to have one.

Nor are these the only forms which the Jurassic discloses. Here and there blank faces of the white wall are brought into view as the sinuous line of its front advances and recedes. Isolated masses cut off from the main formation, and often at considerable distances from it, lie with a majestic repose upon the broad expanse of the terrace. These sometimes become very striking in their forms. They remind us of great forts with bastions and scarps nearly a thousand feet high. The smaller masses become regular truncated cones with bare slopes. Some of them take the form of great domes where the eagles may build their nests in perfect safety. But noblest of all are the white summits of the great temples of the Virgen gleaming through the haze. Here Nature has changed her mood from levity to religious solemnity, and revealed her fervor in forms and structures more beautiful than anything in human art. But we shall see more of this hereafter and from much more advantageous stand-points than the summit of the Markágunt. There only faint suggestions of the reality are given. We only perceive in imperfect detail some throngs of towers, snow-white above and red below, the bristling spires of ornate buttes, or a portion of the grand sweep of a wing-wall thrust out from some unseen façade. None of them appear in their full relations to the whole, and all of them are weakened, faded, and flattened by the distance.



A MIDSUMMERDAY'S DREAM.—JURASSIC.—ON THE COLOB.

At the border of the Jurassic the profile drops upon the summit of the Trias, but from the summit of the Markágunt nothing is visible in detail of that formation. The faces of the escarpments are turned away from us and only the crestlines are visible. The view from the Markágunt, however, is memorable because it is characteristic. To study the Trias we must leave the verge of that Plateau and descend the terraces to the southward.

On our way we may note several things of some importance. We may observe, first, that the strata all have a very slight dip to the north. This dip on the average is less than two degrees, but here and there inclinations as great as four or five degrees may be seen. This dip is very general throughout the terraces. Its effect is to make the altitudes of the higher or more northerly platforms less—or, conversely, to make the altitudes of the lower and more southerly terraces greater—than they would be if the entire series were horizontal. In the entire series of beds which are exposed, the aggregate thickness from the top of the Carboniferous to the summit of the local Eocene is not far from 10,000 feet, but the summit of the Eocene at present lies only about 5,000 to 6,000 feet above the Carboniferous platform of the Grand Cañon District. Thus, if the strata were horizontal, we should in ascending the terraces go up 10,000 feet, but the dip to the northward gradually carries down the horizons so that in crossing the edges of 10,000 feet of strata we only gain 5,000 to 6,000 feet in altitude. We find this same northward dip prevailing in the Carboniferous to the southward, and it is a feature of great moment in the studies which are to follow.

Another point to be noted is that the strata slowly diminish in thickness from west to east. The attenuation, however, is ordinarily very slow and gradual, and the observer would have to travel many miles along the escarpments exposing the edges of the strata before he became aware of it. It is most noticeable in the Trias, and in the sequel this will be more fully discussed. The meaning of this attenuation of the strata towards the east is as follows.

It is a common fact that the greatest thickness of a group of strata is usually found near the shorelines of the mainlands from which their materials came. As we recede from these ancient shorelines we generally find that the strata diminish in thickness, at first quite rapidly, but afterwards more slowly. The materials deposited near the shores are, in many cases, of coarser texture than those deposited at a distance from them. This is not always true of every distinct bed, but if we consider any group of strata with many members we shall usually find it true of the group as a whole. In the case of the Mesozoic strata of the terraces, they are remnants of beds deposited in a sea or bay, the shoreline of which lay to the westward and northwestward. The position of this shoreline, no doubt, varied during the Mesozoic periods, now advancing and now receding; but in general terms its mean position appears to have been nearly along what is now the boundary of the Basin

Province. The Great Basin was then dry land, undergoing denudation, and its detritus was washed down on this side into the sea, where the Mesozoic strata of the Plateau Province accumulated. The position of this ancient shoreline in the Sierra country south of the Great Basin and west of the Grand Cañon district we do not as yet know; the presumed location not being explored as yet. This attenuation of the strata and their relation to the shoreline of the mainland, from which they were in great part at least derived, is another important factor which must be kept in mind in the course of the discussion.

It will be well to bestow also a glance at the distribution of the more important drainage channels. The western portion of the terraces is

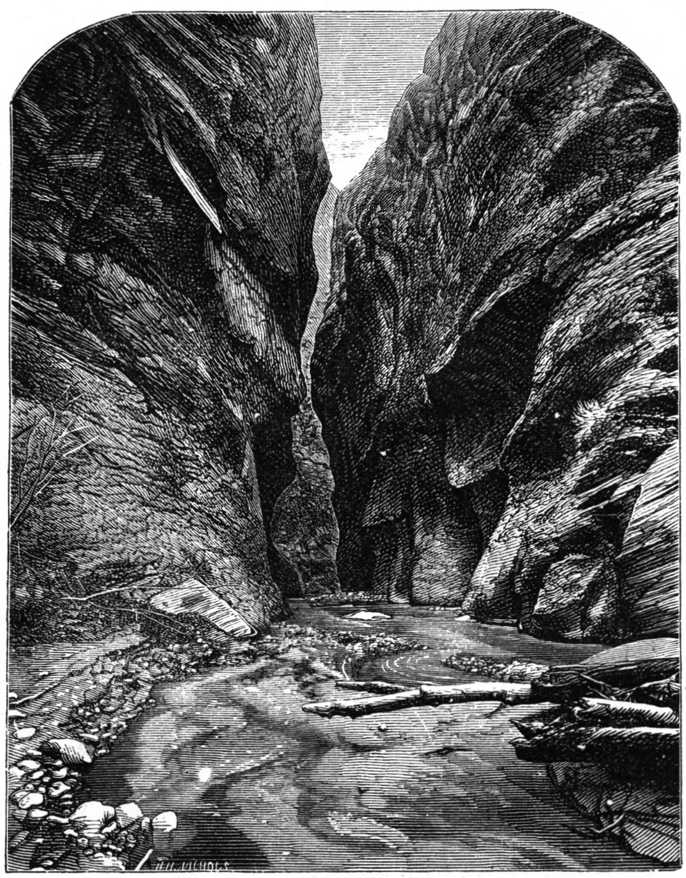
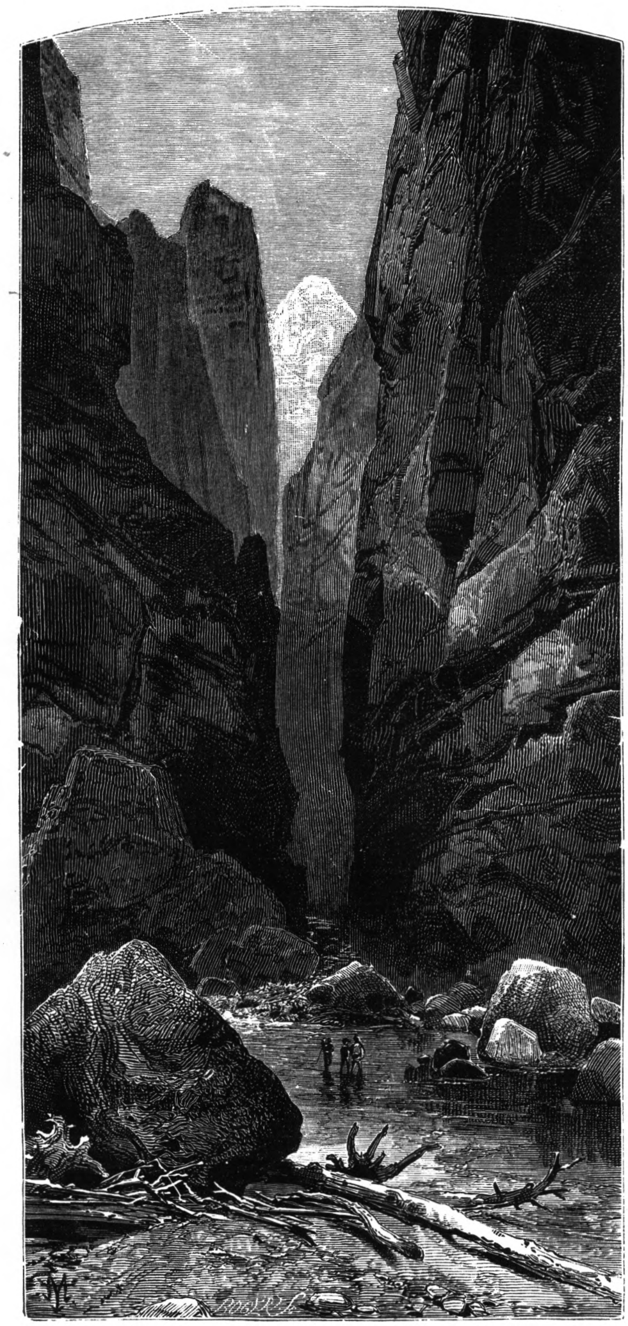


FIG. 5.—Entrance to the Parú-nu-weap.

drained by the branches of the Virgen River. Upon the Colob heads the northern fork of the Virgen, sometimes called the Mu-kún-tu-weap, sometimes Little Zion River. It flows due south. East of this is the eastern fork, called the Pa-rú-nu-weap. Both branches have their sources at the base of the Pink Cliffs (Eocene), and at length unite to form the



THE PARUNUWEAP.

From Powell's Exploration of the Colorado River.

Virgen. Their channels are surely very wonderful freaks of nature. The Parúnuweap, after collecting its several filaments on the slopes of the Cretaceous terrace, at length begins to burrow into the Jurassic, cutting a very deep and remarkably narrow gap in the white sandstone, and then into and through the Trias. For many miles it flows in a mere cleft barely fifty feet wide at the bottom and sometimes narrower, and attaining a depth of more than 2,500 feet. In scouring down its channel into the sandstones the stream did not cut always vertically, but swayed from side to side, so that now great bulges of the wall overhang the bottom of the abyss, and in some places shut out the sky overhead. The Mukúntuweap, or Little Zion fork, is even more remarkable. For a considerable distance this stream also runs in a profound and exceptionally narrow chasm, but it at length widens out, and just where it joins the Parúnuweap is a scene which must ultimately become, when the knowledge of it is spread, one of the most admired in the world. Of this hereafter. Below the junction of the forks the Virgen flows westward, and passes out of the terraces and out of the Plateau Province. At length it joins the Colorado.

East of the drainage area of the Virgen is that of Kanab Creek. It heads in the broad valley of Upper Kanab, which occupies an indentation of the southern margin of the High Plateaus between the Markágunt and Paunságunt. The bulk of the drainage passes through the upper cañon of Kanab Creek, and at length emerges upon the desert to the southward. Further on it sinks another chasm in the Carboniferous, which becomes a mighty side gorge of the Colorado, and unites with the Grand Cañon in the middle of the Kanab division.

Still eastward is the great amphitheater which gives rise to the branches of the Paria. This stream flows southeastward and ultimately enters the Colorado at the head of the Marble Cañon.

In these three subordinate drainage basins of the terraces it is well to notice some features of importance, common more or less to all, but most distinctly seen in Kanab Creek. They all run contrary to the dip of the strata. The summits of the terraces dip to the northward, while the streams run southward. They thus form each a chain of cañons. Thus, Kanab Creek with its upper tributaries flowing in open valleys soon begins to cut into the Jurassic, and its gorge, ever deepening, at length becomes nearly a thousand feet in depth. Suddenly the cañon walls swing to right and left to form the mural front which terminates the Jurassic terrace, and the river, now at the summit of the Trias, is once more in open country; but only for a short distance, for it soon begins to cut into the Trias, forming a great cañon as before. The same process is repeated and the river flows out of its Triassic chasm into the open again, while its walls swing in either direction to form the terminal escarpment of the Triassic terrace.

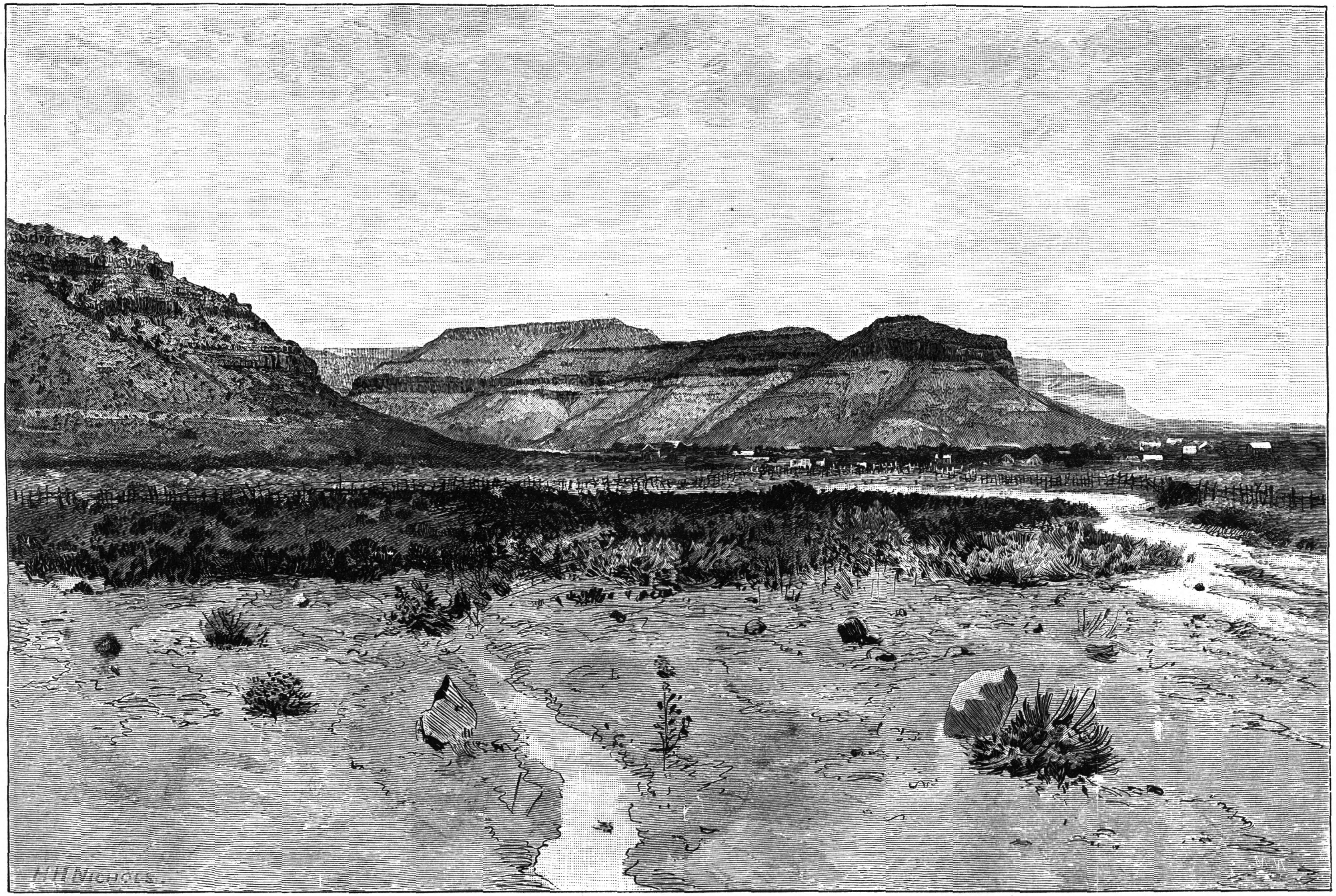
The three streams just mentioned are not the only drainage channels in the terraces, though they are the principal ones, and sooner or later gather the greater part of the drainage. There are many cañons in the terraces, and they all have the same relation to the cliffs and to the dips of the strata. They cut into the terraces and emerge from them at the bases of their several cliffs. All except the three first mentioned are dry, carrying no streams except spasmodic floods during heavy rains and the melting of the snows. Many of them are actually filling up, the floods being unable to carry away all the sand and clay which the infrequent rains wash into them.

It is through the dry and partially refilled chasms that we may easily descend from the High Plateaus to the Carboniferous platform of the Grand Cañon district. To study the Trias, we may best go to the little village of Kanab and prepare for a journey along the base of the Vermilion Cliffs.

THE TRIAS.

Kanab village is situated under the eaves of the Vermilion Cliffs, in the jaws of the cañon of Kanab Creek. It has for several years been the base of operations of the surveying parties working in the Grand Cañon district, and is well located for the purpose. After due preparation, we may leave the village, proceeding about twenty miles southwestward to the southernmost promontory of the Triassic escarpment. Here is Pipe Spring, famous in this far-off region as a watering place. The reader would do well to find the locality on the map, for it is a notable point. The Vermilion Cliffs here change their trend to the northwestward, and we shall presently follow them to admire their beauty and magnitude; but before doing so it is well to take a brief view of their geological relations.

The Trias is in most places separated from the Jura by a purely provisional horizon which marks a change in the lithological aspect of the strata, and in the grouping and habit of the series. Sometimes the passage from one to the other is obscured, but more frequently it is abrupt. The Jurassic sandstone is without a likeness in any other formation, and the sandstones of the Trias can ordinarily be distinguished from it miles away. One of the most conspicuous distinctions is the color, and it is a never-failing distinction. The Jurassic is white; the Trias is flaming red. Equally conspicuous is the difference in bedding and in the architecture. The Jura is a solid indivisible mass of 800 to 1,000 feet in thickness; the Trias is composed of a very great number of beds, most of which are only a few feet in thickness. One bed, however, attains vast proportions. The majority of the layers are common sandstones, and they predominate most in the upper portion of the series. In the middle part the sandstones still predominate but are individually thinner, and are more often separated by shaly layers and by bands of gypsum. In the lower portions, sandy and argillaceous shales of won-



VERMILLION CLIFFS AT KANAB. TRIASSIC.

derful colors predominate. Lime is found in these rocks, and in notable quantity, but it is almost always in the form of gypsum or selenite. No fossils in these parts have yet been found which are of paleontological value; but fish-scales, and fragments of bony scutes are sometimes obtained, which are useless for the purposes of the geologist. In the lower shales we find a great abundance of fossil trees completely silicified and several bulky layers are composed very largely of their fragments.

The Trias makes its appearance upon the outermost western flank of the Markágunt, a little north of the Mormon town Cedar, rising by a fault out of the valley alluvium. With a constantly expanding exposure, it extends southward along the west flank of the Markágunt and along the upthrow of the Hurricane fault, until the whole of its mass comes to the surface; then broadening out into a wide terrace, it sweeps around the southwestern limit of the Colob and over into the valley of the Virgen, where it breaks into cliffs, temples, towers, and buttes of ineffable splendor and beauty. Thence, with a still wider terrace, bounded by a giant wall, it stretches to the southeast as far as Pipe Spring. Here is its southernmost promontory, from which its front trends away northeast and east in proportions diminished somewhat, but still imposing, as far as the Paria River. Thus far the distance is more than 120 miles, in which the sinuosities of the front are not reckoned. Throughout this entire sweep it presents to the southward a majestic wall richly sculptured and blazing with gorgeous colors. The cliff line is very tortuous, advancing in promontories, with intervening bays and broad cañon valleys setting far back into the terrace, and resembling a long stretch of coast-line gashed with fiords. Perhaps also the contour of a maple-leaf may be a suggestive analogy. The altitudes of the cliffs are greatest in their western portions, for there we find greater thickness of strata. They often exceed 2,000 feet, while in the portion extending from Pipe Spring to the Paria the altitude ranges from 1,000 to 1,400 feet.

THE VERMILION CLIFFS.

To this great wall, terminating the Triassic terrace and stretching from the Hurricane Ledge to the Paria, Powell has given the name of The Vermilion Cliffs. Their great altitude, the remarkable length of their line of frontage, the persistence with which their proportions are sustained throughout the entire interval, their ornate sculpture and rich coloring, might justify very exalted language of description. But to the southward, just where the desert surface dips downward beneath the horizon, are those supreme walls of the Grand Cañon, which we must hereafter behold and vainly strive to describe; and however worthy of admiration the Vermilion Cliffs may be we must be frugal of adjectives, lest in the chapters to be written we find their force and meaning exhausted. They will be weak and vapid enough at best. Yet there are portions of the Vermilion Cliffs which in some respects lay hold of the sensibilities with a force not much less overwhelming than the majesty of the Grand Cañon; not in the same way, not by virtue of the same elements of power and impressiveness, but in a way of their own and by attributes of their own. In mass and grandeur and in the extent of the display there is no comparison; it would be like comparing a private picture gallery containing a few priceless treasures with the wealth of art in the Vatican or Louvre. All of the really superlative portions of the Vermilion Cliffs could be comfortably displayed in any one of half a dozen amphitheaters opening into the Kaibab division of the Grand Cañon. These portions occur in the beautiful valley of the Virgen, and they, as well as the features which characterize the entire front of the Vermilion Cliffs, merit some attempt at description.

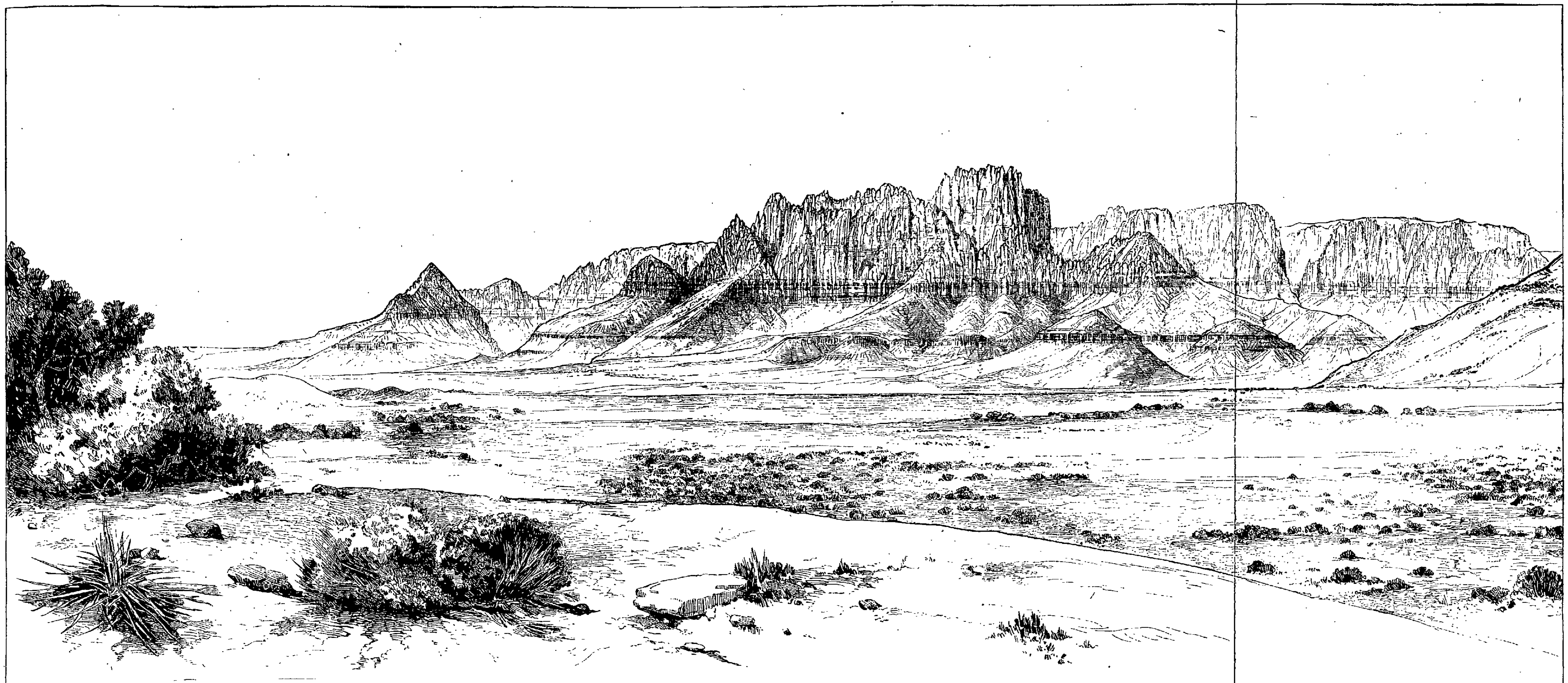
Each of the greater sedimentary groups of the terraces from the Eocene to the Permian inclusive, has its own style of sculpture and architecture; and it is at first surprising and always pleasing to observe how strongly the several styles contrast with each other. The elephantine structures of the Nile, the Grecian temples, the pagodas of China, the cathedrals of Western Europe, do not offer stronger contrasts than those we successively encounter as we descend the great stairway which leads down from the High Plateaus. As we pass from one terrace to another the scene is wholly changed; not only in the bolder and grander masses which dominate the landscape, but in every detail and accessory; in the tone of the color-masses, in the vegetation, and in the spirit and subjective influences of the scenery. Of these many and strong antitheses, there is none stronger than that between the repose of the Jura and the animation of the Trias.

The profile of the Vermilion Cliffs is very complex, though conforming to a definite type and made up of simple elements. Although it varies much in different localities it never loses its typical character. It consists of a series of vertical ledges rising tier above tier, story above story, with intervening slopes covered with talus through which the beds project their fretted edges. The stratification is always revealed with perfect distinctness and is even emphasized by the peculiar weathering. The beds are very numerous and mostly of small or moderate thickness, and the partings of the sandstones include layers of gypsum or gypsiferous sand and shale. The weathering attacks these gypseous layers with great effect, dissolving them to a considerable depth into the wall-face, producing a deeply engraved line between the including sandstones. This line is always in deep shadow and throws into strong relief the bright edges of the strata in the rock-face, separating them from each other with uncommon distinctness. Where the profiles are thrown well into view the vertical lines, which bound the faces of the ledges, are quite perpendicular and straight, while the lines of the intervening slopes are feebly concave, being, in fact, descending branches of hyperbolas. They are graceful in form and indeed genuine lines of beauty. The angles where the straight and curved lines meet, at the bases and summits of the ledges, are very keen and well cut. The composite effect thus given by the multiple cliffs and sloping water-tables rising story above story, by the acute definition of the profiles and horizontal moldings, and by the refined though unobtrusive details, is highly architectural and ornate, and contrasts in the extreme with the rough, craggy, beetling aspect of the cliffs of other regions. This effect is much enhanced by the manner in which the wall advances in promontories or recedes in alcoves, and by the wings and gables with sharp corners and Mansard roofs jutting out from every lateral face where there is the least danger of blankness or monotony. In many places cañons have cut the terrace platform deeply, and open in magnificent gateways upon the broad desert plain in front. We look into them from afar, wonderingly and questioningly, with a fancy pleased to follow their windings until their sudden turns carry them into distant, unseen depths.

Northwestward of the southernmost promontory at Pipe Spring, the cliffs steadily increase in grandeur and animation, and also assume new features. Near the summit of the series is a very heavy stratum of sandstone, which is everywhere distinguishable from the others. This member is seen at Kanab with a thickness of about 200 feet. It increases westward, becoming 400 feet at Pipe Spring. Beyond that it still increases, reaching a thickness of more than 1,200 feet in the valley of the Virgen. It has many strong features, and yet they elude description. One point, however, may be seized upon, and that is, a series of joints nearly vertical with which the mass is everywhere riven. The fissures thus produced have been slowly enlarged by weathering, and down the face of every escarpment run the dark shadows of these rifts. They reach often from top to bottom of the mass and penetrate deeply its recesses. Wherever this great member forms the entablature—and west of Pipe Spring it usually does so—its crest is uneven and presents towers and buttresses produced by the widening of these cracks. Near Short Creek it breaks into lofty truncated towers of great beauty and grandeur, with strongly emphasized vertical lines and decorations, suggestive of cathedral architecture on a colossal scale. Still loftier and more ornate become the structures as we approach the Virgen. At length they reach the sublime. The altitudes increase until they approach 2,000 feet above the plain. The wall is recessed with large amphitheaters, buttressed with huge spurs and decorated with towers and pinnacles. Here, too, for the first time, along their westward trend, the Vermilion Cliffs send off buttes. And giant buttes they verily are, rearing their unassailable summits into the domain of the clouds, rich with the aspiring forms of Gothic type, and flinging back in red and purple the intense sunlight poured over them. Could the imagination blanch those colors, it might compare them with vast icebergs, rent from the front of a glacier and floating majestically out to sea; only here it is the parent mass that recedes, melting away through the ages, while its off-spring stands still. Yet the analogy would be a feeble one, for the buttes are grander, more definite in form, and many times loftier. But the climax of this scenery is still beyond.

Late in the autumn of 1880 I rode along the base of the Vermilion Cliffs, from Kanab to the Virgen, having the esteemed companionship of Mr. Holmes. We had spent the summer and most of the autumn among the cones of the Uinkaret, in the dreamy parks and forests of the Kaibab, and in the solitudes of the intervening desert; and our sensibilities had been somewhat overtasked by the scenery of the Grand Cañon. It seemed to us that all grandeur and beauty thereafter beheld must be mentally projected against the recollection of those scenes, and be dwarfed into commonplace by the comparison; but as we moved onward the walls increased in altitude, in animation, and in power. At length the towers of Short Creek burst into view, and, beyond, the great cliff in long perspective thrusting out into the desert plain its gables and spurs. The day was a rare one for this region. The mild, subtropical autumn was over, and just giving place to the first approaches of winter. A sullen storm had been gathering from the southwest, and the first rain for many months was falling, mingled with snow. Heavy clouds rolled up against the battlements, spreading their fleeces over turret and crest, and sending down curling flecks of white mist into the nooks and recesses between towers and buttresses. The next day was rarer still, with sunshine and storm battling for the mastery. Rolling masses of cumuli rose up into the blue to incomprehensible heights, their flanks and summits gleaming with sunlight, their nether surfaces above the desert as flat as a ceiling, and showing, not the dull neutral gray of the east, but a rosy tinge caught from the reflected red of rocks and soil. As they drifted rapidly against the great barrier, the currents from below, flung upward to the summits, rolled the vaporous masses into vast whorls, wrapping them around the towers and crest-lines, and scattering torn shreds of mist along the rock-faces. As the day wore on the sunshine gained the advantage. From overhead the cloud-masses stubbornly withdrew, leaving a few broken ranks to maintain a feeble resistance. But far in the northwest, over the Colob, they rallied their black forces for a more desperate struggle, and answered with defiant flashes of lightning the incessant pour of sun-shafts.

Superlative cloud effects, common enough in other countries, are lamentably infrequent here; but, when they do come, their value is beyond measure. During the long, hot summer days, when the sun is high, the phenomenal features of the scenery are robbed of most of their grandeur, and cannot or do not wholly reveal to the observer the realities which render them so instructive and interesting. There are few middle tones of light and shade. The effects of foreshortening are



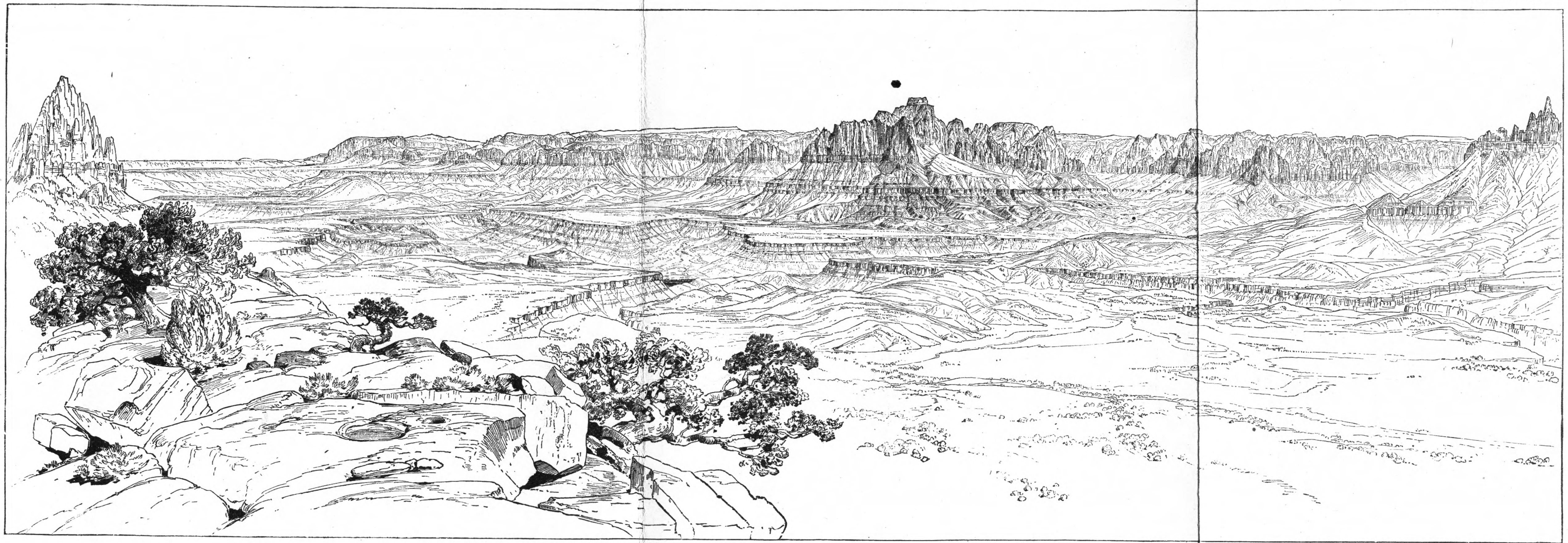
TOWERS AT SHORT CREEK. VERMILION CLIFFS.

excessive, almost beyond belief, and produce the strangest deceptions. Masses which are widely separated seem to be superposed or continuous. Lines and surfaces, which extend towards us at an acute angle with the radius of vision, are warped around until they seem to cross it at a right angle. Grand fronts, which ought to show depth and varying distance, become flat and are troubled with false perspective. Proportions which are full of grace and meaning are distorted and belied. During the midday hours the cliffs seem to wilt and droop as if retracting their grandeur to hide it from the merciless radiance of the sun whose very effulgence flouts them. Even the colors are ruined. The glaring face of the wall, where the light falls full upon it, wears a scorched, overbaked, discharged look; and where the dense black shadows are thrown—for there are no middle shades—the magical haze of the desert shines forth with a weird, metallic glow which has no color in it. But as the sun declines there comes a revival. The half-tones at length appear, bringing into relief the component masses; the amphitheaters recede into suggestive distances; the salients silently advance towards us; the distorted lines range themselves into true perspective; the deformed curves come back to their proper sweep; the angles grow clean and sharp; and the whole cliff arouses from lethargy and erects itself in grandeur and power, as if conscious of its own majesty. Back also come the colors, and as the sun is about to sink they glow with an intense orange-vermilion that seems to be an intrinsic luster emanating from the rocks themselves. But the great gala-days of the cliffs are those when sunshine and storm are waging an even battle; when the massive banks of clouds send their white diffuse light into the dark places and tone down the intense glare of the direct rays; when they roll over the summits in stately procession, wrapping them in vapor and revealing cloud-girt masses here and there through wide rifts. Then the truth appears and all deceptions are exposed. Their real grandeur, their true forms, and a just sense of their relations are at last fairly presented, so that the mind can grasp them. And they are very grand—even sublime. There is no need, as we look upon them, of fancy to heighten the picture, nor of metaphor to present it. The simple truth is quite enough. I never before had a realizing sense of a cliff 1,800 to 2,000 feet high. I think I have a definite and abiding one at present.

As we moved northward from Short Creek, we had frequent opportunities to admire these cliffs and buttes, with the conviction that they were revealed to us in their real magnitudes and in their true relations. They awakened an enthusiasm more vivid than we had anticipated, and one which the recollection of far grander scenes did not dispel. At length the trail descended into a shallow basin where a low ledge of sandstones, immediately upon the right, shut them out from view; but as we mounted the opposite rim a new scene, grander and more beautiful than before, suddenly broke upon us. The cliff again appeared, presenting the heavy sandstone member in a sheer wall nearly a thousand feet high, with a steep talus beneath it of eleven or twelve hundred feet more. Wide alcoves receded far back into the mass, and in their depths the clouds floated. Long, sharp spurs plunged swiftly down, thrusting their monstrous buttresses into the plain below, and sending up pinnacles and towers along the knife edges. But the controlling object was a great butte which sprang into view immediately before us, and which the salient of the wall had hitherto masked. Upon a pedestal two miles long and a thousand feet high, richly decorated with horizontal moldings, rose four towers highly suggestive of cathedral architecture. Their altitude above the plain was estimated at about 1,800 feet. They were separated by vertical clefts made by the enlargement of the joints, and many smaller clefts extending from the summits to the pedestal carved the turrets into tapering buttresses, which gave a graceful aspiring effect with a remarkable definiteness to the forms. We named it Smithsonian Butte, and it was decided that a sketch should be made of it; but in a few moments the plan was abandoned or forgotten. For over a notch or saddle formed by a low isthmus which connected the butte with the principal mesa there sailed slowly and majestically into view, as we rode along, a wonderful object. Deeply moved, we paused a moment to contemplate it, and then abandoning the trail we rode rapidly towards the notch, beyond which it soon sank out of sight. In an hour's time we reached the crest of the isthmus, and in an instant there flashed before us a scene never to be forgotten. In coming time it will, I believe, take rank with a very small number of spectacles each of which will, in its own way, be regarded as the most exquisite of its kind which the world discloses. The scene before us was

THE TEMPLES AND TOWERS OF THE VIRGEN.

At our feet the surface drops down by cliff and talus 1,200 feet upon a broad and rugged plain cut by narrow cañons. The slopes, the winding ledges, the bosses of projecting rock, the naked, scanty soil, display colors which are truly amazing. Chocolate, maroon, purple, lavender, magenta, with broad bands of toned white, are laid in horizontal belts, strongly contrasting with each other, and the ever-varying slope of the surface cuts across them capriciously, so that the sharply defined belts wind about like the contours of a map. From right to left across the further foreground of the picture stretches the inner cañon of the Virgen, about 700 feet in depth, and here of considerable width. Its bottom is for the most part unseen, but in one place is disclosed by a turn in its course, showing the vivid green of vegetation. Across the cañon, and rather more than a mile and a half beyond it, stands the central and commanding object of the picture, the western temple, rising 4,000 feet above the river. Its glorious summit was the object we had seen an hour



THE TEMPLES AND TOWERS OF THE VIRGEN.

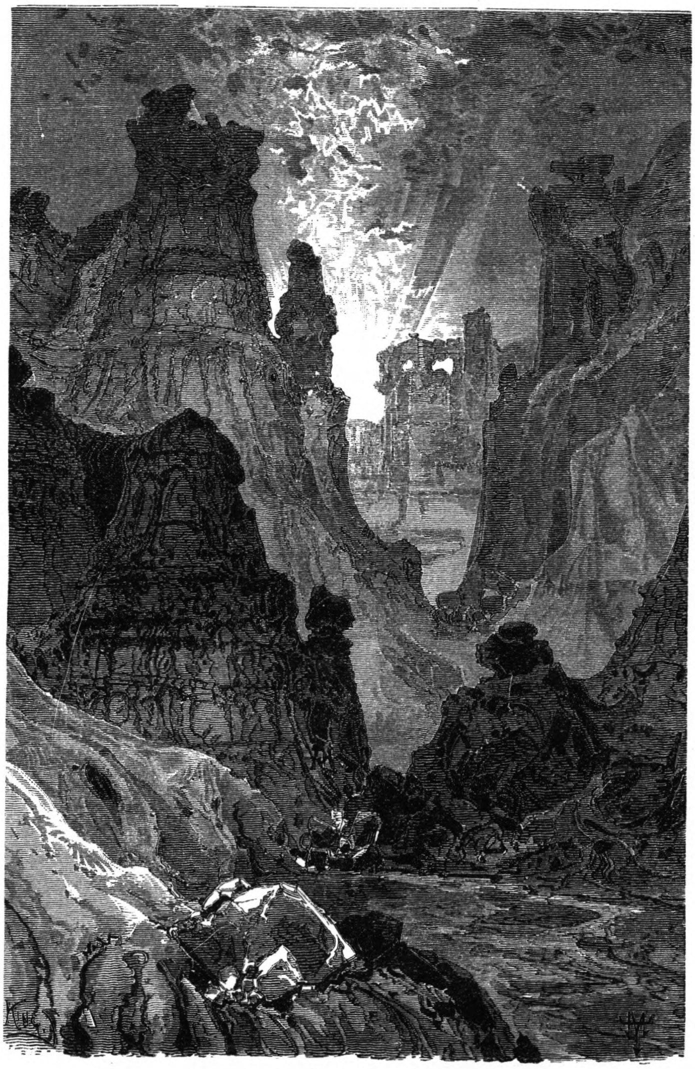
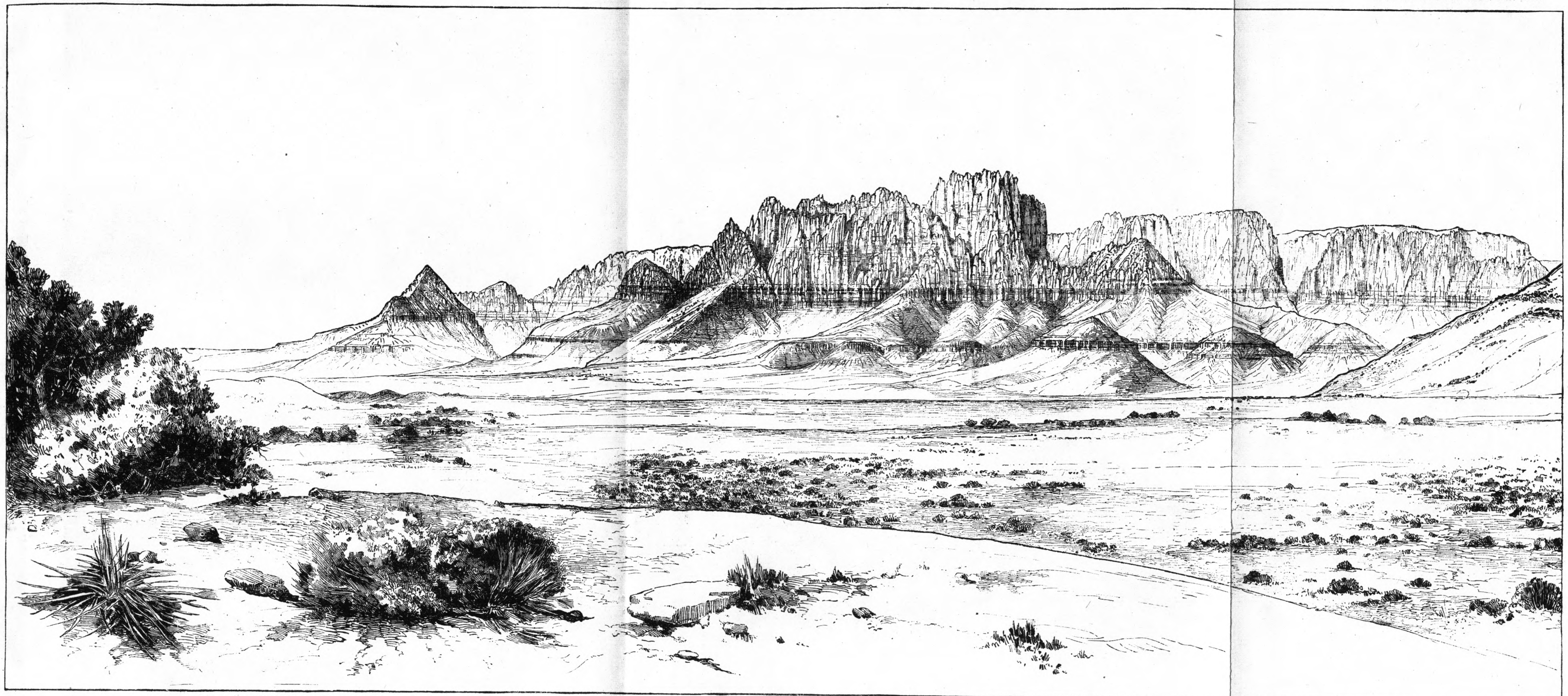


FIG. 6.—The Mu-kún-tu-weap.

the esplanade below. The curtain-wall is decorated with a lavish display of vertical moldings, and the ridges, eaves and mitered angles are fretted with serrated cusps. This ornamentation is suggestive rather than precise, but it is none the less effective. It is repetitive, not symmetrical. But though exact symmetry is wanting, nature has here brought home to us the truth that symmetry is only one of an infinite range of devices by which beauty can be materialized.

And finer forms are in the quarry
Than ever Angelo evoked.

Reverting to the twin temple across Little Zion Valley, its upper mass



TOWERS AT SHORT CREEK. VERMILION CLIFFS.

is a repetition of the one which crowns the western pile. It has the same elliptical contour, and a similar red tablet above. In its effect upon the imagination it is much the same. But from the point from which we first viewed them—and it is by far the best one accessible—it was too distant to be seen to the fullest advantage, and the western temple by its greater proximity overpowered its neighbor.

Nothing can exceed the wondrous beauty of Little Zion Valley which separates the two temples and their respective groups of towers. Nor are these the only sublime structures which look down into its depths, for similar ones are seen on either hand along its receding vista until a turn in the course carries the valley out of sight. In its proportions it is about equal to Yo Semite, but in the nobility and beauty of the sculptures there is no comparison. It is Hyperion to a satyr. No wonder the fierce Mormon zealot, who named it, was reminded of the Great Zion, on which his fervid thoughts were bent—"of houses not built with hands, eternal in the heavens."

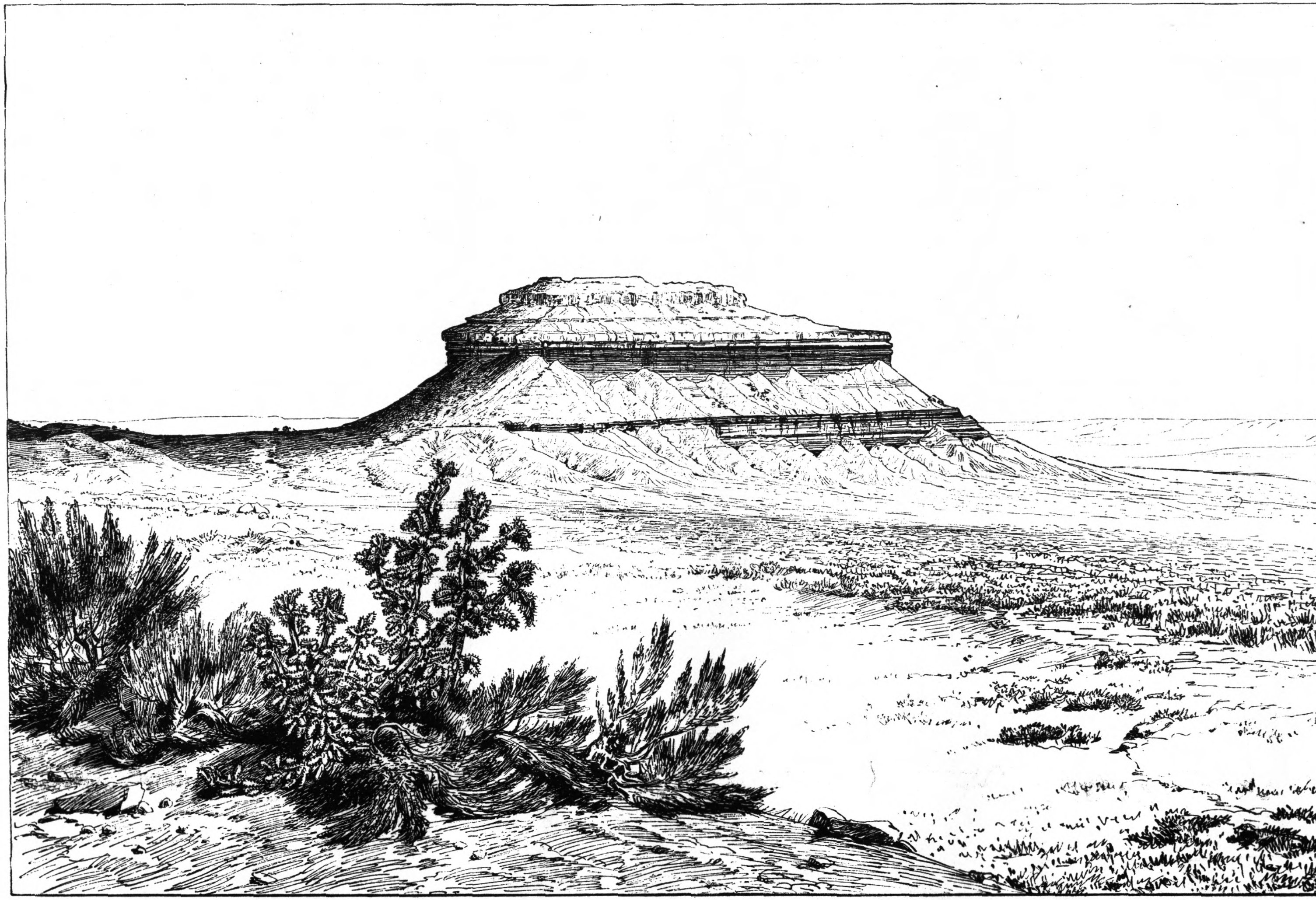
From these highly wrought groups in the center of the picture the eye escapes to the westward along a mass of cliffs and buttes covered with the same profuse decoration as the walls of the temples and of the Parunuweap. Their color is brilliant red. Much animation is imparted to this part of the scene by the wandering courses of the mural fronts which have little continuity and no definite trend. The Triassic terrace out of which they have been carved is cut into by broad amphitheatres and slashed in all directions by wide cañon valleys. The resulting escarpments stretch their courses in every direction, here fronting towards us, there averted; now receding behind a nearer mass and again emerging from an unseen alcove. Far to the westward, twenty miles away, is seen the last palisade lifting its imposing front behind a mass of towers and domes to an altitude of probably near 3,000 feet and with a grandeur which the distance cannot dispel. Beyond it the scenery changes almost instantly, for it passes at once into the Great Basin, which, to this region, is as another world.

THE PERMIAN.

The idea of a terrace is not so typically represented in the Permian as it is in the superior formations. In many parts of the great stairway it clearly forms the lowest step; in others it forms one cliff with the Trias; in still others it is beveled off and covered with alluvium. On the whole it is more frequently presented as a distinct terrace. There is another qualification which requires some mention, because when we refer to the geological map to study the surface distribution of the strata, we should find some anomalies unless the point referred to were duly explained.

Wherever we encounter a cliff which discloses the upper Permian beds we find at the summit of the escarpment a band of pale-brown sandstone of very coarse texture, often becoming a conglomerate. Its thickness is usually from 40 to 75 feet. In a few places it is wanting from its proper horizon, and in some others its thickness becomes more than 100 feet. But on the whole it is a remarkably persistent bed, and its persistence is all the more striking when we consider the coarseness of its texture; for no beds are so variable as the coarse ones. This member has been named by Powell the Shin-á-rump Conglomerate. The name Shinarump he also applies provisionally to a large group of beds in which the conglomerate is included.* For several years it was thought very probable that these beds were a part of the Triassic system, though no positive proof could be cited to sustain that presumption. In the summer of 1879 Mr. C. D. Walcott, of this survey, at length found some limestone bands near the base of Powell's Shinarump, which seem to establish pretty conclusively their Permian age. But the fossils so far discovered have only a small vertical range, and lie near the base of the group. Above them are many hundred feet of beds which yield no fossils at all. While some of them are unquestionably Permian, it still remains to find the horizon where the Permian ends and the Trias begins. The Trias is as destitute of fossils as the Permian, excepting, however, some which are useless for determining age. In cases like this the geologist finds himself in trouble. He is quite sure that he has beds of two distinct ages; and he must, for purposes of discussion, separate them somehow; if not by a natural and unmistakable dividing horizon, then by an arbitrary and provisional one, subject to amendment by future research. But he must look very carefully for a natural horizon of separation. His course of procedure would be somewhat as follows. Starting, for instance, with those strata which he was sure were Triassic, he would examine the beds downwards and finding no fossils would pay attention to their lithological characters. Finding no marked difference in the beds, and finding a strict parallelism or "conformity" in the several members, he would infer that they were deposited under conditions which were substantially identical throughout the period of deposition. But if he at length reached a stratum of very different character, say, for instance, after passing down through a great series of sandstones and shales, he came to a heavy mass of limestone or a bulky conglomerate, he would have found at last a "break" in the continuity or homogeneity of the group. Here, at last, is something which he can use. It may or it may not be synchronous with the dividing horizon used in Russia, England, or Kansas, but it is at all events not far from it; and it is something palpable, distinct, and recognizable by those who come after him. In this way Mr. Walcott

*For the information of the general reader it may be explained that when the geologist entering a new region discovers a well-defined group of beds which either yield no fossils at all or yield such as do not enable him to determine conclusively the age of the series, he does not assign the beds to any definite age or system, but gives them a purely provisional and local name which is dropped as soon as the true age is established.



PERMIAN BUTTE NEAR KANAB.

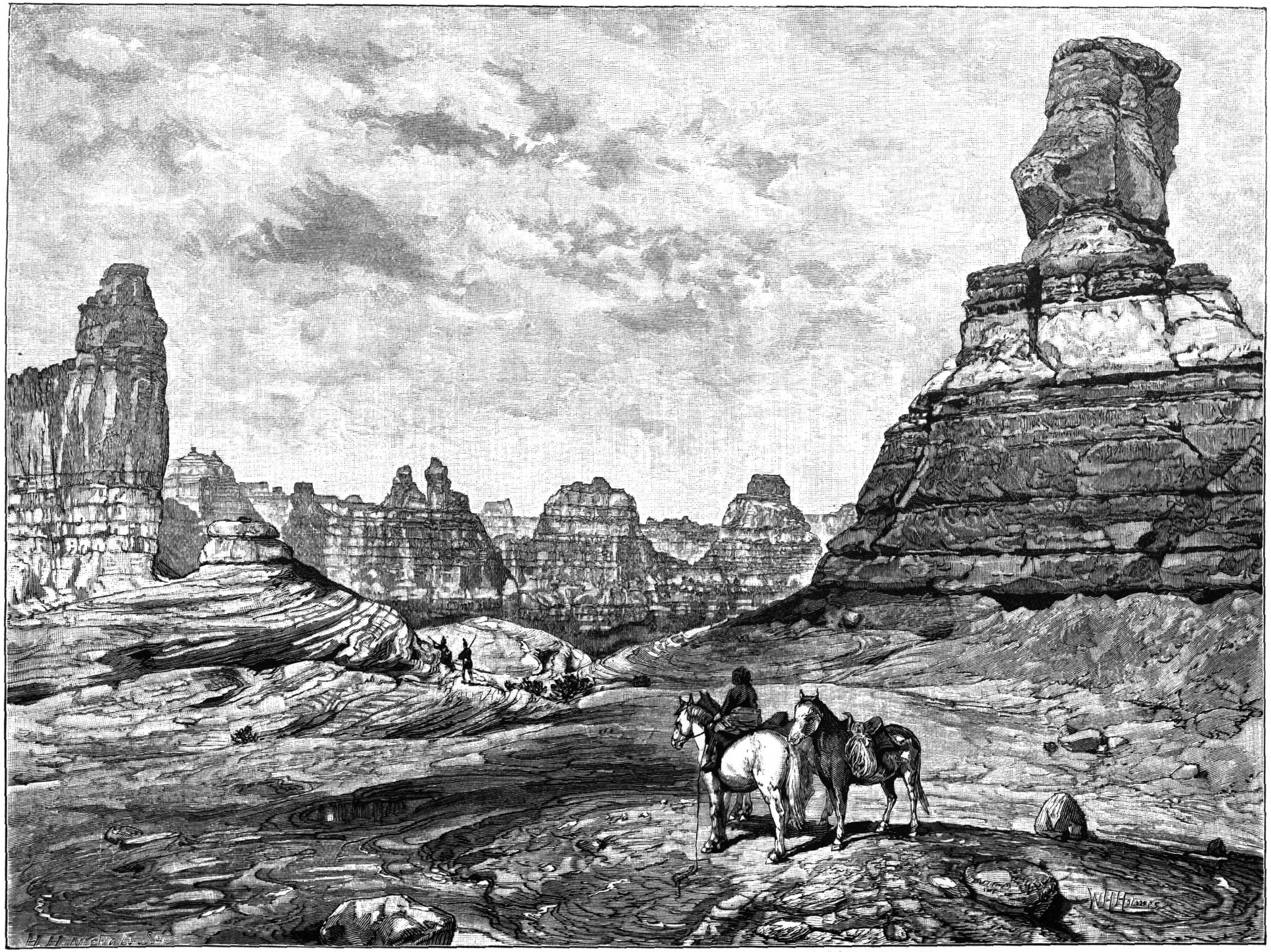
seized upon the Shinarump conglomerate as a divisional stratum between the Trias and Permian. But another perplexing question arose. To which of the two series should the conglomerate itself be assigned? And the question is not at first an easy one to answer. Immediately above it is a series of sandy shales such as beggar description on account of their gorgeous colors. Immediately below it is another series of sandy shales so similar to the one above that we never know which of the two we are looking at unless the conglomerate is in sight as a "bench-mark." Mr. Walcott settled the question (provisionally, of course) in the following way. The summit of the lower series shows in many places that immediately after it was deposited it was slightly eroded, and the contact of the conglomerate shows an "unconformity by erosion." The contact of the conglomerate with the upper series shows no such unconformity. Now, an unconformity means to the geologist a break in the continuity of deposition, and in the absence of reasons to the contrary, and with no better divisional criterion at hand, it may be used to separate two series of beds. He therefore assigned the conglomerate to the Trias, and the beds below he placed in the Permian.

Mr. Walcott's conclusion is no doubt the best which can be reached with our present knowledge, but it is very inconvenient and awkward to the geologist who is required to map the distribution of the strata and their topographical features. In all of the other formations each group forms its own terrace or series of terraces. As we descend them we find ourselves, when we reach the foot of the Eocene cliff, upon the summit of the Cretaceous. Reaching the foot of the Cretaceous cliffs, or slopes, we are upon the broad expanse of the Jurassic platform. Descending the Jurassic, we find the Trias coming out from the base of the Jurassic Cliffs; but when we descend the Vermilion Cliffs, we have not reached the Permian. The Trias is still beneath us, pushing out its basal member, the Shinarump conglomerate, clear to the crest-line of the Permian wall. In the Jurassic terrace and in its terminal cliff we find none but Jurassic strata. Similarly, also, on the cliffs and terrace platforms of the Cretaceous and Eocene; but the Permian terrace is everywhere sheeted over with a solitary stratum of the Trias. Somehow we cannot help thinking that the conglomerate has no business there, and that it ought to have been cut off at the base of the Vermilion Cliffs, or else it ought to be relegated to the Permian. In delineating the distribution of the formations by means of colors on the map, the ordinary practice would require us to extend the Trias to the brink of the Permian Cliffs, for in such delineations we only profess to show the surface exposures of the several groups; but this would confound the Permian terrace with the Trias, and obliterate the individuality of the former, whereas in the topography both are as distinct as land and water. To preserve this distinction the Shinarump is denoted by a special modification of the color, which is to be interpreted as meaning an arbitrary subdivision of the Trias.

The Permian beds consist of sandy clay-shales in very many thin beds and a few thin beds of impure limestone. They are very striking on account of their dense, rich colors, which are sometimes also wonderfully delicate. They are belted in a surprising way. Horizontal streaks of chocolate, purple and red-brown are interstratified with violet, lavender, and white. Perhaps the richest tone is the red-brown, which is almost exactly like the color of the fumes of nitrous acid. Lower in the series are layers of a very peculiar shade of Indian red, alternating with grayish white. In the lower Trias and Permian the colors reach their climax. Surely no other region in the world, of which I have any knowledge, can exhibit anything comparable to it. Wonderfully even is the bedding. Thin layers may be traced for miles without showing any variation of thickness, color, or texture. In the escarpments the weathering has etched out the harder layers, leaving a line of shadow in the places of the softer layers, and this greatly emphasizes the stratification and gives it finer detail.

The Permian series is of considerable magnitude. In the western portion of the district its thickness is greater than elsewhere, reaching, probably, 1,400 feet, and possibly 1,600 feet, while in the vicinity of Kanab it is less than 1,000 feet. It gives rise to terminal cliffs, which in the northern part of the Uinkaret are from 800 to 1,000 feet high, while around Kanab their height seldom exceeds 500 or 600, and is often less than 300. But what they lack in magnitude they make up in refinement and beauty of detail and in sumptuous color. It is in the Permian that we find the most remarkable buttes. They are never large, but their resemblances to human architecture or works of design are often amazing. Very few Permian buttes are found in the Grand Cañon district, but further eastward, especially in the neighborhood of the junction of the Grand and Green Rivers, they are innumerable and of such definiteness that the geologist feels as if he were taxing the credulity of his hearers when he asks them to believe that they are the works of nature alone, and not of some race of Titans.

At the foot of the Permian cliffs begins the Carboniferous platform of the interior region of the Grand Cañon district. It stretches southward without visible bound, an almost featureless plain. It terminates beyond the San Francisco Mountains in the Aubrey Cliffs.



LAND OF THE STANDING ROCKS.

CHAPTER IV.

THE GREAT DENUDATION.

Before leaving the terraces we may with advantage pause to contemplate the great lesson in geology which they lay open to us. The subject of the lesson is EROSION. In a preliminary way we examined the type of it in the San Rafael district, which was briefly treated of in the first chapter. The same fact confronts us again in the Grand Cañon district. Here, however, the attendant facts are more complex, more difficult to grasp, and less easy to summarize. And vast as the erosion has been in the San Rafael it has been many times greater in the Grand Cañon district. In this discussion three classes of facts will be utilized: 1st, the stratification; 2d, the faults and flexures, or vertical displacements; 3d, the drainage. Each class furnishes its quota of evidence. Yet, so intimately are the several threads of argument interwoven, that it is almost impossible to separate them and view each independently of the others. Hence if the argument skips about from one to another before the one is fully developed, it is because no other method of treatment seems practicable.

The geologist seeing the series of Mesozoic and Eocene strata suddenly terminating in the terraces in the faces of the cliffs, would at once say that these strata formerly extended further southward. For he is ever mindful of the fact that in the lapse of long periods the rocks decay, and the rains and rills gather up the débris and carry it away. He also has had impressed upon his mind the general fact that the most rapid waste takes place on the edges of the strata exposed in vertical wall-faces. Every year the rains wash away something from the mural fronts. In a single year it may be a mere film, but in the lapse of thousands of centuries the amount whittled off becomes a vast aggregate. Like the motion of the fixed stars the change is not perceptible to a generation; but a million years would change the aspect of a denuding country as profoundly as they would change the aspect of the heavens. How long in terms of years this "Recession of the Cliffs" has been going on, the geologist does not know, though he presumes the period to have been certainly hundreds of thousands of years and very probably some millions. Feeling assured, then, that the terraces once projected further south, the inquiry arises, how far? Let me answer at once. They extended southward over the entire Grand Cañon district, into central Arizona, where they ended along the shore of the ancient mainland from which their materials were in part derived. The distance of that shore-line, from the summit of the Pink Cliffs, is from 130 to 180 miles, and the width of the denuded district is from 120 to 140 miles. From the base of the Vermilion Cliffs the distance is 25 to 30 miles less. The area of maximum denudation is from 13,000 to 15,000 square miles, and the average thickness of the strata removed from it was about 10,000 feet.

The general reader will no doubt feel a strong aversion to such prodigious figures on their first presentation, and even the geologist whose credulity has been shocked so often that he has gotten used to it may wince once more. It is not from a love of the marvelous or dramatic; it is not without a full sense of the oppression of unaccustomed magnitudes that these assertions are made. They are made because they follow inexorably from the facts, and because they are necessary conclusions from clear premises. But, in order that the reader may not be obliged to carry a heavy burden of prejudice as he follows the various steps of the argument, it is well to anticipate some part of the discussion, and thus relieve him of a great part of the load at the outset, for it can be shown that the figures, while they are certainly very large, are in no respect abnormal, and in only one respect are they at all unusual.

Erosion, viewed in one way, is the supplement of the process by which strata are accumulated. The materials which constitute the stratified rocks were derived from the degradation of the land. This proposition is fundamental in geology—nay, it is the broadest and most comprehensive proposition with which that science deals. It is to geology what the law of gravitation is to astronomy. We can conceive no other origin for the materials of the strata, and no other is needed, for this one is sufficient and its verity a thousand times proven. Erosion and "sedimentation" are the two half phases of one cycle of causation—the debit and credit sides of one system of transactions. The quantity of material which the agents of erosion deal with is in the long run exactly the same as the quantity dealt with by the agencies of deposition; or, rather, the materials thus spoken of are one and the same. If, then, we would know how great have been the quantities of material removed in any given geological age from the land by erosion, we have only to estimate the mass of the strata deposited in that age. Constrained by this reasoning, the mind has no escape from the conclusion that the effects of erosion have indeed been vast. If, then, these operations have achieved such results, our wonder is transferred to the immensity of the periods of time required to accomplish them; for the processes are so slow that the span of a life-time seems too small to render those results directly visible. As we stand before the terrace cliffs and try to conceive of them receding scores of miles by secular waste, we find the endeavor quite useless. There is, however, one error against which we must guard ourselves. We must not conceive of erosion as merely sapping the face of a straight serried wall a hundred miles long; the locus of the wall receding parallel to its former position at the rate of a foot or a few feet in a thousand years; the terrace back of its crest line remaining solid and uncut; the beds thus dissolving edgewise until after the lapse of millions of centuries their terminal cliffs stand a hundred miles or more back of their initial positions. The true story is told by the Triassic terrace ending in the Vermilion Cliffs. This terrace is literally sawed to pieces with cañons. There are dozens of these chasms opening at intervals of two or three miles along the front of the escarpment and setting far back into its mass. Every one of them ramifies again and again until they become an intricate net-work, like the fibers of a leaf. Every cañon wall, throughout its trunk, branches, and twigs, and every alcove and niche, becomes a dissolving face. Thus the lines and area of attack are enormously multiplied. The front wall of the terrace is cut into promontories and bays. The interlacing of branch cañons back of the wall cuts off the promontories into detached buttes, and the buttes, attacked on all sides, molder away. The rate of recession therefore is correspondingly accelerated in its total effect.

The largeness of the area presents really no difficulty. The forces which break up the rocks are of meteoric origin. The agency which carries off the débris is the water running in the drainage channels. Surely the meteoric forces which ravage the rocks of a township may ravage equally the rocks of the county or state, provided only the conditions are uniform over the larger and smaller areas. And what is the limit to the length of a stream, the number of its branches and rills, and to the quantity of water it may carry? It is not the area, then, which oppresses us by its magnitude, but the vertical factor—the thickness of the mass removed. But upon closer inspection the aspect of this factor also will cease to be forbidding.

For if the rate of recession of a wall fifty feet high is one foot in a given number of years, what will be (*ceteris paribus*) the rate of recession in a wall a thousand feet high? Very plainly the rate will be the same.* If we suppose two walls of equal length, composed of the same kind of rocks, and situated under the same climate, but one of them much higher than the other, it is obvious that the areas of wall face will be proportional to their altitudes. In order that the rates of recession may be equal, the amount of material removed from the higher one must be double that removed from the other, and since the forces operating on the higher one have twice the area of attack, they ought to remove from it a double quantity, thus making the rates of recession equal. In the same way it

*The geologist will no doubt recognize that this is a simple and unqualified statement of a result which is in reality very complex, and sometimes requiring qualification. But a candid review of it in the light of established laws governing erosion will, I am confident, justify it for all purposes here contemplated. Though some qualifying conditions will appear when the subject is analyzed thoroughly, they are of no application to this particular stage of the argument. The statement is amply true for the proposition in hand, and it would be hardly practicable, and certainly very prolix, to give here the full analysis of it.

may be shown that the rate of recession is substantially independent of the magnitude of the cliff, whatever its altitude. Here a momentary digression is necessary.

We have hitherto spoken of the recession of cliffs as if it comprised the whole process of erosion, and have hardly alluded to the possible degradation of the flat surfaces of plateaus, terraces, and plains. Is it meant that there is no degradation of the horizontal surfaces, and that the waste of the land is wholly wrought by the decay of cliffs? Approximately that is the meaning, but some greater precision may be given to the statement.

Erosion is the result of two complex groups of processes The first group comprises those which accomplish the disintegration of the rocks, reducing them to fragments, pebbles, sand, and clay. The second comprises those processes which remove the débris and carry it away to another part of the world. The first is called disintegration; the second, transportation. We need not attempt to study these processes in all their scope and relations, but we may advert only to those considerations which are of immediate concern. When the débris produced by the disintegration of rocks is left to accumulate upon a flat surface it forms a protecting mantle to the rocks beneath, and the disintegration is greatly retarded, or even wholly stopped. In order that disintegration may go on rapidly the débris must be carried away as rapidly as it forms. But the efficiency of transportation depends upon the declivity. The greater the slope the greater the power of water to transport. When the slope is greater than 30° to 33° ("the angle of repose") loose matter cannot lie upon the rocks, and shoots down until it finds a resting place. Hence the greater the slope the more fully are the rocks exposed to the disintegrating forces, and the more rapidly do they decay. This relation is universal, applying to all countries, and explains how it comes about that the attack of erosion is highly effective against the cliffs and steep slopes, and has but a trifling effect upon flat surfaces.

Reverting to the main argument, it now appears that erosion goes on by the decay and removal of material from cliffs and slopes; that the recession of high cliffs is as rapid as the recession of low ones, and that the quantity of material removed in a given time increases with the altitudes of the cliffs and slopes. In other words, the thickness of the strata removed in a given period of erosion should be proportional to the amount of *relief* in the profiles of the country. But in the Plateau country, and especially in the Grand Cañon district, these reliefs are very great. It is a region of giant cliffs and profound cañons, and, as will ultimately appear, it has been so during a very long stretch of geological time. The thickness of the strata removed from it is only proportional to the values of those conditions which favor rapid erosion. In the foregoing discussion it may appear that the area of denudation in the Grand Cañon district, though large, and the thickness of the strata denuded, though very great, are not so excessive as to impose such a heavy burden upon the credulity as the first announcement of the figures portended.

In drawing inferences from the stratification the geologist is obviously bound to presume that the strata cut off in the terraces extended originally without a break until they reached some locality where the conditions of deposition failed. There are two, and only two, cases to be considered. The first case is that in which the extension is towards the shore line of the sea or lake in which the strata were deposited. At the shore line the strata, of course, end. In the present case no shore line could have existed southward, between the terraces and the Aubrey Cliffs, beyond the San Francisco Mountains. This is quite certain. We know the country so well that if there had been such a shore line in this interval its traces would have been discovered. We are quite sure that no such traces exist. The second case arises when sediments gradually thin out seawards and either vanish entirely or become so thin that their bulk is only nominal. We have already noted that the strata in the terraces (p. 79) grow thinner from west to east, and we know that the shore line of the marine basin, in which they were deposited, lay to the west and northwest. But here we are considering their extensions towards the south, and we already know that more than one hundred miles in that direction was another part of the shore line surrounding the basin trending northwest and southeast. Supposing strata to attenuate as they recede from, and to thicken as they approach, their shore lines, the case we are considering would perhaps be about as follows. Southward as far as the Grand Cañon, *i. e.*, half way or thereabout between the terraces and the southern shore, there might be some slight reason for inferring a very little attenuation, but beyond the Grand Cañon we might with equal reason infer a thickening. But this reasoning is obviously precarious, since the attenuation of strata as they approach or recede from shore lines does not follow any rigorous law—does not conform to any definite proportion. The best and apparently the only use we can make of it is rather of a negative character, leading us to infer merely that the stratification does not offer any reason for presuming that their original southward extensions were notably thinner than the portions preserved in the terraces. But there is another class of facts which is somewhat more to the purpose.

Of the denuded formations, some outliers are preserved at a considerable distance from the terraces. In the case of the Permian there is no doubt. The great Carboniferous platform of the Grand Cañon district is spotted in many places with Permian remnants, though rarely is the whole series preserved. One important remnant shows very nearly the whole series—at Mount Logan, in the Uinkaret Plateau, near the Grand Cañon. A conspicuous knoll, called the Red Butte, south of the Kaibab and about 30 miles from the San Francisco Mountains, also preserves a large part of the series, and innumerable patches of lower Permian beds are found on both sides of the great chasm. They show no attenuation whatever, and indeed the Mount Logan mass is one of the thickest exposures of Permian beds thus far discovered. The former extension of this series over the entire district in full volume may therefore be regarded as proven. In the case of the Trias the evidence is from this point of view not quite so clear. South of the Vermilion Cliffs two or three remnants of it have been seen. One lies in the Grand Wash, a lateral valley joining the Colorado from the north just where it issues from the lower end of the Grand Cañon. Another has been recognized by Mr. Gilbert under the protection of lavas in the gigantic pile of San Francisco Mountain. But in neither of them is the entire Triassic series represented. These may be held to prove also the extension of the Trias over the entire district, and they give no sign of any attenuation in the beds preserved. But of the Jura and Cretaceous not a solitary outlier has yet been detected at any considerable distance from their principal terraces. As to these two later formations we can only reason from general considerations. The Jura and Trias, wherever found, appear to be merely different portions of one period of deposition; the physical conditions attending the accumulation of both appear to have been almost identical. Nor have we any reason to doubt that the same considerations apply to the Cretaceous and Eocene.

Still more forcibly is the same conclusion presented to us when we come to the study of the faults and flexures. The Grand Cañon district, the High Plateaus, and indeed the entire Plateau country, has been hoisted during Tertiary time far above the Sierra region lying west of it. At the western border of the plateaus are found gigantic faults where the strata have been sheared, and the country on the eastern side presents beds lying thousands of feet higher than the continuations of the same strata on the western side of the faults. These faults have been studied, and the amounts of the displacements are very approximately known. Owing to the remarkably clear manner in which all the facts are displayed, we are able, theoretically, to restore the country to the position and configuration existing before these beds were faulted and flexed. In this treatise, only the results can be given. The discussion and treatment of the problem is too purely technical for popular explanation. This restoration, so far as it has progressed, shows, without reasonable doubt, that throughout Mesozoic time, and very probably during a part of Tertiary time, the Carboniferous and Permian strata of the Grand Cañon district were horizontal and unbroken, the greatest possible discrepancies being very small. Thus another and important point is gained, for it supports the conclusion that the configuration of the Mesozoic sea-bottom, as well as its relations to the adjoining coasts, was, in the middle and southern portions of the Grand Cañon district, favorable to the reception of the same mass of sediments as we now find in the terraces of the High Plateaus.

The argument from the drainage system is, in principle, the same as that applied to the San Rafael Swell, though different in details. The

Colorado River and its tributaries entering the Grand Cañon had their origin at the time the country emerged from the waters and became land. This was in early Tertiary time. The rivers then must have had their courses laid out in conformity with the very feeble slopes of the newly risen country and in conformity with the surfaces of the newest strata. In the progress of Tertiary time this surface, originally as level as the prairies of Illinois, or more so, began to deform by unequal uplifting; but the rivers remained unchanged, and some of them are flowing to-day along the same routes as of old. Others have dried up, and the very strata which contained their troughs have been swept away. Those which remain occupy a very different relation to the strata from that which they held at first. The tributaries on the north side now run *against* the dips; those on the south side run *with* the dips, or nearly so. But the change has been in the attitudes of the strata and not in the positions of the rivers. And if we theoretically reconstruct the attitudes of the strata to conform to the courses of the drainage channels we reach a reconstruction exactly the same as that which we deduced from a restoration of the faults and flexures.

Thus the stratification, the outliers, the faults and flexures, and the drainage all yield their quotas of testimony to the great fact of denudation, and indicate that at some initial epoch the whole Mesozoic system and the lower Eocene once extended over the entire platform of the Grand Cañon district, with a thickness varying somewhat, no doubt, but on the whole differing but little, from that which we now find in the terraces of the High Plateaus. It is to be noted that the evidence of this former extension is more complete in the older formations than in the younger ones. In the case of the Permian it is quite perfect; in the case of the Trias very nearly so; in the case of the Jura it is very little less cogent than in that of the Trias; and in the Cretaceous practical certainty is exchanged for a very high degree of probability barely distinguishable from certainty. In the case of the Eocene there still remains a strong probability, but there is room for reservation. No reason to the contrary can be shown at present, and it may be regarded as one of those cases where "the tail goes with the hide"; but we cannot promise that future research will not develop reasons for a different conclusion. As the evidence now stands we are impelled to accept the full extension of the Eocene with some reservations, arising not from conflicting evidence, but from want of perfection in the evidence known to us.

BASE LEVELS OF EROSION.

In his popular narrative of Explorations of the Colorado River, Powell has employed the above term to give precision to an idea which is of much importance in physical geology. The idea in some form or other has, no doubt, occurred to many geologists, but, so far as known to me, it had not before received such definite treatment nor been so fully and justly emphasized. It may be explained as follows.

Whenever a smooth country lies at an altitude but little above the level of the sea, erosion proceeds at a rate so slow as to be merely nominal. The rivers cannot corrade their channels. Their declivities are very small, the velocities of their waters very feeble, and their transporting power is so much reduced that they can do no more than urge along the detritus brought into their troughs from highlands around their margins. Their transporting power is just equal to the load they have to carry, and there is no surplus left to wear away their bottoms. All that erosion can now do is to slowly carry off the soil formed on the slopes of mounds, banks, and hillocks, which faintly diversify the broad surrounding expanse. The erosion is at its base-level or very nearly so. An extreme case is the State of Florida. All regions are tending to base-levels of erosion, and if the time be long enough each region will, in its turn, approach nearer and nearer, and at last sensibly reach it. The approach, however, consists in an infinite series of approximations like the approach of a hyperbola to tangency with its asymptote. Thus far, however, there is the implied assumption that the region undergoes no change of altitude with reference to sea-level; that it is neither elevated nor depressed by subterranean forces. Many regions do remain without such vertical movements through a long succession of geological periods. But the greater portion of the existing land of the globe, so far as known, has been subject to repeated throes of elevation or depression. Such a change, if of notable amount, at length destroys the pre-existing relation of a region to its base-level of erosion. If it is depressed it becomes immediately an area of deposition. If it is elevated new energy is imparted to the agents and machinery of erosion. The declivities of the streams are increased, giving an excess of transporting power which sweeps the channels clear of débris; corrasion begins; new topographical features are literally carved out of the land in high relief; long rapid slopes or cliffs are generated and vigorously attacked by the destroying agents; and the degradation of the country proceeds with energy.

It is not necessary that a base-level of erosion should lie at extremely low altitudes. Thus a large interior basin drained by a trunk river, across the lower portions of which a barrier is slowly rising, is a case in point. For a time the river is tasked to cut down its barrier as rapidly as it rises. This occasions slackwater in the courses above the barrier and stops corrasion, producing ultimately a local base-level. Another case is the Great Basin of Nevada. It has no outlet, because its streams sink in the sand or evaporate from salinas. Its valley bottoms are rather below base-level than above it. The general result of causes tending to bring a region to an approximate base-level of erosion is the obliteration of its inequalities.

During the progress of the great denudation of the Grand Cañon District the indications are abundant that its interior spaces have occupied for a time the relation of an approximate base-level of erosion. Throughout almost the entire stretch of Tertiary and Quaternary time the region has been rising, and in the aggregate the elevation has become immense, varying from 11,000 to 18,000 feet in different portions. But it seems that the movement has not been at a uniform rate. It appears to have proceeded through alternations of activity and repose. Whether we can point to more than one period of quiescence may be somewhat doubtful, but we can point decisively to one. It occurred probably in late Miocene or early Pliocene time, and while it prevailed the great Carboniferous platform was denuded of most of its inequalities, and was planed down to a very flat expanse. Since that period the relation has been destroyed by a general upheaval of the entire region several thousands of feet. The indications of this will appear when we come to the study of the interior spaces of the Grand Cañon District and of the Grand Cañon itself. To this study we now proceed.

CHAPTER V.

THE TOROWEAP AND UINKARET.

The present chapter will contain an account of a journey from the village Kanab to the Toroweap Valley, and a description of the middle portion of the Grand Cañon; also of the Uinkaret Plateau. Kanab is the usual rallying place and base of operations of the survey in these parts, being located on the only living stream between the Virgen and the Paria.

The first stage of the journey from Kanab to Pipe Spring is an easy one. It leads southwestward to a gap cut through the low Permian terrace, and out into the open desert beyond. The road, well traveled and easy, then turns westward and at length reaches the spring twenty miles from Kanab. Pipe Spring is situated at the foot of the southernmost promontory of the Vermilion Cliffs, and is famous throughout Southern Utah as a watering place. Its flow is copious and its water is the purest and best throughout that desolate region. Ten years ago the desert spaces outspreading to the southward were covered with abundant grasses, affording rich pasturage to horses and cattle. To-day hardly a blade of grass is to be found within ten miles of the spring, unless upon the crags and mesas of the Vermilion Cliffs behind it. The horses and cattle have disappeared, and the bones of many of the latter are bleached upon the plains in front of it. The cause of the failure of pasturage is twofold. There is little doubt that during the last ten or twelve years the climate of the surrounding country has grown more arid. The occasional summer showers which kept the grasses alive seldom come now, and through the long summer and autumn droughts the grasses perished even to their roots before they had time to seed. All of them belong to varieties which reproduce from seed, and whose roots live but three or four years. Even if there had been no drought the feeding of cattle would have impoverished and perhaps wholly destroyed the grass by cropping it clean before the seeds were mature, as has been the case very generally throughout Utah and Nevada.

Northeastward the Vermilion Cliffs extend in endless perspective towards Kanab, and beyond to the Paria. Northwestward, with growing magnitude, they extend towards the Virgen, ever forming a mighty background to the picture. To the southward stretches the desert, blank, lifeless, and as expressionless as the sea. For five or six miles south of the Pipe Spring promontory there is a gentle descending slope, and thence onward the surface feebly ascends through a distance of thirty miles to the brink of the Grand Cañon. Thus the range of vision is wide, for we overlook a gentle depression of great extent. Though the general impression conveyed is that of a smooth or slightly modulated country, yet we command a far greater expanse than would be possible among the prairies. To the southeastward the Kaibab looms up, seemingly at no great distance, and to the southwestward the flat roof of Mount Trumbull is more than a blue cloud in the horizon. Towards this latter mountain we take a straight course. The first few miles lie across drifting sands bare of all vegetation. The air is like a furnace, but so long as the water holds out the heat is not enervating and brings no lassitude. Everything is calm and still, except here and there a hot whirling blast which sends up a tall, slender column of dust diffusing itself in the air. At a slow pace the sand-hills at length are passed and we enter upon a hard, firm soil, over which we move more rapidly. Just here, and for three or four miles in either direction, the Permian terrace has been obliterated. It has been beveled off by erosion and buried beneath the wash brought down from the foot of the Vermilion Cliffs to the northward. But seven miles from Pipe Spring, the Permian terrace springs up out of the earth, scarped by its characteristic cliff. Stretching northwestward it increases in altitude, becoming at last 800 to 1,000 feet high. At its summit is seen the Shinarump conglomerate, of a pale brown color, and beneath are the gorgeous hues of the shales. Nothing can surpass the dense, rich, and almost cloying splendor of the red-brown seen in these shales. They suggest the color of old mahogany, but are much more luminous and quite uniform. Under them are belts of chocolate, slate, lavender, pale Indian red, and white. Very wonderful, too, is the evenness of the bedding, which is brought out in great clearness and sharpness by the etching of minute layers of clays holding selenite. Between the shales and overlying conglomerate careful scrutiny enables us to detect an unconformity by erosion without any unconformity of dip. As stated in a preceding chapter, Mr. Wolcott fixed provisionally the separating horizon between the Permian and Trias at this unconformable contact.

Along the route the vegetation is scanty indeed. Several forms of cactus are seen looking very diseased and mangy, and remnants of low desert shrubs browsed to death by cattle. Yet strangely enough there is one plant and one alone that seems to flourish. It is the common sunflower (*Helianthus lenticularis*), found anywhere from Maine to Arizona, and seeming indifferent to the vicissitudes of climate.

About 18 miles from Pipe Spring the trail leads gently down into a broad shallow valley known as the Wild Band Pockets. The drainage from the fronts of the Permian cliffs now far to the northward here collects into a gulch, which gradually deepens and becomes a tributary of Kanab Cañon. In every stream-bed may be found many depressions which would hold water even though the sources of supply were cut off. This is as true of wet-weather channels as of perennial streams. After the infrequent showers, and after the surface waters have ceased to run, the bed of the stream will still retain pools of water, provided the bottom of it is of a consistency which will prevent it from filtering away. To these pools the people of the west have given the name of "water-pockets." They are very common in the stream-beds which bear away the wash from the Permian and lower Triassic shales. These shales yield a very fine impervious clay, which forms an excellent "puddling" for water holes and basins. The Wild Band Pockets have received their name from the fact that they are the resort of bands of wild horses that roam over these deserts, far from human haunts, ranging from spring to spring, which they visit by stealth only at night, and never so long as they can find chance water in these and other pockets. Beyond the Wild Band Valley there is a slight ascent to a rocky platform, consisting of the summit beds of the Carboniferous. In the course of 20 miles we have crossed the entire Permian series, which now lies to the north of us. A few stunted cedars, most of which are dead or dying of drought, are scattered over this platform and give us until nightfall some slight shelter from the sun. It is as good a camping place as we are likely to find, and if we are fortunate enough to reach it after a copious shower, the hollows and basins in the flat rocks may contain a scanty supply of clear rain-water. It is a good locality, also, from which we may overlook the outspreading desert, which is not without charms, however repulsive in most respects

To the northward rises the low escarpment of the Permian, forming a color picture which is somewhat indistinct through distance, but weird because of its strange colors and still stranger forms. Beyond and in the far distance rise the towering fronts of the Vermilion Cliffs, ablaze with red light from the sinking sun. To the eastward they stretch into illimitable distance, growing paler but more refined in color until the last visible promontory seems to merge its purple into the azure of the evening sky. Across the whole eastern quarter of the horizon stretches the long level summit of the Kaibab as straight and unbroken as the rim of the ocean. To the southwestward rises the basaltic plateau of Mount Trumbull, now presenting itself with somewhat imposing proportions. Around it a great multitude of basaltic cinder cones toss up their ominous black waves almost as high as Trumbull itself. Their tumultuous profiles and gloomy shades form a strong contrast with the rectilinear outlines and vivid colors of the region roundabout.

At dawn we move onward, reaching soon the summit of a hill which descends two or three hundred feet to a broad flat depression called the Wonsits Plain. It is a smooth and very barren expanse, dotted with a few moldering buttes of Upper Carboniferous rocks, now wasted to their foundations. The plain is about seven miles in width, and on the further side rises a low mesa of great extent capped with basalt. It is the Uinkaret. Beyond the nearer throng of basaltic cones Mount Trumbull rises with a striking aspect dominating strongly the entire western landscape. The smaller cones are now seen to be very numerous, and all of them are apparently perfect in form, as if time had wrought no great ravage among them. The *lapilli* and *peperino* with which they are covered, has become dull red by the oxidation of the iron, and this peculiar color is easily recognized though the cones are still far away. Just before reaching the basaltic mesa we must make our choice between two routes to the Toroweap, one direct, the other very circuitous. No spring is to be found until we reach the further side of Mount Trumbull, but we know of a large water-pocket on this side, which has never been known to dry up. The spring water is sure to be good, but the water in the pocket will depend for its quality upon the length of time which has passed since the last heavy rain. Let us here choose the shorter one, and go to the water-pocket.

Ascending the mesa which rises abruptly about 200 feet above the Wonsits Plain, we find ourselves at once upon the basalt. The ground is paved with cinders and fragments half buried in soil, the débris of decaying lava sheets. These sheets are rarely of any great thickness, seldom exceeding 30 or 40 feet, and often much less, and none of the individual eruptions of lava seem to have covered any very great expanse. Probably the area covered by the largest would be less than a square mile. They show no perceptible differences in composition or texture, and all are basalts of the most typical variety—very black and ferruginous in the unweathered specimens and speckled with abundant olivine. At the time of eruption they appear to have been in a state of perfect liquidity, spreading out very thin and flowing rapidly and with ease. In none of them has erosion wrought much havoc, though here and there some local destruction has been effected, most conspicuously upon the edges of the principal mesa where the sheets have been undermined and their fragments scattered upon the plain below. The cones, which stand thick around us, are still in good preservation. They are of ordinary composition—mere piles of cinders thrown out of central vents and dropping around it. The fume and froth of the lava surfaces, the spongy inflated blocks, the lapilli and peperino, are not greatly changed, though all of them here show the oxidation of the iron. We wonder what their age may be; what time has elapsed since they vomited fire and steam. But there is no clew—no natural record by which such events can be calendared. Historically they have doubtless stood in perfect repose for very many centuries. Not a trace of activity of any kind is visible, and they are as perfectly quiescent as the dead volcanoes of the Auvergne or of Scotland. Geologically, they are extremely recent; yet even here where historic antiquity merges into geologic recency the one gives us no measure of the other.

Following a course which winds among the silent cones and over rough, flat surfaces of lava beds half buried in drifting sands, we at length reach the border of a slight depression, into which we descend. It is hardly noteworthy as a valley just here, and might be confounded with any one of the innumerable shallow-water courses which occur round about; only when we look beyond we see it growing broader and much deeper. It is the head of the Toroweap. Upon its smooth bottom is a soft clayey soil, in which desert shrubs and stunted sage-brush grow in some abundance. Here and there a cedar, dwarfed indeed, but yet alive, displays a welcome green, and upon the valley slopes are a few sprays of grass. The valley bottom descends at a noticeable rate to the southward, and as we put the miles behind us we find the banks on either side rising in height, becoming steeper, and at last displaying rocky ledges. In the course of six or seven miles the left side has become a wall 700 feet high, while the other side, somewhat lower, is much broken and craggy. Huge piles of basalt lie upon the mesa beyond, sheet upon sheet, culminating in a cluster of large cones. At length the course of the valley slightly deflects to the left, and as we clear a shoulder of the eastern wall, which has hitherto masked its continuation, a grand vista breaks upon the sight. The valley stretches away to the southward, ever expanding in width; the walls on either side increase in altitude, and assume profiles of wonderful grace and nobility. Far in the distance they betoken a majesty and grandeur quite unlike anything hitherto seen. With vast proportions are combined simplicity, symmetry, and grace, and an architectural effect as precise and definite as any to be found in the terraces. And yet these walls differ in style from the Trias and Jura as much as the Trias and Jura differ from each other. In the background the vista terminates at a mighty palisade, stretching directly across the axis of vision. Though more than 20 miles distant it reveals to us suggestions of grandeur which awaken feelings of awe. We know instinctively that it is a portion of the wall of the Grand Cañon.

The western side of the valley is here broken down into a long slope descending from the cones clustered around the base of Mount Trumbull, and covered with broad flows of basalt. Turning out of the valley we ascend the lava bed, which has a very moderate slope, and about a mile from the valley we find the Witches' Water Pocket. In every desert the watering places are memorable, and this one is no exception. It is a weird spot. Around it are the desolate Phlegræan fields, where jagged masses of black lava still protrude through rusty, decaying cinders. Patches of soil, thin and coarse, sustain groves of cedar and piñon. Beyond and above are groups of cones, looking as if they might at any day break forth in renewed eruption, and over all rises the tabular mass of Mount Trumbull. Upon its summit are seen the yellow pines (*P. ponderosa*), betokening a cooler and a moister clime. The pool itself might well be deemed the abode of witches. A channel half-a-dozen yards deep and twice as wide, has been scoured in the basalt by spasmodic streams, which run during the vernal rains. Such a stream cascading into it has worn out of the solid lava a pool twenty feet long, nearly as wide, and five or six feet deep. Every flood

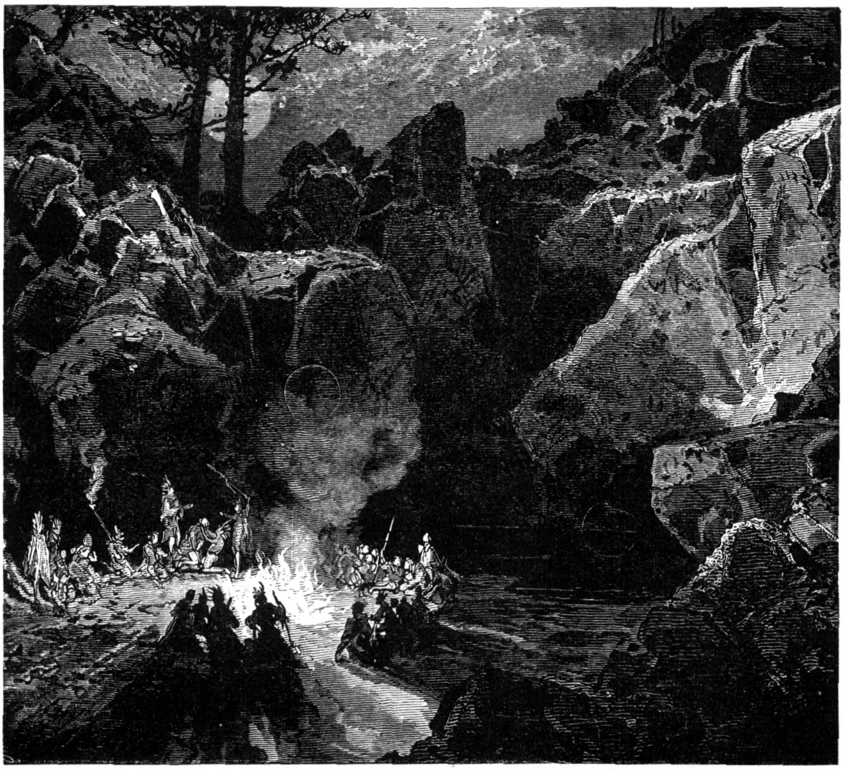


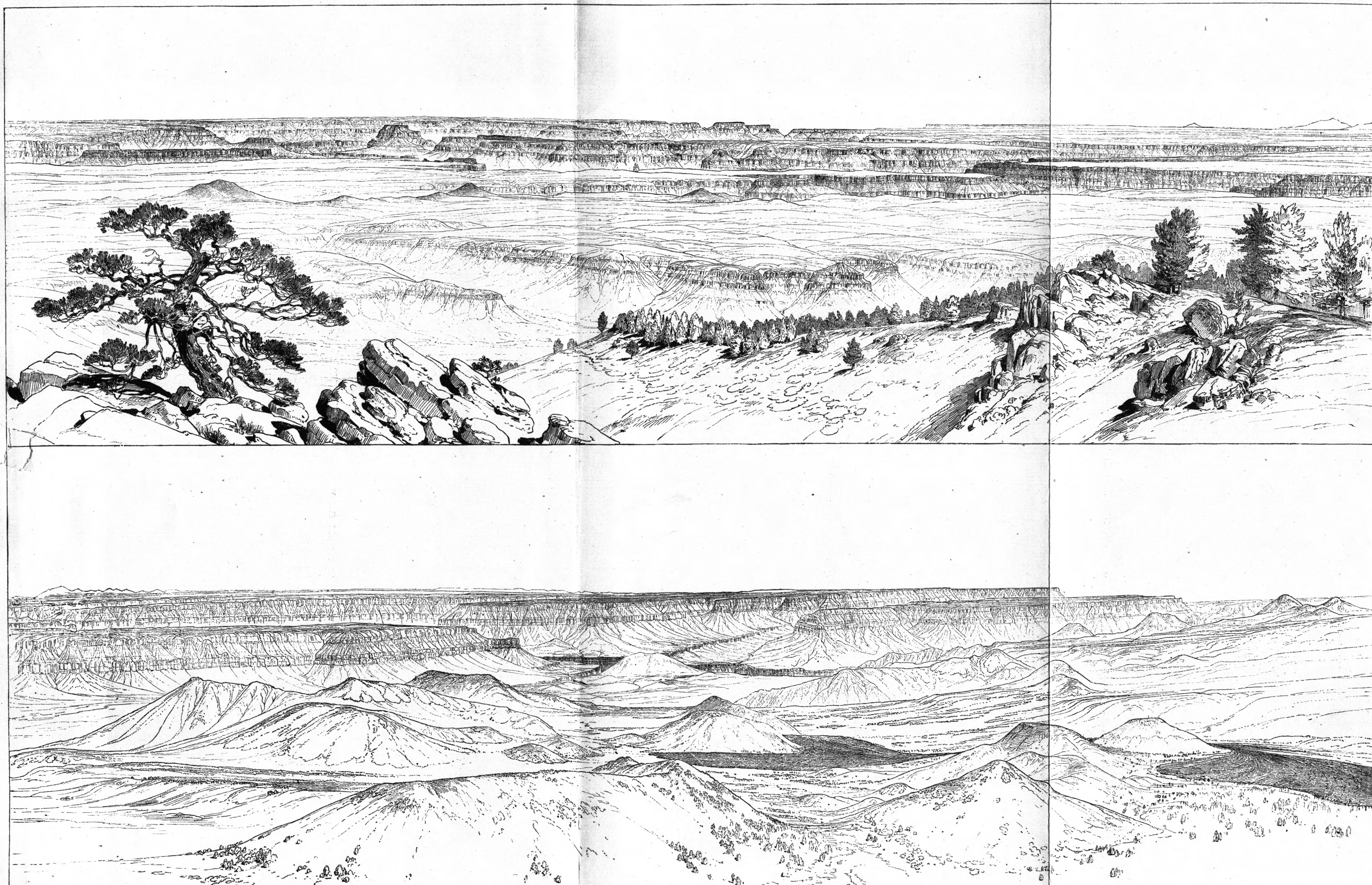
FIG. 7.—The Witches' Water Pocket.

fills it with water, which is good enough when recent, but horrible when old. Here, then, we camp for the night.

Filling the kegs at daylight, we descend again into the Toroweap and move southward. Our attention is strongly attracted by the wall upon the eastern side. Steadily it increases its mass and proportions. Soon it becomes evident that its profile is remarkably constant. We did not notice this at first, for we saw in the upper valley only the summit of the palisade; but as the valley cuts deeper in the earth the plan and system begin to unfold. At the summit is a vertical ledge, next beneath a long Mansard slope, then a broad plinth, and last, and greater than all, a long, sweeping curve, descending gracefully to the plain below. Just opposite to us the pediments seem half buried, or rather half risen out of the valley alluvium. But beyond they rise higher and higher until in the far distance the profile is complete. In this escarpment are excavated alcoves with openings a mile wide. As soon as we reach the first one new features appear. The upper ledge suddenly breaks out into a wealth of pinnacles and statues standing in thick ranks. They must be from 100 to 250 feet high, but now the height of the wall is more than a thousand feet, and they do not seem colossal. Indeed, they look like a mere band of intricate fretwork—a line of balustrade on the summit of a noble façade. Between the alcoves the projecting pediments present gable-ends towards the valley plain. Yet whithersoever the curtain wall extends the same profile greets the eyes. The architect has adhered to his design as consistently and persistently as the builders of the Thebaid or of the Acropolis. As we pass alcove after alcove, and pediment after pediment, they grow loftier, wider and deeper, and their decoration becomes more ornate. At length we pass one which is vast indeed. It is recessed back from the main front three-fourths of a mile, and shows three sides of an oblong room with walls 1,800 feet in height. The fourth side is obliterated and the space opens into the broad valley. Wonderfully rich and profuse are the pinnacles and statues along the upper friezes. The fancy is kindled as the eye wanders through the inclosure.

We look across the valley, which is here three miles in width, and behold the other wall, which presents an aspect wholly different, but quite as interesting. The western wall of the Toroweap is here lower than the eastern, but still is more than a thousand feet high. The geologist soon surmises that along the valley bottom runs a fault which drops the country on the west several hundred feet, and the conjecture soon becomes certainty. Above and beyond the western escarpment is the platform of the Uinkaret Plateau. Upon its summit is a throng of large basaltic cones in perfect preservation. Streams of lava larger than any hitherto seen have poured from their vents, flooding many a square mile of mesa land, and in the wide alcoves they have reached the brink of the wall and cascaded over it. Still pouring down the long taluses they have reached the valley bottom below and spread out in wide fields, disappearing underneath the clayey alluvium, which has buried much of their lower portions. The appearance of these old lava cascades, a mile or more wide, a thousand feet high, and black as Erebus, is striking in the extreme. There are five of these basaltic cataracts, each consisting of many individual *coulées*. Between them the bold pediments of brightly-colored Carboniferous strata jut out into the valley.

At length we approach the lower end of the Toroweap. The scenery here becomes colossal. Its magnitude is by no means its most impressive feature, but precision of the forms. The dominant idea ever before the mind is the architecture displayed in the profiles. It is hard to realize that this is the work of the blind forces of nature. We feel like mere insects crawling along the street of city flanked with immense temples, or as Lemuel Gulliver might have felt in revisiting the capital of Brobdingnag, and finding it deserted. At the foot of the valley the western wall is nearly 1,500 feet high, the eastern about 2,000, and the interval separating them is about three miles. Suddenly they turn at right angles to right and left, and become the upper wall of the Grand Cañon of the Colorado. The Toroweap now opens into the main passageway of the great chasm. The view, however, is much obstructed.



PANORAMA FROM MOUNT TRUMBULL.

Upper view looking East, with the Grand Cañon in the distance. Lower view looking down the Toroweap.

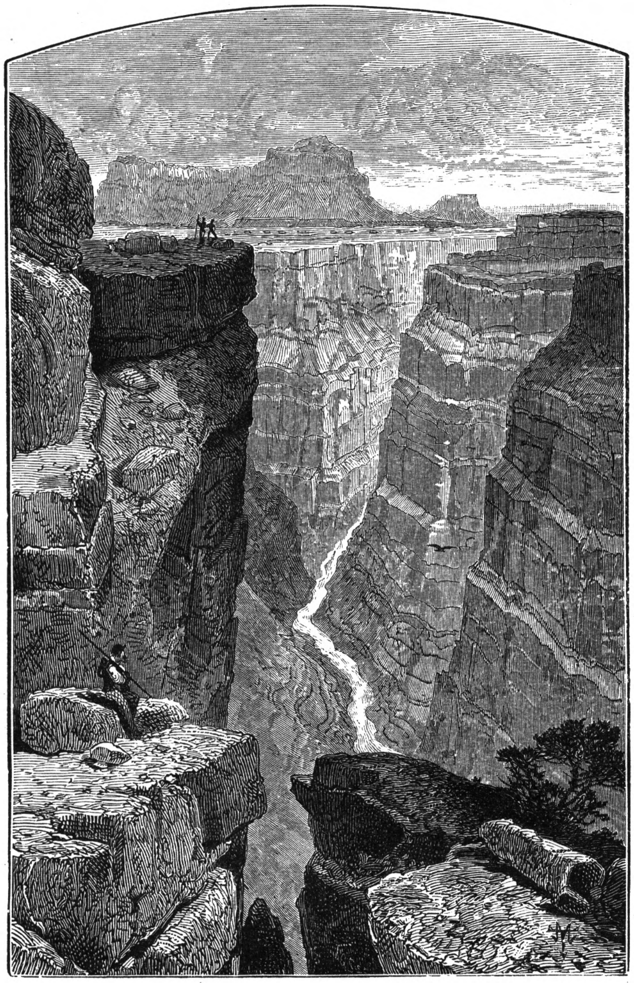
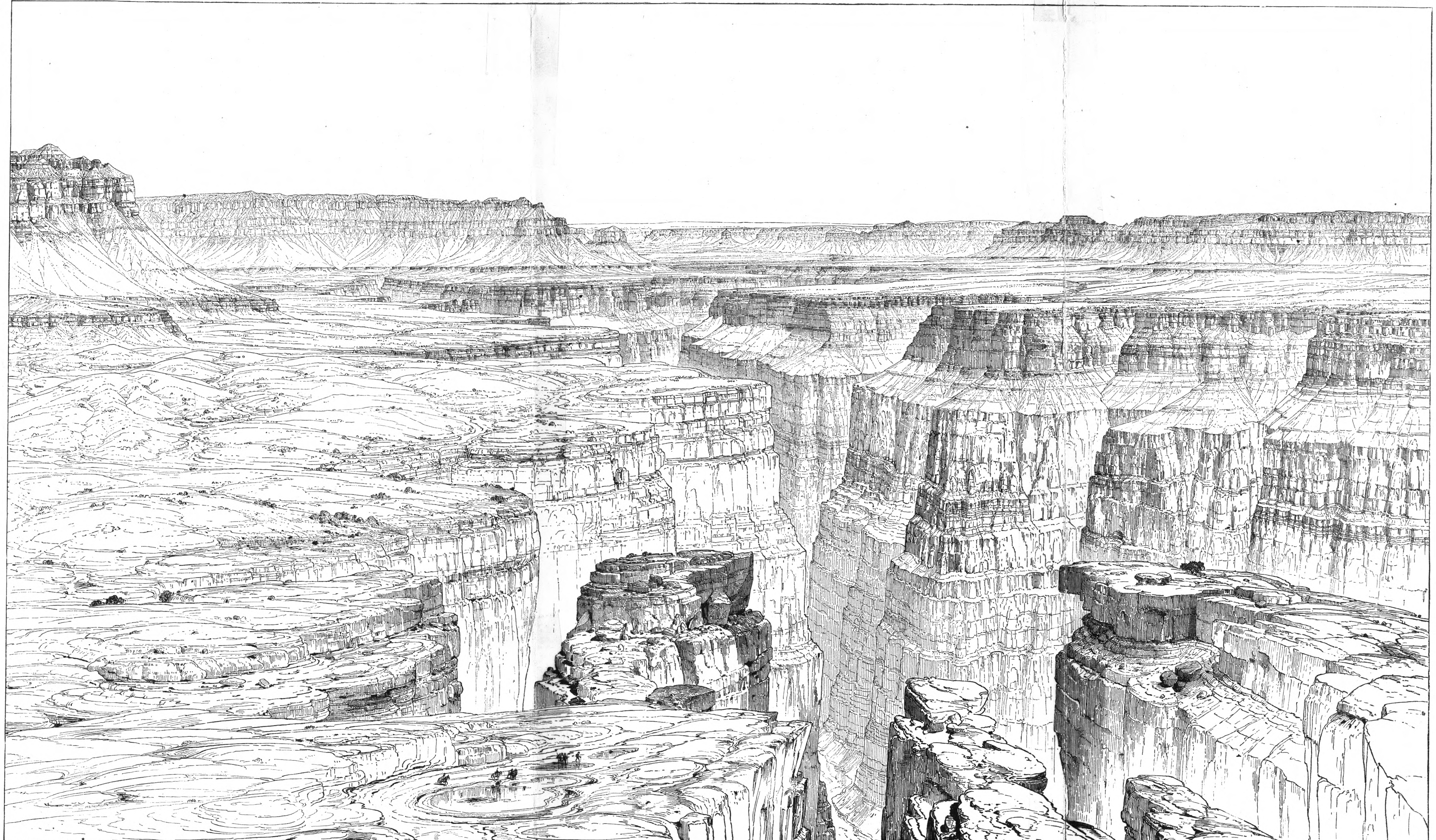


FIG. 8.—The brink of the Inner Gorge at the foot of the Toroweap, looking east.

At the foot of the eastern gable is a medley of rocky ledges of red sandstone, while around the base of the western gable are large masses of basalt reaching more than half-way across the valley. In front rises a crater, which is about 600 feet high, seemingly a mere knoll in the midst of this colossal scenery. Beyond it, and five miles distant, rises the palisade which forms the southern upper wall of the chasm, stretching athwart the line of vision interminably in either direction. Its altitude is apparently the same as that of the palisade above us, and its profile is also identical. Climbing among the rocky ledges which lie at the base of the escarpment, we at length obtain a stand-point which enables us to gain a preliminary view of the mighty avenue. To the eastward it stretches in vanishing perspective forty miles or more. Between symmetric walls 2,000 feet high and five miles apart is a plain, which in comparison with its limiting cliffs might be regarded as smooth, but which in reality is diversified by rocky hummocks and basins, and by hillocks where patches of soil give life to scattered cedars and piñons. Of the inner chasm nothing as yet is to be seen. Moving outward into this platform we find its surface to be mostly bare rock, with broad shallow basins etched in them, which hold water after the showers. There are thousands of these pools, and when the showers have passed they gleam and glitter in the sun like innumerable mirrors. As we move outward towards the center of the grand avenue the immensity and beautiful proportions of the walls develop. The vista towards the east lengthens out and vanishes against the blue ramp of the Kaibab, which lies as a cloud upon the horizon. To the west the view is less symmetric and regular, and the eye wanders vaguely among cliffs and buttes of stupendous magnitude, displaying everywhere the profile with which we have become of late familiar. Much of the distance towards the west is obstructed by the crater, but the portions in view bewilder us by the great number of objects presented, and oppress us by their magnitudes. At a distance of about two miles from the base of the northern wall we come suddenly upon the inner chasm. We are not conscious of its proximity until we are within a few yards of it. In less than a minute after we have recognized the crest of the farther wall of this abyss we crane over its terrible brink and gaze upon the waters of the river full 3,000 feet below.

The scene before us is a type of the Grand Cañon throughout those portions which extend through the Kanab, Uinkaret, and Sheavwits Plateaus. The plan and section here presented are quite simple. They consist of a broad upper chasm from five to six miles in width with walls varying in altitude but little from 2,000 feet. Between these escarpments is a rocky plain, rough indeed, but in the overpowering presence of such walls seeming relatively smooth and uniform. In this floor is cut the inner chasm 3,000 feet deep and from 3,500 to 4,000 feet wide from crest to crest. The true profile will be best understood by consulting the diagram, Fig. 10, which is drawn to scale. The strata in which the chasm is excavated are all of Carboniferous age excepting three or four hundred feet at the bottom of the gorge. The strata beneath the Carboniferous are at present believed to be Lower Silurian, and their contact with the Carboniferous is unconformable, both by dip and by erosion. In the upper part of the palisades which form the wall of the upper chasm we find at the summit two series of limestones. The upper contains an abundance of siliceous matter, one portion of which is intimately disseminated through the mass while another portion is aggregated into myriads of cherty nodules varying from two to ten inches in diameter. The lower one is a purer limestone with few nodules. The cherty members form a nearly vertical band at the summit of the wall; the purer members form a Mansard slope beneath, covered with talus. The total thickness of the limestones is about 700 to 750 feet. Beneath them come



THE GRAND CAÑON AT THE FOOT OF THE TOROWEAP—LOOKING EAST.

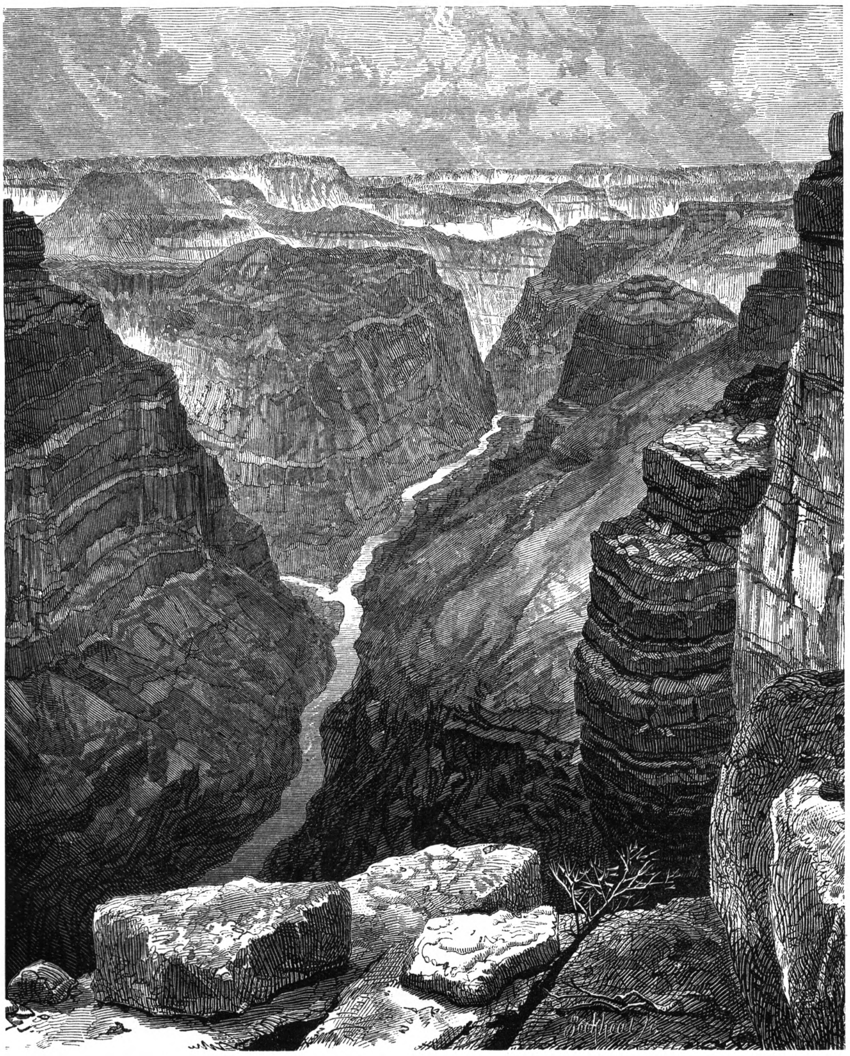


FIG. 9.—The brink of the Inner Gorge at the foot of the Toroweap, looking west.

sandstones a little more than 250 feet thick, which form everywhere a vertical plinth or frieze. They are very adamantine in texture, and one of the members, about 160 feet thick, is in every exposure seen to be uniformly cross-bedded. Under the cross-bedded sandstone is a mass of thinly bedded and almost shaly sandstones, having an aggregate thickness very closely approximating to 1,000 feet. They are of an intensely brilliant red color, but are, in greatest part, covered with a heavy talus of imperishable cherty nodules, fragments of the cross-bedded sandstones, and spalls of limestone shot down from above. The color of these is pale gray, with occasionally a yellowish or creamy tinge.

The brilliant red sandstones form the long curved slope which descends from the plinth of cross-bedded sandstone to the plain below.

The walls of the inner gorge have at the summit about 325 feet of hard sandstone of a brown red color. Beneath the sandstone are about 1,800 feet of impure limestone in layers of the most massive description. Very few such ponderous beds of limestone are found in any part of the world. The color is deep red with a purplish tone, but the brilliancy of the coloring is notably weakened by weathering. Still lower are red-brown sandstones again having a dark and strong shade and lying in very massive beds. The strata forming the walls of the outer chasm from the summit to the plain below are designated the Aubrey group, and this is again subdivided at the base of the cross bedded plinth into Upper and Lower Aubrey groups. The two subdivisions are believed to be the equivalents, in age, of the Coal Measures of Pennsylvania and England. The strata disclosed in the inner gorge correspond in age to the Lower Carboniferous of those countries, and are here termed the Red Wall group. Some uncertainty exists regarding the beds which lie at the base of the conformable series deep down in the chasm, but they are regarded at present as being just what they seem and just what they would naturally be inferred to be—a part of the Carboniferous system. Of the strata at the bottom of the cañon, we shall have more to say hereafter. They are regarded at present as being of Lower Silurian or Primordial age.

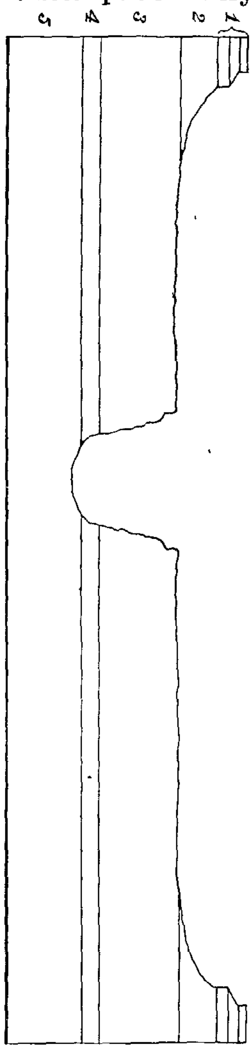


FIG 10—Section of the Grand Cañon at the foot of the Toroweap Valley 1, Upper Aubrey, 2, Lower Aubrey, 3, Red Wall, 4, Base of the Carboniferous, 5, Lower Silurian and Archæan unconformable Scale one mile to the inch.

The observer who, unfamiliar with plateau scenery, stands for the first time upon the brink of the inner gorge, is almost sure to view his surroundings with commingled feelings of disappointment and perplexity. The fame of the chasm of the Colorado is great; but so indefinite and meager have been the descriptions of it that the imagination is left to its own devices in framing a mental conception of it. And such subjective pictures are of course wide of the truth. When he first visits it the preconceived notion is at once dissipated and the mind is slow to receive a new one. The creations of his own fancy no doubt are clothed with a vague grandeur and beauty, but not with the grandeur and beauty of nature. When the reality is before him the impression bears some analogy to that produced upon the visitor who for the first time enters St. Peter's Church at Rome. He expected to be profoundly awe-struck by the unexampled dimensions, and to feel exalted by the beauty of its proportions and decoration. He forgets that the human mind itself is of small capacity and receives its impressions slowly, by labored processes of comparison. So, too, at the brink of the chasm, there comes at first a feeling of disappointment; it does not seem so grand as we expected. At length we strive to make comparisons. The river is clearly defined below, but it looks about large enough to turn a village grist-mill; yet we know it is a stream three or four hundred feet wide Its surface looks as motionless as a lake seen from a distant mountain-top. We know it is a rushing torrent. The ear is strained to hear the roar of its waters and catches it faintly at intervals as the eddying breezes waft it upwards; but the sound seems exhausted by the distance. We perceive dimly a mottling of light and shadow upon the surface of the stream, and the flecks move with a barely perceptible cloud-like motion. They are the fields of white foam lashed up at the foot of some cataract and sailing swiftly onward.

Perhaps the first notion of the reality is gained when we look across the abyss to the opposite crest-line. It seems as if a strong, nervous arm could hurl a stone against the opposing wall-face; but in a moment we catch sight of vegetation growing upon the very brink. There are trees in scattered groves which we might at first have mistaken for sage or desert furze. Here at length we have a stadium or standard of comparison which serves for the mind much the same purpose as a man standing at the base of one of the sequoias of the Mariposa grove. And now the real magnitudes begin to unfold themselves, and as the attention is held firmly the mind grows restive under the increasing burden. Every time the eye ranges up or down its face it seems more distant and more vast. At length we recoil, overburdened with the perceptions already attained and yet half vexed at the inadequacy of our faculties to comprehend more.

The magnitude of the chasm, however, is by no means the most impressive element of its character; nor is the inner gorge the most impressive of its constituent parts. The thoughtful mind is far more deeply moved by the splendor and grace of Nature's architecture. Forms so new to the culture of civilized races and so strongly contrasted with those which have been the ideals of thirty generations of white men cannot indeed be appreciated after the study of a single hour or day. The first conception of them may not be a pleasing one. They may seem merely abnormal, curious, and even grotesque. But he who fancies that Nature has exhausted her wealth of beauty in other lands strangely underestimates her versatility and power. In this far-off desert are forms which surprise us by their unaccustomed character. We find at first no place for them in the range of our conventional notions. But as they become familiar we find them appealing to the æsthetic sense as powerfully as any scenery that ever invited the pencil of Claude or of Turner.

The inner gorge, as we sit upon its brink, is indeed a mighty spectacle; but as we withdraw a little, it fades out of view, and, strangely enough, the sublimity of the scene is not very greatly impaired. It is, after all, a mere detail, and the outer chasm is the all-engrossing feature. On either side its palisades stretch away to the horizon. Their fronts wander in and out, here throwing out a gable, there receding into a chamber, or gaping widely to admit the entrance of a lateral chasm. The profile is ever the same. It has nothing in common with the formless, chaotic crags, which are only big and rough, but is definite, graceful, architectural, and systematic. The width of the space inclosed between the upper walls is one of the most essential elements of the grandeur It varies from five to six miles. If it were narrower the effect would be impaired; nor could it be much wider without diluting and weakening the general effect. This proportion seems quite just. It is a common notion that the distinctive and overruling feature of the great chasm is its narrowness relatively to its depth. No greater mistake could be made. Our highest conceptions of grandeur are most fully realized when we can see the greatest mass. We must have amplitude in all of the three dimensions, distance, breadth, and depth, and that spectacle is in point of magnitude the grandest which has the three dimensions so proportioned and combined as to make the most of them. Another common and mistaken idea is that the chasm is pervaded by a deep, solemn gloom. The truth is almost the reverse. In the depths of the inner gorge there is a suggestion of gloom, but even in the narrower portions there is seldom less than sixty degrees of sky from crest to crest, and a hundred and sixty along the track of the river. In the outer chasm the scene is unusually bright. The upper half of the palisades have a pale, ashy, or pearl-gray color, which is very lustrous, and this sometimes gives place to a creamy or Naples yellow tint in the frieze of cross-bedded sandstone. The Lower Aubrey sandstones are bright red, but they are in great part masked by the talus shot down from the pale gray limestones above, and peep out in lustrous spots where the curtain of the talus is drawn aside. There is nothing gloomy about such colors. Under a burning sun that is rarely clouded they have a brilliancy seldom seen in any rocks, and only surpassed by the sugary whiteness of the Jurassic sandstone or the brilliant red of the Vermilion Cliffs.

Directly in the southward prolongation of the axis of the Toroweap Valley there stands a basaltic cinder-cone immediately upon the brink of the inner gorge. Its altitude above the surrounding plain is 580 feet. The summit is readily gained. and it is an admirable stand-point from which the entire panorama may be viewed. We named it Vulcan's Throne. To the eastward about forty miles of the main chasm are well in view. The altitude of the cone, though small in comparison with surrounding objects, is sufficient to bring into view about twelve miles of the opening of the inner gorge, while in the foreground its depths are seen. To the westward the scenery is much more broken and diversified The chasm is seen through the entire stretch in the Uinkaret Plateau and reaching a few miles into the Sheavwits. But about twenty miles westward it makes a southward turn and disappears. From the north the Toroweap Valley descends from near Mount Trumbull. It is cut down only to the base of the upper cañon wall and opens into the main chasm on the level of the plain above the inner gorge. There is reason to believe that at some prior epoch it was cut a few hundred feet deeper than its present floor, and was subsequently built up by many floods of basalt coming from the cones on the Uinkaret and by considerable quantities of alluvium washed from its cliffs and overlooking mesas. On the south side of the Grand Cañon is a valley quite the counterpart of the Toroweap. It enters the main chasm directly opposite to the Toroweap, so that the two form the arms of a transept, the main chasm being regarded as the nave. Vulcan's Throne is situated almost exactly at the intersection of the axes of nave and transept.

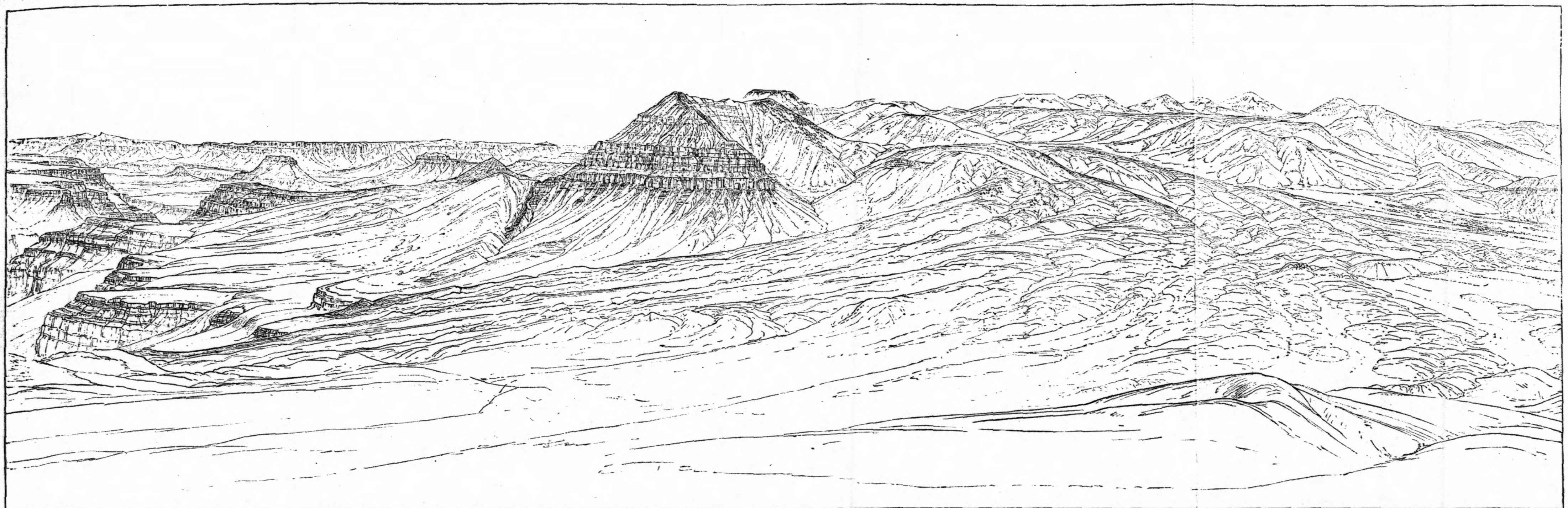
It would be difficult to find anywhere else in the world a spot yielding so much subject-matter for the contemplation of the geologist; certainly there is none situated in the midst of such dramatic and inspiring surroundings. The chasm itself, with its marvelous story of erosion, and the two lateral valleys adding their quotas of information are grand subjects indeed; but other themes are disclosed which are scarcely less surprising and suggestive. The cone stands immediately upon the line of a large fault. And never was a fault and its consequences more clearly displayed. The Toroweap fault is one of six which at wide intervals traverse the Grand Cañon district from north to south with a rude approximation to parallelism. It is the smallest of the six. Twenty miles north of the chasm no trace of it is visible. Its beginning there is small, but as it approaches the chasm it increases in the amount of displacement; and at the crossing of the river the shear or "throw" is between 600 and 700 feet. In the wall-face of the inner gorge it is disclosed as clearly as a draughtsman could delineate it on paper. The masses of horizontal limestones and sandstones, displaying their fretted edges and lines of bedding, advance from the eastward in the face of the wall until they reach the vertical fault plane. Then they "break joints" and drop at once six or seven hundred feet, and continue westward as before, but at a lower level. The whole topography goes with it. Looking beyond to the upper wall of the outer chasm the "jog" where the break occurs is plainly seen. The whole platform of the country is dropped to the westward. The plain between the upper palisades descends by a single step from east to west across the fault by an amount equal to the displacement, and the inner gorge and the whole chasm becomes by so much reduced in depth.

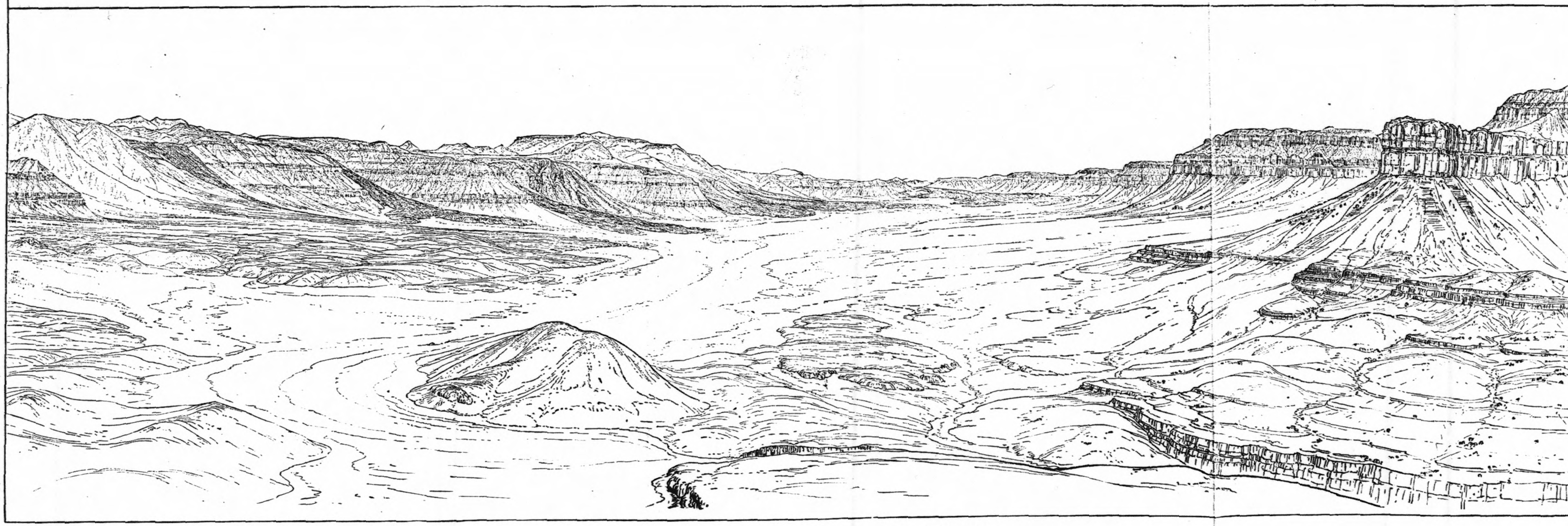
Excepting the dislocation itself, the faulting does not appear to have been accompanied by any injury to the strata. Not a trace of shattering, crumbling, or mashing of the beds is discernible. All looks as clean and sharp as if it had been cut with a thin saw and the smooth faces pressed neatly together. But the only attainable view of it is from the distance of a mile. Yet miles here are less than furlongs in other countries, and all details as well as broader features are upon the Brobdingnagian scale. What a nearer view might disclose is of course impossible to conjecture. The plane of the fault is about vertical, though there seems to be a slight inclination to the east, which may be apparent only and a result of perspective.

After a careful study of the surroundings of the fault, it becomes apparent that it is of recent occurrence in comparison with other events which have been in progress here. The tenor of all evidence bearing upon the subject goes to show that these faults were not suddenly produced by violent convulsions, but gradually developed through long stretches of time, and inch by inch or foot by foot. The Toroweap fault gives no evidence of being exceptional in this respect. Its recency is disclosed by many facts. It is seen that the amount of erosion in the face of the transverse "cliff of displacement" produced by the faulting is very small. This cliff has not receded from the fault plane to any considerable extent. Yet the giant palisades which wall the outer chasm have receded from the median line of the cañon more than two miles since the corrasion of the river laid bare the edges of their strata. It seems very plain that the outer chasm had been formed and attained very nearly its present condition before the fault started. But there is still more conclusive evidence of recency. At the foot of the southern palisade and at the jaws of the lateral valley are several basaltic craters. They look like mere bee-hives under the eaves of such an escarpment, though in truth they are four or five hundred feet high. From their vents streams of basalt are seen flowing down into the lateral valley across the fault plane, and clear to the brink of the inner abyss. The fault shears the lava floods as neatly as it does the Red Wall limestone.* Many other facts might be cited to the same purport, but this one is so conclusive that nothing further is necessary. We shall find similar evidences of recency when we come to the study of the great Hurricane fault.

Another subject which will awaken the enthusiasm of the geologist who visits this unique spot is the volcanic phonomena. Turning to the northwestward he beholds the heights of the Uinkaret. Upon its broad expanse stand many basaltic craters in perfect preservation. We know of about a hundred and fifty distinct cones in this plateau, included in the space which lies between the Grand Cañon and a limit forty miles north of it. But it is in the vicinity of the chasm that they cluster most thickly together and present the largest proportions. This part of the Uinkaret is thickly covered with basalt, above which rises the tumultu-

* It seemed to me, so far as could be judged from a distance, that a part of the faulting had been accomplished before the lava outflowed. The main fact, however, is clear that most of the faulting took place after the eruption, and of course settles the question of relative age or recency.





LOOKING UP THE TOROWEAP VALLEY. LAVA CASCADES.

ous throng of craters. Very many wide and deep floods of basalt have poured over the edge of the plateau into the lower Toroweap Valley and upon the great esplanade of the cañon, 1,500 to 1,800 feet below, and, spreading out into wide fields, have reached the brink of the inner gorge. Pouring over its brink, the fiery cascades have shot down into the abyss and pursued their way many miles along the bed of the river. At one epoch they had built up the bed of the Colorado about 400 feet, but the river has scoured out its channel again and swept them all away, regaining its old level, and is now cutting the sandstones below. The spectacle of the lava floods descending from the Uinkaret, as seen from Vulcan's Throne, is most imposing. It tells the story so plainly that a child could read and understand it. Compared with many classic volcanic regions the volcanism of the Uinkaret is a small affair. In those classic regions the mind does not come into direct contact with the enormity of the facts by a single glance of the eye. But here, if kind Asmodeus were to lift the basaltic roof of the plateau, we should see no more than we do now. The boldness of the picture is much increased by the pediments of Carboniferous strata projecting from the body of the plateau, showing the brilliant colors of the strata and their sharply-defined architecture, with the dark masses of basalt wrapping around them. Hard by, and almost within hail, is a superb gable projecting between two broad floods of lava, and so beautifully proportioned and richly colored that we cannot help wishing to transport it by magic to some more habitable region.

The Toroweap Valley has a significance to the geologist which might not be at once apparent to the tourist. Even the geologist would be slow to discern it unless familiar with cognate facts displayed in the country at large bordering the Grand Cañon. In the effort to interpret its meaning it becomes necessary to take a hasty view of one or two broad facts relating to the lateral drainage of the chasm. Upon the north side, in all the distance between the head of the Marble and the foot of the Grand Cañons, there is but one side cañon carrying drainage from distant regions. This single exception is Kanab Cañon. In this respect the Colorado is much like the lower courses of the Nile; and the cause is plainly the same. The region is too arid to sustain any living streams or even to keep open the conduits which in former periods might have sustained them. Yet upon the assumption that at some former period the climate was much more humid all analogy compels us to believe that the Colorado once received many tributaries which are now extinct, and upon examination we find good evidence that this was really the case. The Toroweap Valley is the modified channel of an ancient river. On the west side of the Uinkaret is another. A third is seen upon the south side of the Colorado, directly opposite the Toroweap; and a few others may be easily designated. It appears that all these rivers dried up before the inner gorge was excavated. For if they had continued to carry water we may be sure that they would have cut their chasms as deep as the Grand Cañon itself—just as the Little Colorado, Kanab Creek, and Cataract Creek have done. For we have only to look at the great multitude of lateral chasms of the upper courses of the Colorado and of its forks, the Grand and Green, to be deeply impressed with the fact that so long as a tributary river carries, we will not say a living stream, but even occasional floods, its channel will be scoured down to the same level as the trunk river itself. It is apparent, then, that the Toroweap dried up before the cutting of the inner gorge of the Grand Cañon began, and hence we infer that the arid climate which caused it to dry up existed before the beginning of the inner gorge.

By the application of other homologous facts, and by the same method of reasoning, we infer that the outer chasm has also been excavated during the prevalence of an arid climate. The platform of country adjoining the cañon is at present devoid of lateral chasms, yet traces are often found of ancient channels which became dry at about the time the excavation of the outer cañon began, or very soon thereafter. They are cut to comparatively slight depths—from one hundred to three or four hundred feet. That they are not of recent origin is proved by the fact that they often have slopes away from the river, though it is clear that they formerly sloped towards it. In truth, the entire chasm betrays everywhere the continued action of an arid climate through the entire period of its formation. This arid period is limited, approximately, to Pliocene and Quaternary time. The general tenor of the facts is to the effect that the Miocene was a humid period and the Pliocene a dry one throughout the greater part of the West. This is one of the reasons which lead us to the very probable conclusion that the age of the Grand Cañon is not older than the beginning of Pliocene time. We might also draw a similar inference from a consideration of the enormous erosion which took place here before the excavation of the chasm was begun. The denudation of the Mesozoic system was an incomparably greater work, and yet that denudation could not have begun until the last strata (the Lower Eocene) were deposited. If these inferences are well founded, we may assign the greater part of Eocene and the whole of Miocene time for the principal denudation of the Mesozoic, and the Pliocene and Quaternary for the excavation of the entire cañon. The proportion thus suggested between the portions of the work done and the divisions of time required to accomplish them seems very fair and reasonable. But the strongest evidence of all it would be almost impossible to recite here in detail. In general terms, it may be characterized as that internal evidence which appears when a vast array of facts, at first disjointed and without obvious relation, are subsequently grouped aright into a coherent system. Each constituent fact is then seen to admit of one intelligible interpretation and no other; and each subsidiary proposition has an overwhelming justification and an evidence of verity far stronger than any which could be summoned if we endeavored to prove it independently.

Another question which the geologist asks here is, how happens it that the outer chasm is so broad while the inner one is so narrow? The outer chasm is five to six miles wide and 2,000 feet deep; the inner is about 3,500 feet wide and 3,000 feet deep. The disparity is great. We have seen enough to say at once that the widening of the outer chasm was effected by the recession of its cliffs. If the corrasion of the cañon went steadily onward without a halt or respite this disparity demands some explanation. Although we should expect less recession in the cliffs of the inner gorge than in those of the outer, we should not expect it to be so much less if the only variable concerned was length of time. We might explain it by assuming the rocks of the inner gorge to be much more obdurate than those above. This is true in part, but still the difference in this respect is insufficient. A much more satisfactory explanation is found in the supposition that the broad esplanade of the cañon between the upper palisades was an ancient base-level of erosion (page 101). We might imagine that when the Colorado had cut its channel down to that level, it had reached the limiting depth of corrasion for the time being. Then for a long period the palisades on either side wasted and receded from the river. At last another epoch of upheaval set in; the entire platform of the district was lifted several thousand feet; the power of the river to corrade was restored; and with comparative rapidity it sank the inner gorge. This becomes more than a mere guess when we take account of its relation to the general category of facts. Thus the great faults attest the fact that such an upheaval did occur; that it occurred, too, just at the time supposed; and that in amount it was quite equal and probably not more than equal to the amount required. Other evidences might also be produced, but they are too intricate to be discussed here.*

We leave the Toroweap Valley and the Grand Cañon, regretting that all its wonderful and instructive subjects should receive such brief notice. Retracing our steps up the Toroweap for a distance of about six miles, we at length select one of the great lava streams on the western side. Although quite steep, we may ascend it with the animals and packs without serious difficulty. At the end of an arduous climb upon the rugged slope, we find ourselves upon the platform of the Uinkaret. Around us are the old cinder-cones, most of which are of considerable dimensions. All of them have given vent to floods of basalt, which have

* I would, if space admitted, be glad to describe the remarkable phenomena presented in the wall of the inner gorge directly across from Vulcan's Throne Upon the very brink stands the remnant of an old crater (cinder-cone) which has been partially undermined and destroyed by the sapping of the wall-face. A lateral gorge sets back into the esplanade from the river to a distance of a mile or more. In the wall-faces are disclosed the dikes through which the lava came up. Their "strike" is parallel to the course of the river, and perpendicular to the course of the Toroweap fault. Two of them protrude from the face of the wall about 600 to 1,400 feet below the summit; others protrude just at the brink. It is extraordinary that none are seen in the depths of the gorge All of the attendant circumstances are surprising and curious, and yet it has frequently been noted that basalts habitually seek improbable places to erupt.

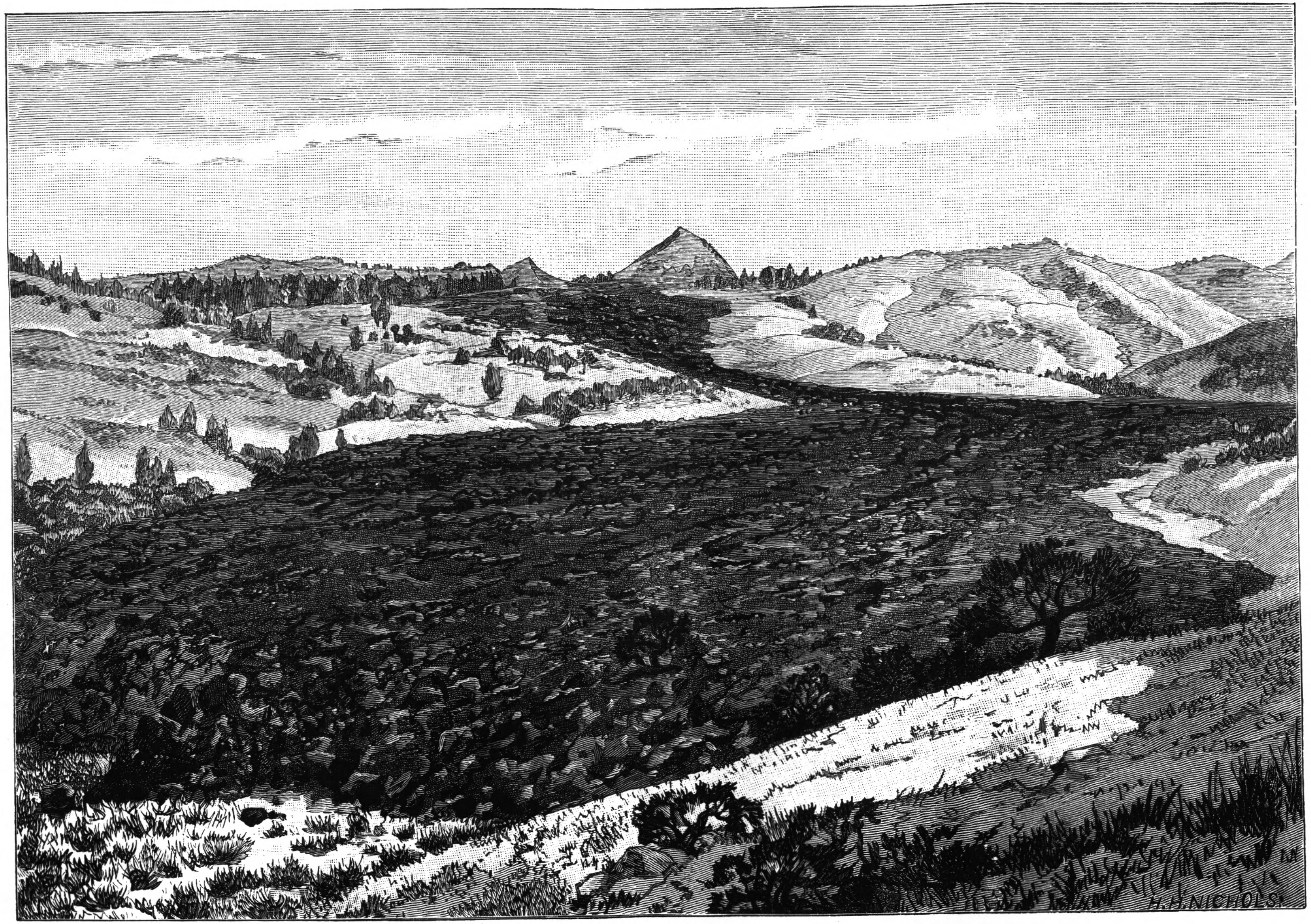
spread out thinly over extensive surfaces, but as the number of superposed sheets is considerable in this part of the plateau, the aggregate thickness, though somewhat roughly inferred, must be three or four hundred feet, and occasionally much more. There is not much to add to this description. The lava is apparently all of one kind, but some of it much older than other portions. In truth, it soon becomes apparent that the period of volcanic activity was a long one. A few miles from the point where we attained the summit of the plateau and in a northwest direction from it, we come upon the termination of a lava stream which has the appearance of being extremely recent. It looks as fresh as the emanations from Vesuvius or Ætna which have outflowed within the last fifty years. Its surface is intensely black, and only here and there can we perceive that weathering has even impaired its freshness. Two miles away is seen the cone from which it emanated. The last eruptions from it have almost destroyed it, and melted down the greater part of its mass.

Skirting the edge of this lava-sheet, we find at the eastern base of Mount Logan a small spring, named the Oak Spring. It is a central point, from which the southern part of the plateau may be visited. There is another very small spring high up on the southwestern side of Mount Trumbull, and its waters have been brought down by a wooden pipe to the plain below, to supply the wants of a saw-mill. A third and much larger spring is found on the western side of the Uinkaret. These are the only available sources of supply, and each may be used as occasion requires for the examination of different parts of the plateau.

It will be necessary here to advert, with the greatest brevity, to the facts which the Uinkaret presents. Its most conspicuous subject is its volcanism. Almost as striking a subject is the great Hurricane fault, which forms the western boundary of the plateau. It also presents many other features of interest, but only the briefest allusion to them can be made here.

The lavas of the Uinkaret are all basaltic, and are quite typical of their class. They appear to vary but little in their constitution, and, so far as the cursory examination hitherto made indicates, the only differences are such as are incident to varying conditions under which they solidified after eruption, or to subsequent weathering. But it also appears that the period of volcanic activity has covered a considerable duration of geological time. There are old lavas and young lavas; perhaps we may say there are middle-aged lavas. The older lavas are presented in the largest masses, the largest individual *coulées*. Another noteworthy feature is that the oldest lavas are now found upon the summits of the loftiest portions of the plateau, while the younger lavas are found chiefly on the lower levels. It is well worth studying to see how this comes about. The facts and explanation are best presented in the fine mass of Mount Trumbull.

This mountain is in reality a gigantic butte; that is to say, a mass of



RECENT LAVA STREAM ON THE UINKARET.

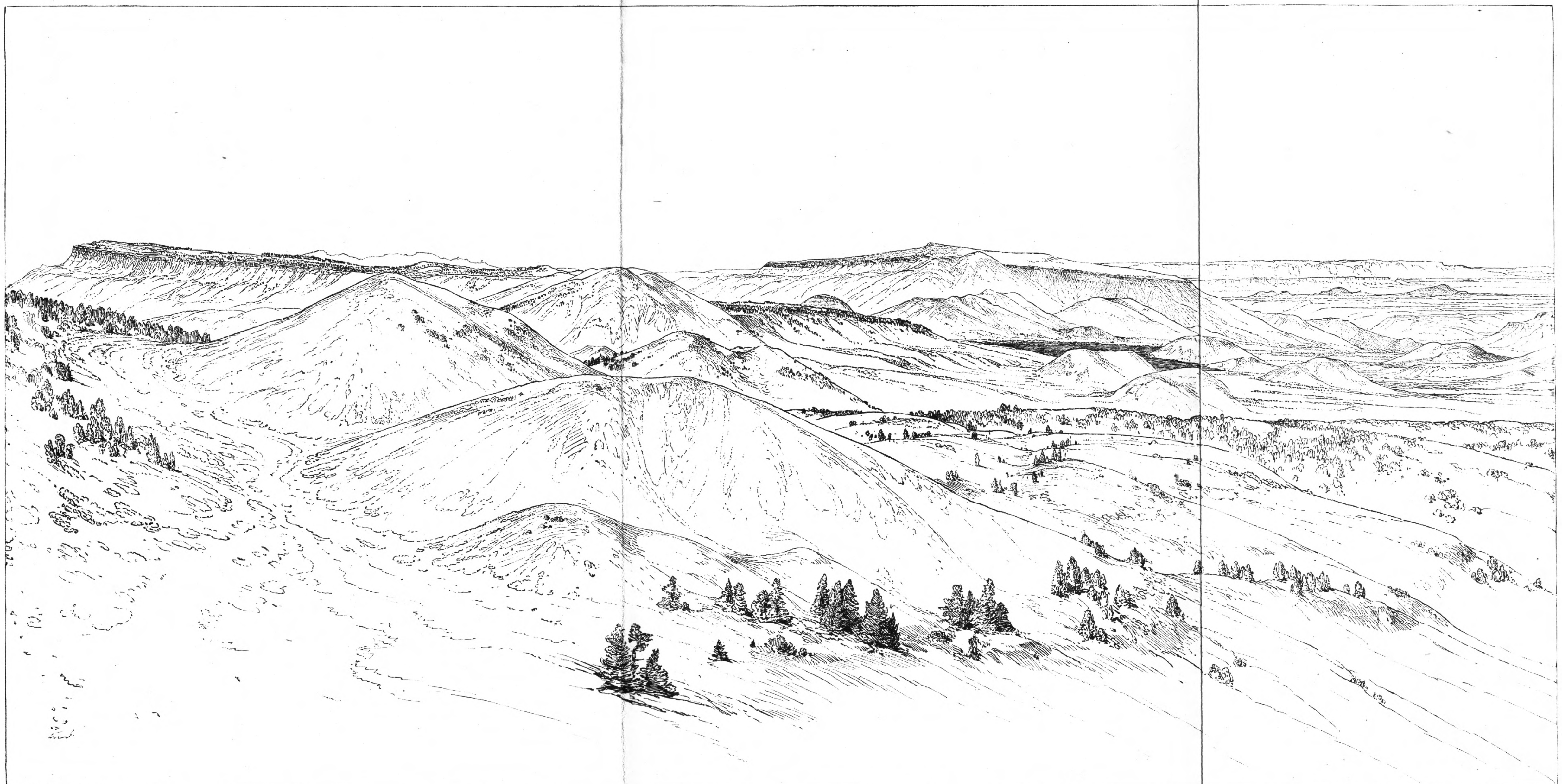
sensibly horizontal strata left by the denudation of the same beds from the platform surrounding. It is roofed over with a ponderous lava-cap, 500 to 800 feet thick. Under this lava-cap are seen in numerous places the horizontal edges of the strata, though the flanks of the mountain are so thickly covered with the débris formed by the disintegration of the basalts at the summit that these strata are for the most part buried. The beds beneath the lava are of Permian age, and it is evident that nearly the whole and possibly quite all of the Permian series remains in the mountain mass. That these basalts are very old is evident at a glance. The evidences of erosion are seen on every hand, and their aspect is strikingly different from that of the younger or middle aged basalts. On the summit of the mountain we find a cluster of old vents, from which a great part at least of these lavas were expelled. They are simply large craters torn down, dissolved and rotted away to their very roots by the ravage of time. It is evident, too, that the lava-cap itself is as a whole a mere remnant of a mass of superposed sheets which once extended much beyond the steep ledge which now limits them all around the mountain. The geologist draws his conclusion very quickly. These basalts in the lava-cap were extravasated at a time when the aspect of the surrounding country was very different from that which is now presented. At that time large bodies of Permian strata, since swept away extended continuously from the edges now exposed in the mountain flanks over spaces far away from it. We cannot indeed affirm that the great denudation had not already begun its havoc in the Permian, but we may be sure that it had not reached nearly its present stage. Mount Trumbull then is a remnant of a platform of lava-capped Permian beds, which was once of much greater extent. What was the extent of this platform at the time of the eruptions, we do not yet know, nor are we likely to know.

Around the base of the mountain on all sides the more recent craters are thickly clustered. The cones are for the most part in an admirable state of preservation; though here and there one may be found which has suffered considerable ravage. About two miles north of the base of Trumbull, especially, is an old cone, which has been laid open in such a manner as to disclose its interior structure very clearly. It is in all respects similar to the cones of the Mediterranean islands and countries. All of these craters were built at a much later period than the lava-cap of the mountain.

Mount Logan which lies near Trumbull to the southwestward, presents a similar state of affairs. It is a tabular mass capped with the more ancient basalts and with a great body of Permian beds beneath. South of Logan is another mass of ancient basalts, overlying Permian strata. Upon this southern table, however, are planted some well preserved craters which belong to the middle age of eruptions. Chief among these is Mount Emma, whose summit has been used as a primary topographical station. In general, these more ancient basalts appear to have been erupted at a time when the summit of the Permian constituted the principal part or certainly a great part of the platform of the country. Since their outflow, the great denudation has made progress, so that at present only these lava-capped and lofty masses remain. A considerable number of patches of the basal members of the Permian, however, are still preserved in the country roundabout, while the greater part of the Permian series has been removed. It is indeed quite possible that at the time of the eruption of the most ancient basalts, considerable ravage may have already been made in the Permian strata; but the probabilities are that the amount of such destruction was not very great.

It is not easy, perhaps it is impossible, to fix the relative age of these eruptions in geological terms. It is, however, certain that they date well back in Pliocene time, and may even have taken place in late Miocene time. I am inclined to refer them, doubtfully, indeed, yet not wholly at random, to an epoch in which the excavation of the Grand Cañon had either just begun or had made only a little progress. This period, with somewhat more confidence, I assign to the early part of the Pliocene. The middle-aged eruptions, of course, were much later, and may come not far from the glacial epoch, but whether immediately before or immediately after, or during that period, I see no means of determining. The later eruptions are in all probability Quaternary, and it can hardly be doubted that the very fresh lava streams already spoken of had their eruption within the Christian era; nay, they may have broken forth since the conquest of Mexico by Cortez. Some light is thrown upon the question of age by a study of the great Hurricane fault.

The Uinkaret Plateau is bounded on the west at the brink of an escarpment differing radically from the cliffs of the terraces. So far as outward topographic features are concerned, the superficial observer would not note any marked peculiarity. But its origin is wholly different. The terrace cliffs are all cliffs of erosion, produced by the denudation of the country in front of them. The Hurricane Cliff which bounds the Uinkaret is a cliff of displacement. At its base is a gigantic fault, letting down the whole country to the westward as far as the eye can reach. The Hurricane fault has its southern end far south of the Colorado—we know not where at present—but we do know that it extends south of the river, with a great amount of displacement, for more than thirty miles; and at the farthest point thus far observed it has still great force, and shows no signs of vanishing or running out. At the point where it crosses the Colorado it has a shear of about 1,400 feet, and the displacement increases northward. Abreast of the southern portion of the Uinkaret it is no longer a single fault, but suddenly splits into four branches or steps, the "throw" being distributed irregularly among the several steps. To see this we must descend into the Queantoweap Valley, lying on the west side of the Uinkaret, and, in some sense, the mate or homologue of the Toroweap on the eastern side. Reaching the bottom we

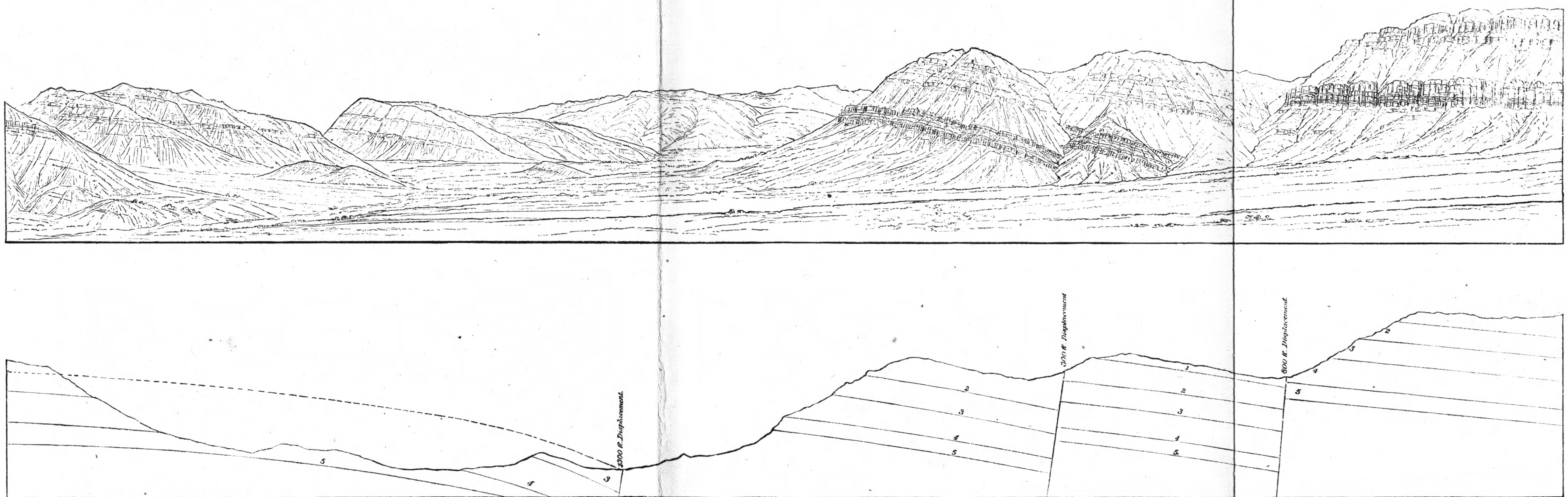


LOOKING NORTHEAST FROM MOUNT EMMA. MOUNTS LOGAN AND TRUMBULL IN THE DISTANCE.

descend the Queantoweap a few miles, and turning about we see the effects of the fault so plainly that a child could hardly mistake them. Right in the bottom of the valley is the lower branch with a displacement of about 1,300 feet. (Plate XXVIII). On the cliff to the right is a second smaller displacement of about 350 feet. Still farther to the right is a third of about 700 feet. Beyond the limits of the diagram is a fourth of about 500 feet. Twenty-five miles north of the Colorado the branches have disappeared and a single fault remains, with a shear of about 1,800 feet, and this amount continues nearly constant to the northward for a few miles. At length the fault rapidly increases. Seventy-five miles north of the river, and at the point where the Virgen River crosses it, the throw has become colossal. We stand upon the brink of the cliff with our feet upon the summit of the Carboniferous, and within musket range, 1,500 feet below, is the Jurassic white sandstone. Most of the Jurassic (800 feet), the whole of the Trias, which here has unusual thickness (2,800 or 2,900 feet), and the whole of the Permian and Permo-Carboniferous (1,200 or 1,300 feet), overlie the continuation of the strata on which we stand. The total throw is not far from 6,500 feet. Still northward extends the fault, and still it rapidly increases. At length it reaches a maximum displacement of more than 12,000 feet on the west side of the Markágunt. Continuing northward it gradually decreases, and finally disappears near the western flank of the Tushar Mountains. The entire length of this fault is more than 200 miles. It is throughout its whole extent a primary geological and topographical feature of the region it traverses.

With regard to the age of the fault we have some information. It is not probable that all its portions were sheared simultaneously, and it is quite certain that its development was very slow and gradual and progressed through a long stretch of geological time. Confining our attention to that portion extending along the western flank of the Uinkaret, we find that nearly the whole displacement took place after the eruption of the oldest basalts, for the fault dislocates the most ancient lava beds. Whether some small portion of it may or may not have existed before these eruptions we cannot positively say, but no evidence of such priority has been noted. On the other hand, all the younger lavas, and some, at least, of the middle-aged lavas flowed across the fault and have not since been cut by it. But some of the middle-aged lavas appear to have suffered some dislocation. Hence we infer (1), That the age of this part of the Hurricane fault is not older than the beginning of the Pliocene. (2), That the displacement went on in harmony and conjunction with the volcanic activity. (3), That for a long period, historically speaking, it has been quiescent, and no movement has within the historic epoch taken place. (4), That the beginning of the Hurricane fault is older than the beginning of the Toroweap fault. These conclusions are of great importance in unraveling the history of the Grand Cañon district, for they at once become links in a chain of reasoning which, though complex, is very systematic and self-consistent. The faults are evidences of vertical movements. The amount of shearing and the time of its occurrence give us in great part the data to determine the amounts and epochs of upheaval. Uplifting has been one of the prime factors of erosion, for it controls the declivity, velocity, and corrasive power of the streams, which in turn determine the amount of relief throughout the region; and the amount of relief is the chief factor which determines the rapidity and aggregate of erosion. Thus the entire range of facts presented in the geology and topography of this region are woven together, thread by thread, into a definite pattern of warp and woof. Volcanism, displacement, drainage, stratification, erosion, climate, each contributes its quota. To weave them together is no easy matter. Yet the region has had a history, and though its record is broken, disjointed, and scattered, we are still able to find many fragments and restore them to their proper places and sequence. The Uinkaret abounds in curious little facts, many of which, besides being instructive in themselves, are of great utility in piecing together this narrative. But their discussion must be reserved for a more deliberate and comprehensive work.

Before leaving the Uinkaret we may remark briefly that the Sheavwits Plateau, which lies to the west of it, is a region of much the same character. From the summit of Mount Logan it is well in view. Broad lava fields are spread over its surface, and these are all basaltic. One considerable volcanic pile stands upon its platform surrounded by younger craters and is named Mount Dellenbaugh. There are also several large buttes or broad mesas, upon its surface, composed of Permian beds capped with basalt, though the main platform is Carboniferous. The plateau, however, has been reconnoitered only and not minutely investigated. Upon its western verge is the Grand Wash fault, a gigantic displacement, where the whole country to the westward is dropped down between 6,000 and 7,000 feet. Upon the thrown side is found the Permian series complete in great force, and above it some of the basal members of the Trias. This fault is the boundary of the Grand Cañon district and of the Plateau country itself. The region beyond is a sierra country, with the same characteristics as the Great Basin of Nevada and Western Utah.



THE HURRICANE FAULT—IN THE QUEANTOWEAP VALLEY

CHAPTER VI.

THE KAIBAB.

The Kaibab is the loftiest of the four plateaus through which the the Grand Cañon extends. It is from 1,500 to 2,000 feet higher than the Kanab Plateau on the west, and from 2,500 to 4,000 feet higher than the Marble Cañon platform on the east. Its superior altitude is due wholly to displacement and not to erosion, for the strata upon its summit are the same as those upon the surfaces of the others. The upheaval has produced a sharp fault upon the western flank and a great monoclinal flexure upon its eastern flank. Throughout its entire platform the upper Carboniferous forms the surface. The Kaibab begins at the base of the Vermilion Cliffs near the little village of Paria; its northern extremity terminating in a slender cusp. Steadily widening and increasing very slowly in altitude, it reaches southward nearly a hundred miles to the Colorado River, where it attains a breadth of about 35 miles. Its highest point is about 9,280 feet above the sea, but most of its surface is between the altitudes of 7,800 and 9,000 feet.

When viewed from a distance its summit, projected against the sky, looks remarkably smooth and level. The slow increase of altitude from north to south may be discerned, and yet, in the absence of positive knowledge, it would be doubted by the careful observer whether this might not be due to perspective, and not real. When we actually visit the plateau we find the summit, seeming so smooth when viewed from afar, to be really very rugged. It is scored with a minutely ramified system of ravines, varying much in depth, but averaging about 300 feet in the heart of the plateau, and much deeper at the flanks. The whole summit is magnificently forest-clad. In this respect it is in strong contrast to the other plateaus, excepting, however, in a much inferior way, the higher parts of the Uinkaret. The other plateaus are formidable deserts; the Kaibab is a paradise. The forests are due to the superior altitude of the plateau, for the higher the altitude the moister the climate. Through the southern portion of the Kaibab is cut the finest portion of the Grand Cañon. Vast and imposing as is the scenery at the foot of the Toroweap, the scenery of the Kaibab is much more impressive. I propose in the present chapter to describe in familiar language a journey from Kanab to the Kaibab, and to the brink of the chasm, where we may contemplate its sublimity. Its geological significance must be discussed in a future work.

When the order is given to the party encamped at the little village of Kanab to prepare for the Kaibab, it is obeyed with more than ordinary alacrity. From the chief of the party down to the herders and cooks all look forward to delightful wanderings in a cooler atmosphere, in open forests of noble pines and spruces, in flowery parks and winding avenues of rich verdure; to scenery the grandest of earth, and to communion with Nature in her noblest and loveliest moods. As we descend

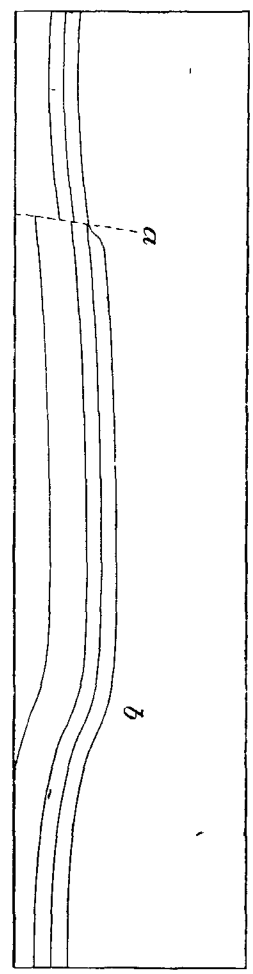


FIG 11.—Section across the Kaibab. The vertical scale is double the horizontal. *a*, West Kaibab fault. *b*, East Kaibab monocline. Length of section about 32 miles.

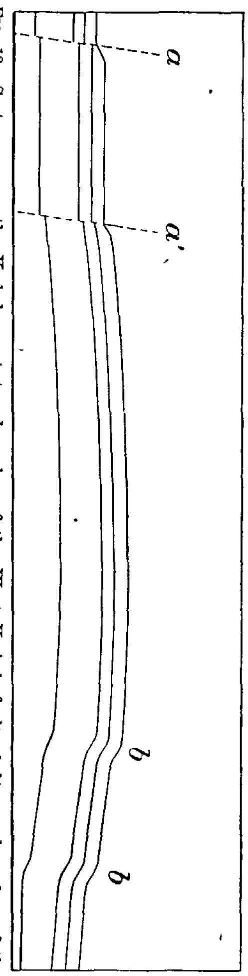


FIG 12.—Section across the Kaibab. *a a'*, two branches of the West Kaibab fault. *b b'*, two branches of the East Kaibab monocline. The vertical scale is double the horizontal.

the village street and take a well-known by-path upon its outskirts, even the poor animals know whither they are going; they have traveled this trail before and remember the long, green bunch-grass and tufted "gramma," the lupine and wild oats. They trot along with nimble steps, requiring neither spur to urge nor rein to guide them. Before us is the Permian terrace rising by the gentlest of slopes; through it the Kanab River has cut a wide shallow gap in which stand several pretty little buttes carved sumptuously in the characteristic style of the formation. Beyond it the Carboniferous platform extends southward without visible bound. Over the Permian terrace the Kaibab is in full view, its flat unruffled summit occupying a whole quadrant of the horizon, and its western escarpment facing towards us. The light of the declining sun* is upon it, and the larger details stand forth in clear relief, displaying the openings of grand ravines and the massive faces of the intervening pediments.

In the course of an hour we pass through the Permian gap, and the boundless desert is before us with the Kaibab upon our left. Our route is not directly towards the plateau front, but obliquely towards a point in it far to the southeast. In the portion of the plateau nearest to us there is no water, either upon the summit or in the great ravines, and without water the journey would be indeed arduous. Moreover, it is the southern portion which commands our greatest interest, and the northern part possesses no features which are not still more advantageously presented in the southern. The southern prospect is very extended. The desert before us is really no more uneven than the rolling prairie of Iowa, but the range of vision is vastly greater. The reason is soon explained. In the prairie the curvature of the earth soon carries the surface out of sight. In the Kanab Desert we are constantly looking across a very wide but shallow depression of the surface, of which the center is located where Kanab Cañon begins to cut into the Carboniferous platform. In a word, the earth's surface is here slightly concave instead of convex, and the radius vector of the concavity has a length varying from fifteen to thirty miles. Anywhere within the depression, therefore, the prospect is a very wide one. The general impression conveyed is that of a gently undulating plain of immense extent.

As the sun nears the horizon the desert scenery becomes exquisitely beautiful. The deep rich hues of the Permian, the intense red of the Vermilion Cliffs, the lustrous white of the distant Jurassic headlands are greatly heightened in tone and seem self-luminous. But more than all, the flood of purple and blue which is in the very air, bathing not only the naked rock faces, but even the obscurely tinted fronts of the Kaibab and the pale brown of the desert surface clothes the landscape with its greatest charm. It is seen in its climax only in the dying hour of daylight. At length the sun disappears and the glory is extinguished.

Almost instantly the air becomes cool and refreshing, and as we ride onward through the deepening twilight it grows even chilly. It matters little how hot the days may be, the nights here are always cool and also

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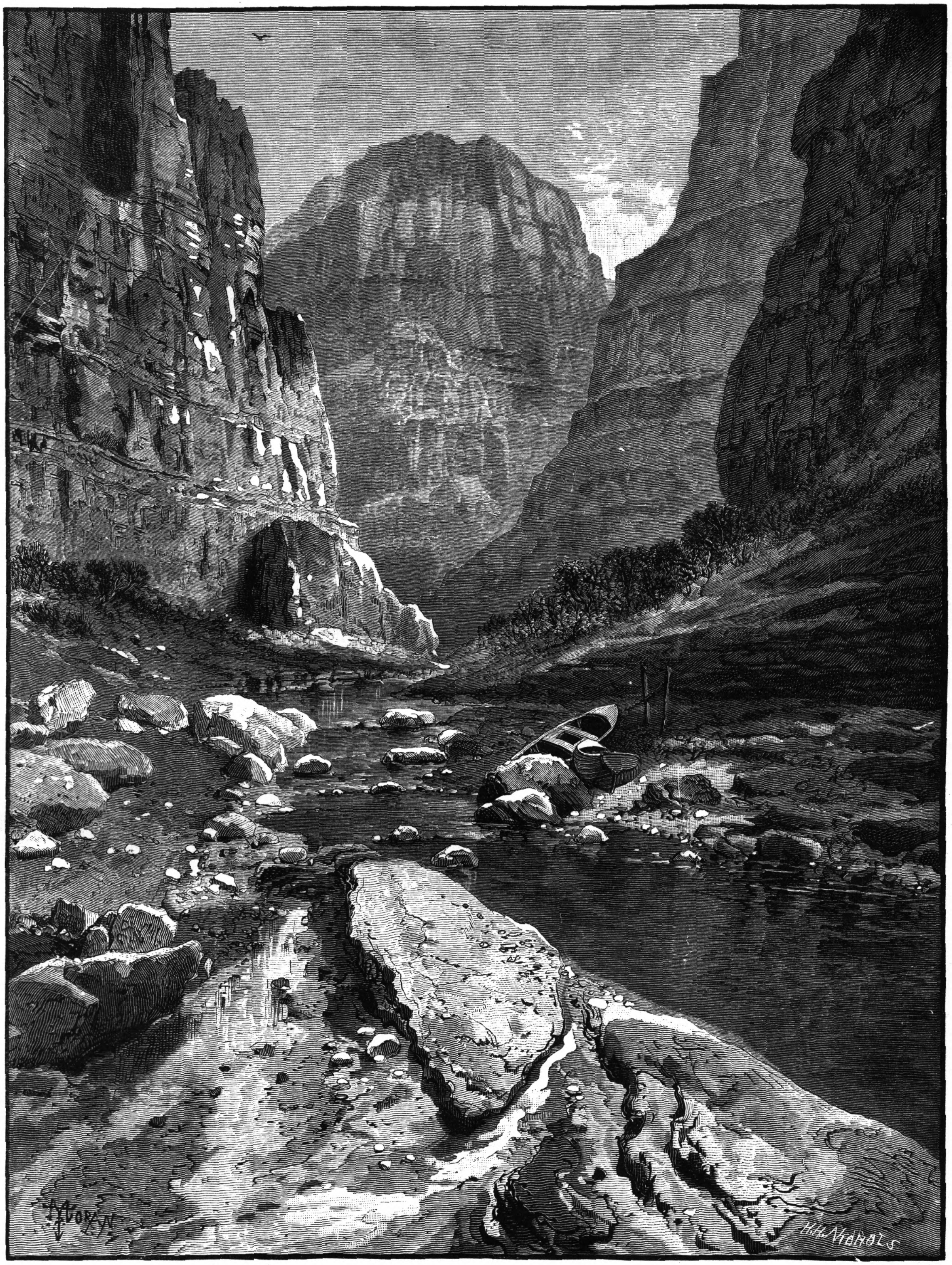
* In midsummer it is best to begin this journey late in the afternoon. The distance between watering places is about 40 miles, and when the sun is high the heat upon the open desert is intense. The packs must be heavy, and if the attempt is made to accomplish the entire distance between sunrise and sunset, the animals are liable to be overtaxed, and what may be gained by a long march in a single day will be lost subsequently. It is better to start late in the afternoon, march until near midnight, and complete the distance to water the next morning. Night traveling is usually to be avoided, but here it is the better choice of two evils

dry. I have known the temperature of the air to be 110° at midday, falling to 54° at midnight, without any general atmospheric disturbance or change except that which is due to nocturnal radiation. Upon the open desert the air is almost always still both by day and night. Rarely do the high winds blow over it in summer, and even strong breezes are uncommon except in the vicinity of great cliffs. At night the stillness is profound, and unless there is water or green vegetation hard by even the chirping of insects is unheard. The only sound which breaks upon the ear is the howling of the wolves that prowl about the camp and follow the tracks of the animals.

The hours roll quickly past as we move onward in the darkness. At length when the stars betoken the approach of midnight we halt, strip off the packs and saddles, hobble the animals and turn them loose to browse upon the scanty herbage. As the sun rises we are once more on the road. For ten miles from Kanab the trail descends by a hardly perceptible grade. Thence it ascends gradually at a rate of about 150 feet to the mile. From the fifteenth to the twenty-third mile it lies in shallow ravines but at last emerges upon more open ground. As we look back towards the north one of the grand spectacles of the Plateau country is disclosed to us. It is a view of the great cliffs which bound the southern terraces of the High Plateaus rising one above another. Nearly 10,000 feet of strata are exposed edgewise and occupy a line of frontage from 50 to 60 miles in length. It includes the stratigraphic series from the base of the Permian to the summit of the Lower Eocene. The view of the terraces from the north, from the brink of the Markágunt or Paunságunt, is of a very different character from this. There we see only their sloping summits with now and then a fragment of a mural front swung into view obliquely by the meandering course of the line of escarpment. Here the general line of frontage faces us while the terrace platforms are invisible. The view is a distant one but it requires great distance to bring into the field of vision an exposure so vast. At their nearest points the Permian is 15 miles away, the Trias 20, the Jura 35, and the Eocene more than 50. It should be observed that we are looking across the broad depression or concavity before spoken of, and that there is a gentle slope downwards for 15 miles to the base of the Permian, which lies 1,900 feet below us. Notwithstanding the distance there is no difficulty in distinguishing the different formations, and there would have been none even if we had never before seen the terraces, provided we had become familiar with their several aspects elsewhere; so strongly individualized are their colors and their sculptural forms. The Cretaceous alone is obscure, for in the portions of the terraces now in sight it does not form cliffs but breaks down in long slopes covered with soil and débris. If we were a few miles further west the Cretaceous cliffs of the Paria amphitheater would be visible and be as easily determined as the others, but here the Kaibab hides them. Although nearly 10,000 feet of strata are disclosed the summit of the Eocene lies only



KANAB CAÑON.

5,000 to 5,500 feet above the base of the Permian, for in the interval between the two exposures the northward dip of the whole mass has carried down the Eocene about 5,000 feet.

From every elevated point on the Kanab Plateau this magnificent display is in full view. All of the broader geological facts in the stratigraphy and structure of the terraces may be distinctly seen and interpreted. The increment in thickness of the Mesozoic strata towards the west is very plain. The effect of the great Sevier fault, which comes down from the High Plateaus cutting across the terrace platforms and disappearing at the Pipe Spring promontory of the Vermilion Cliffs is now visible. By a simple reconstruction, lifting up the thrown side of this fault and gradually depressing the westward extension of the strata until the Eocene is horizontal, we can restore mentally the whole mass to the attitude it held in Eocene time, and it will require but a slight effort of the imagination to detect the original configuration which determined the present positions of the drainage basins of the Virgen, Kanab, and Paria Rivers. With a measured base-line extending east and west upon this part of the Kanab Plateau and with a fine large theodolite it would be practicable to make all the measurements necessary for determining the masses and positions of the several stratigraphic members with a degree of accuracy not materially less than could be obtained by studying them upon their own ground.

A spectacle of this kind is most impressive to the geologist. It brings into one view the coördinated results of observations made laboriously by months of travel and inspection in a very broad and rugged field. The great distances through which the eye can reach, the aspect of cliffs towering above and beyond cliffs, the great cumulative altitude thus attained, the immensity of the masses revealed, the boldness of form, the distinctness of the lines of stratification, and especially the brilliant coloring, subdued indeed, but also refined by the haze, give to the scene a grandeur which has few parallels.

But we turn our backs upon it, and pursue our way, pausing anon to look at it with a reverent enthusiasm. The daylight discloses the western Kaibab wall upon our left, only five or six miles distant, and our course changes from southeast to south parallel to its front. Already we feel the influences of its long spurs sweeping outward and dying away in the desert platform, and the trail becomes more hilly. Once or twice it takes us down into ravines which are the continuations of the great chasms which cut it to its base and recede far into its mass, winding out of sight in profound depths. Vegetation has made its appearance all around us, not abundantly, indeed, but sufficiently to contrast with the desolation behind us. Upon the crest of the plateau we can see the giant pines and spruces, and we covet their luxurious shade. Nearer, on either hand, are piñons and cedars, mountain mahogany and mesquite, with many low forms of desert shrubbery. Many species of cactus are seen, the most abundant of which are the opuntias, or prickly pears. Of these there are four or five very common species. A large cactus "orchard" in blossom is a very beautiful sight, displaying flowers which, for beauty of form and richness of color, are seldom surpassed by the choicer gems of the conservatory. Nor is it less attractive when in the fruit, for it yields a multitude of purple "pears," which are very juicy and refreshing, and by no means contemptible in flavor. There is another form of cactus not likely to be forgotten by anybody who has once seen it, and which is very common on the Kanab desert. It is a stout bush, with many branches, growing from 3 to 6 feet high. The trunk and branches have a hard, woody core, and are thickly fringed with rows of strong, sharp spines which present a very ferocious aspect. Altogether it is the most truculent looking member of the vegetable kingdom I happen to be acquainted with. Very common, too, are the yuccas, or "Spanish bayonets," which resemble, on a small scale, the noted agave or century plant. Another common species, somewhat resembling the last, bears a cluster of melon-like seed cases of the size and form of cucumbers, which the Indians gather and dry for food.*

At length the trail leads down into "Stewart's Cañon," a rather broad cañon valley descending towards us from the south. Just where we enter it it turns sharply to the west forming an elbow, and, sinking thence ever deeper into the earth through a course of fifteen miles, it opens at last into the heart of Kanab Cañon at a depth of nearly 3,500 feet. Here at the elbow it is comparatively shallow. Before reaching the elbow it runs northward close to the base of the Kaibab wall, which rises more than 1,200 feet above its floor, while the opposite or western side is only about 400 feet high. The difference in the altitudes of the two sides is accounted for by the presence of the West Kaibab fault, which runs at the foot of the wall throwing down the western side more than 800 feet. The geological relations here are worthy of some study. The presence of the fault is detected in a moment. Upon the western side the familiar grey limestones of the Upper Aubrey series form the entire wall. Upon the eastern side the same beds are seen upon the summit more than 800 feet higher than on the western side. Beneath them is the hard crossbedded sandstone, and still lower down the brilliant red sandy shales of the Lower Aubrey. Here, too, is seen that curious phenomenon so often presented in connection with the faults of this region. As the thrown beds approach the fault-plane they are turned *down*.

The trail leads southward up Stewart's Cañon with an ascent that is barely perceptible. We become conscious of increasing altitude indirectly by the barometer and by the change in the vegetation. The desert shrubs have mostly disappeared and given place to the scrub-oaks and weeds which are the unfailing indications of a cooler and

* The Mormons find a singular use for this plant. The pounded root, macerated in water, yields a thick liquid which makes a very good substitute for soap.

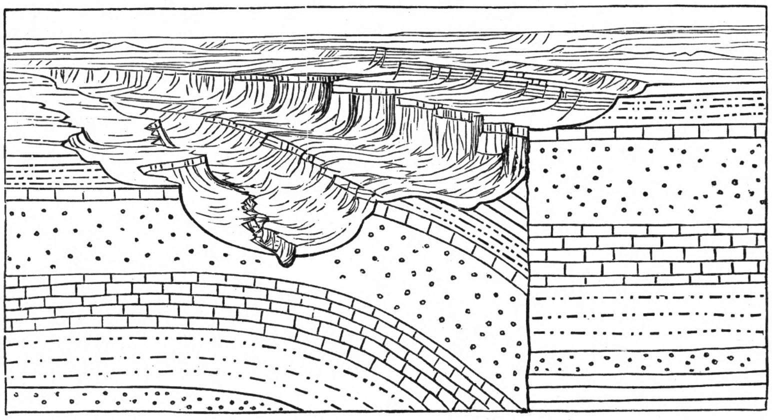


FIG. 13.—A fault with the beds flexed downward on the sunken side

moister climate. But the most welcome sight is the close proximity of the yellow pines which stand upon the summit above and even upon the lower platform which looks down from the western side. As yet they do not grow in the valley bottom. We have not quite reached the Kaibab, though it is close at hand—nay, we pass right by its open gates which seem to invite us in with a welcome; for at intervals of a mile or two we perceive upon the left the openings of grand ravines leading up to its platform and the moment we enter any one of them we are within the precincts of the great plateau. Stewart's Cañon is the trunk valley which receives the drainage of a considerable section of the western side of the Kaibab. The large affluents all come from the east, and none of any importance from the west.

About five miles from the point where the trail enters the valley we reach the first water—a tiny stream coming down from one of the great ravines and sinking into the soil a few hundred yards beyond the mouth. Halting long enough to allow the animals to drink we move onward about two miles further up the valley and make camp. Here there comes out of the Kaibab wall, about 300 feet above us, a stream of water as large as a man's body, which cascades down the rocks into a pool covering half an acre. There is a phenomenon here worth noticing, for it is a prelude to some very singular facts of general prevalence throughout this wonderful plateau. Across the outlet of the pool a rude dam has been constructed of stones and mud, which may be easily torn open or replaced. When the dam is open a large stream equal to the influx pours out of it, but the whole outpour sinks within a quarter of a mile. When the dam is closed the water in the pool rises about 15 inches and there is no outflow. All the water which enters the pool then sinks along the newly submerged margin. A stream of that size anywhere else in the Plateau country would ordinarily run eight or ten miles, and in a moist country would run much further. The sudden sinking of streams is by no means rare, but is generally exceptional. On the Kaibab it is the rule. Upon all its broad expanse there is nothing which can be properly called a brook or a living stream. About a dozen springs are known, but their waters in every instance sink in the earth within a few hundred yards of their sources. And the "Big Spring" in Stewart's Cañon yields several times as much water as all the others put together. With this foreknowledge the prospects of water supply upon the Kaibab might seem discouraging; but we shall not suffer for the want of it.

Although the sun is still high when the Big Spring is reached nothing will be gained by prolonging the day's march, and it is well to take a look at the surroundings. In some way, without knowing exactly when and where, we seem to have gotten into the Kaibab; for around us is the sylvan scenery and a rolling country traversed by many valleys and ravines. True they are not the finest types, but when we recall the desert we have just left this place looks like a paradise. The barometer shows a considerable altitude, 7,850 feet, and the air though warm is not oppressive. As we approached the plateau from the desert and saw its battlements towering grandly in the distance and becoming hourly more grand, its level parapet retreating into indefinite distance in either direction, it never occured to us that we might be spared the arduous struggle of scaling the wall, or, as a still more arduous alternative, the forcing of a rough passage through some narrow ravine for many miles. Yet we have reached this spot by a route as easy as an old-fashioned turnpike. In truth, the configuration of the southern part of the Kaibab could not be discerned as we approached it from the north. But putting together the observations of the journey it now becomes apparent that the surface of the Kanab Plateau rises quite rapidly towards the south, while the Kaibab gains in altitude much more slowly. Opposite our last camp the difference in the altitudes of the two plateaus is about 2,300 feet. Here it has greatly diminished, and the passage from one to the other is now partly by a very gentle inclined plane and partly by a fault. Fifteen miles further south the fault vanishes or becomes insignificant, and the passage is by a long slope.*

Resuming in the morning the route up Stewart's Cañon, a half-hour's ride brings us to an abandoned saw-mill. Here the trail leaves the valley which we have followed for ten miles and turns up into a large ravine coming from the east or southeast. It is much narrower than Stewart's Cañon, with very abrupt and almost precipitous walls about 600 feet

*It may be remarked here that every fault in the district is accompanied with a corresponding break in the topography. A cliff or steep slope is produced by it. I do not recall an instance where the lifted beds are planed off by erosion, so as to make a continuous level with the thrown beds. The cliffs generated by displacement have a character of their own which the experienced observer distinguishes quickly and confidently from cliffs of erosion. These characteristic breaks in the topography often betray a fault in localities where it would otherwise have been passed over unnoticed and unsuspected.

high. The traveler in the Plateau province learns to dread the necessity which compels him to thread a deep gorge or cañon unless he knows beforehand that there is a practicable and easy trail through it. If it is dry it is almost certain to be obstructed by fallen fragments and thickly set with scrub, its bottom scoured into rough gullies by the sudden floods; and half the time it will be necessary to mount the steep talus and thread it. If it carries a living stream the way is still worse, for in addition to the foregoing difficulties there are dangerous quicksands, impenetrable thickets of willows and thorny bushes, and the stream meanders from wall to wall. Unless there is a good trail the traveler will usually prefer to mount the cliff if a break can be found in it and seek the mesa above, and thus by a single struggle get rid of the miseries below. Not so the ravines of the Kaibab. Like the paths trodden by the pilgrims in the Delectable Mountains, "their ways are pleasantness and all their paths are peace." The ravine we enter is but a fair specimen of a vast number of them which cover the whole broad surface of the plateau with an infinite network of ramifications. Its bottom is covered with a carpet of grass and flowers growing rankly in a smooth firm soil free from rocks and undergrowth. Here and there a clump of aspens or noble pines grow in the way, but offer no obstacles to progress. It is like riding through a well-kept park or an avenue shaded by ancient trees. And now the effect of the absence of streams becomes manifest. Not only are there no perennial brooks, but there are no indications that even in the time of heavy rains or of melting snow any notable amount of water ever runs in these channels. Yet the Kaibab is a moist region. In summer the rains are frequent and in winter the snow lies deep. Horses cannot winter there and the wild cattle and deer, late in October, abandon it and seek the lower regions around its flanks. In all other plateaus or mountain ranges of equal mass and altitude and with equal precipitation there are many goodly streams and even large creeks fed throughout the summer by numberless copious springs; and when the snows melt these streams become raging torrents. But so rare are the indications of running water on the Kaibab even in times of melting snow, or of vernal rains, that whenever we find a "wash" we look at it with surprise as if it were a strange phenomenon demanding special explanation. But the very absence of these traces of running water constitutes one of the greatest charms of the Kaibab, for every ravine is as smooth as a lawn and carpeted with a turf of mountain grass, richly decked with flowers of rare beauty and luxuriance.

The great trees grow chiefly upon the main platform above us. Except in the highest part of the plateau they are mostly the yellow pine (*Pinus ponderosa*), but large spruces are also common (*Abies grandis*, *A. Engelmanni*). Upon the flanks of the ravines they also grow, the pines upon the northern or sunny side, the spruces upon the opposite. In the valley bottom they grow scatteringly, and for the most part leave it quite open. Contrasting finely with these are the aspens (*Populus tremuloides*) with their white trunks and pale green foliage. Throughout the greater part of the plateau these three genera comprise all the arboreal forms that occur. But upon its borders we also find cedars, mountain mahogany, and piñon (*Juniperus occidentalis*, *Cercocarpus ledifolius*, *and Pinus edulis*), the latter, though classed as a pine, differing greatly from the more typical forms of the genus.

The ravine, where we enter its mouth, is about 600 feet in depth. The ascent is by a very easy grade, averaging about 100 feet to the mile. As we progress it becomes shallower, but not so rapidly as the grade might indicate, for the plateau summit also rises though at a lower grade towards the east. The course is a crooked one, but none the less agreeable on that account. Every traveler on foot or horseback has probably observed how tiresome and monotonous the road becomes when he can see it stretching away before him for many miles, and how charming the diversity when it wanders hither and thither. It matters not if the successive vistas are as much alike as two turns of a kaleidoscope, there is always an impatience to see what is beyond the next turn. So it is here. The successive scenes are much alike, or change by insensible degrees, but the same general view is presented in ever varying detail, and its subject matter is always delightful.

It is difficult to say precisely wherein the charm of the sylvan scenery of the Kaibab consists. We, who through successive summers have wandered through its forests and parks, have come to regard it as the most enchanting region it has ever been our privilege to visit. Surely there is no lack of beautiful or grand forest scenery in America, and it is a matter of taste what species of trees are the most pleasing. Probably few people would select the conifers and poplars as the highest types of arboreal beauty. I suspect that the charm consists in influences far more subtle than these outward forms. The delicious climate, neither cold nor hot, neither wet nor excessively dry, but always exhilarating, is a fundamental condition by virtue of which the body and mind are brought into the most susceptible mood. The ease with which we move from place to place, the absence of all anxiety or care for the three great requisites of camp life, fuel, water, and grass, are accessory conditions. The contrast of the desert with its fatigue, its numberless discomforts and privations, is still another. But the scenery is also very beautiful in itself. The trees are large and noble in aspect and stand widely apart, except in the highest parts of the plateau where the spruces predominate. Instead of dense thickets where we are shut in by impenetrable foliage, we can look far beyond and see the tree trunks vanishing away like an infinite colonnade. The ground is unobstructed and inviting. There is a constant succession of parks and glades—dreamy avenues of grass and flowers winding between sylvan walls, or spreading out in broad open meadows. From

June until September there is a display of wild flowers which is quite beyond description. The valley sides and platforms above are resplendent with dense masses of scarlet, white, purple, and yellow. It is noteworthy that while the trees exhibit but few species, the humbler plants present a very great number, both of species and genera. In the upper regions of the High Plateaus, Mr. Lester F. Ward collected in a single season more than 600 species of plants, and the Kaibab, though offering a much smaller range of altitude and climate, would doubtless yield as rich a flora in proportion to the diversity of its conditions.

At a distance of about eight miles from its mouth, the ravine we have chosen has become very shallow, with gently sloping sides. At length we leave it and ascend its right bank to the upper platform. The way here is as pleasant as before, for it is beneath the pines standing at intervals varying from 50 to 100 feet, and upon a soil that is smooth, firm, and free from undergrowth. All is open, and we may look far into the depths of the forest on either hand. We now perceive that the surface of the plateau undulates with rolling hills and gently depressed vales. These valleys are the ramifications of the drainage channels. They are innumerable and cover the entire surface of the plateau. The main channels all deepen as they approach the edges of the plateau and often attain considerable depth, becoming at the same time precipitous. The deepest are those which emerge near the elbow of Stewart's Cañon and north of that point. These attain depths exceeding a thousand feet. The ravines which descend towards the eastern flank of the plateau terminate in a different manner. In the interior parts of the plateau these drainage valleys are all shallow, rarely exceeding 300 or 400 feet in depth, and seldom abrupt.

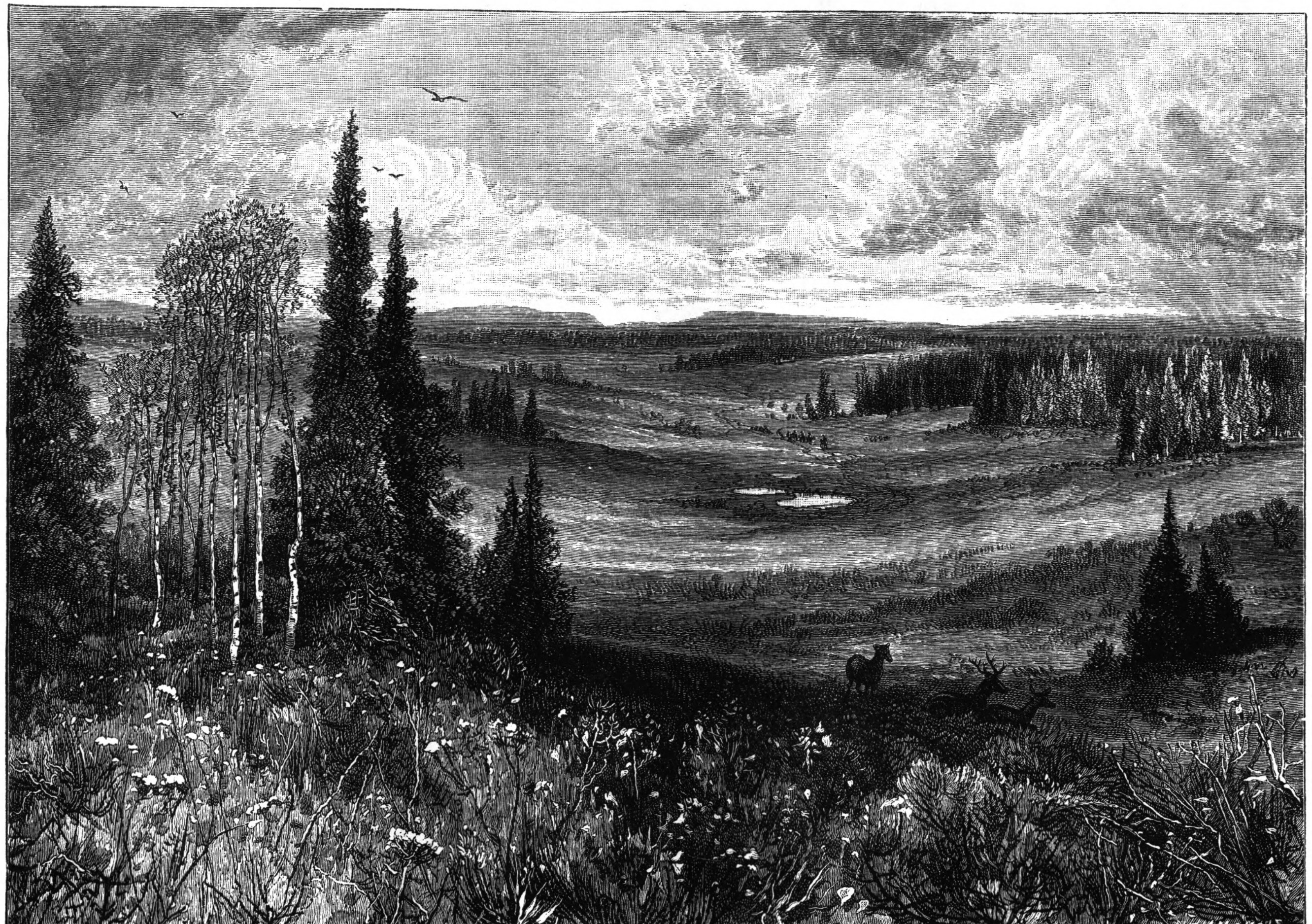
After two or three miles upon the summit, the trail descends into another valley, whose course we follow upward for about seven miles. At the distance of about twenty miles from Stewart's Cañon, we find that we have gained about 1,200 feet of altitude, and that the vegetation has changed its aspect somewhat. The pines, though still abundant, are now in the minority, and the spruces and aspens greatly predominate. The spruces form dense thickets on either hand, which nothing but the direst necessity would ever induce us to enter. Of this genus there are several species, varying much in habit. The great firs (*Abies grandis*, *A. Engelmanni*) are exceedingly beautiful on account of their sumptuous foliage. But the most common species is a smaller one (*A. subalpina*), with a tall and straight trunk, its branches spreading only five or six feet. These trees cluster so thickly together that a passage through them is extremely difficult and sometimes impossible. But we are not constrained to attempt it, for they seldom grow in the valley bottoms. Again we leave the ravine, and winding about among the hills, passing from glade to glade, we at length find ourselves upon the summit of a long slope, which descends rapidly into a great park, the largest on the Kaibab. It has received the name of

DE MOTTE PARK.

Its length is about ten miles, its average width about two miles. It is a depressed area in the heart of the plateau and is on every side girt about by more elevated ground rising by strong slopes 300 or 400 feet above its floor. The borders and heights above are densely forest-clad, but not a tree stands within the park itself. Descending into its basin and proceeding southward about two and a half miles, we reach a little spring where we make camp. The distance from the Big Spring to Stewart's Cañon is about 26 miles by trail.

De Motte Park is eminently adapted to be the base of operations in a campaign of geological investigation upon the southern part of the Kaibab. It is a central locality from which we may radiate in any direction to the bounds of the plateau. Here the great bulk of the supplies may be deposited, and from the supply camp we make journeys with light packs for one, two, or three days, as it may suit our convenience, and to it we may return to fit out for another short trip. The circumstances which make the park so advantageous in this respect are worth reciting.

Notwithstanding the open character of the forest there are two difficulties in the way of travel on the Kaibab. The first has already been mentioned, scarcity of water. We know of about a dozen small springs, some of them conveniently located for the purposes of the explorer, others not. There is, however, another source of water supply which will be described presently. The second difficulty is the danger of getting lost and bewildered in the forest. This may seem to be a singular source of danger for an explorer, who of all men is bound to know his exact whereabouts at every step. But if he were to visit the Kaibab with that easy confidence and without a guide he would probably learn a severe lesson in less than a fortnight. The young Mormon herders who range over this region, and who follow a trail with the keen instincts of Indians, and with more than an Indian's intelligence, dread the mazes of the forest until they come to know them. Even the Indians who live and hunt there during the summer and autumn have sad tales about comrades lost when the snows came early and buried the trails so that they could not be followed. The bewildering character arises from the monotony of the scenery. There are hundreds of hills and gulches, but they all look alike. There are no landmarks except trees, which are worse than none at all. If you enter a ravine for the second time at a point other than that at which you first entered it you would probably fail to recognize it. As with the faces of the Chinese, no conscientious white man would be willing to swear that he had ever seen any particular one before. Yet the riddle of the Kaibab is soon solved, and, once read, all danger is over. If the traveler is lost there is an infallible clew. He must go at once to De Motte Park. But how shall he find the way? If he has reason to



DEMOTTE PARK.

suppose that he is within a dozen miles of it he has only to enter a main ravine and follow it to its head. This, however, does not apply to the portions of the plateau which lie more than five miles north of the park. The way may be long, but is easy and sure. A few ravines fade out before reaching the near neighborhood of the park. In that event take the nearest one on the right or left. All of them head upon the summit which looks down into the park. It is necessary, however, to keep to the *main* ravine and avoid its minor tributaries, and there is a criterion by which it may be distinguished. At the confluence of a lateral ravine the grade of the main ravine is always the less of the two.

Although this may seem to be nothing more than a trival bit of woodcraft, it really illustrates an important fact—the drainage system of a large portion of the Kaibab. The study of this drainage system will shed some light upon the geological history not only of the plateau itself, but of the region adjoining, and of the Grand Cañon.

The thought which must be predominant in the mind of one who for the first time enters the Kaibab is of the Grand Cañon. The fame of its grandeur is world-wide, and the desire to see it as it is grows stronger the nearer he approaches to it. This longing must be at least tempered if not wholly satisfied before the mind is in the humor to contemplate anything else. Our first expedition, then, shall be to the brink of the great abyss.

As the sun is rising and before his beams have penetrated to the bottom of the park we are on the way. On either hand is the forest, covering the slopes and the heights above, but ending suddenly at the foot of every incline. Before us to the southward stretches the open field with hardly an undulation. Six or seven miles away we can see the sylvan walls approach each other, leaving a narrow gateway between the tall spruces where the surface of the ground for a moment is sharply projected against the sky. The scene is, on the whole, a very attractive one. There is a great wealth of vegetation, somber indeed, and monotonous, but the darkness of the tone is suggestive of depth and richness of color. The only alleviating contrast is between the smooth expanse of the park and the myriads of sharp spikes which terminate the tree tops. The spirit of the scence is a calm, serene, and gente one, touched with a tinge of solemnity and melancholy.

About a mile from camp we came upon an object worthy of attention. It is rather a deep depression in the earth about 200 feet across and very nearly circular. Within it is a large pool of water. Its depth below the valley floor may be about 40 feet, and the depth of the water 5 or 6 feet in the middle. It is a fair specimen of a frequent occurrence upon the Kaibab. I have never seen them elsewhere, and the explanation is difficult. The interest lies in the mystery of their origin. In every day's ride we usually find three or four of them and sometimes more. Some of them contain water, but the majority do not. Some hold water throughout the year, some only in the early summer or until autumn. They vary in size and depth very considerably. Some are as narrow as 20 feet; some are 300 to 400 feet across. The depths vary from a yard or two to a hundred feet. The form is crater-like—always approximately circular. They do not appear to occur under any special set of conditions. They are found as often upon the platforms as in the valleys and are not uncommon upon the slopes of the ravines. In a few instances traces may be seen of rain gullies or washes leading into them, but not often, and none have ever been noted leading out of them. Whatever running water may enter them sinks within their basins; but it is certain that many of them rarely receive any running water In the cases of those which do the wonder is that they do not soon fill up with sand and silt, for the water generated by heavy rain storms or by melting snows, when sufficient in volume to run in a stream, is always thick with mud. The scarcity of running water on the Kaibab has been mentioned. Yet the precipitation is comparatively great and the evaporation small. It is apparent that all the water which falls upon its vast expanse, with the exception of a slight percentage evaporated, must sink into the earth, where it is doubtless gathered in subterranean drainage channels which open in the profound depths of the great amphitheaters of the Grand Cañon. In those depths are large creeks of perennial water issuing from the openings of those underground passages. This implies a system of subterranean rivulets, but it is not more wonderful than the endless caverns in the limestones of Kentucky and Indiana, and it is probably not upon so large a scale nor so greatly ramified. It also argues a high degree of permeability both in the upper strata and in the overmantling soil. The water sifts through them as easily as through sand, and rarely gathers into streams even in the most copious showers or most rapid melting of the snow. Whether these "lagoons" and "sink-holes," as we termed them, are the openings of pipes leading down into the subterranean rivers and kept open by a gradual solution of the limestone, it is difficult to say. There are some difficultes in the way of this theory.

Moving rapidly southward, at length we reach the Sylvan Gate at the lower end. Passing through we immediately find ourselves at the head of a second park very similar to De Motte's, but smaller, having a length of nearly three miles. It is named Little De Motte Park, and the Sylvan Gate occupies a divide between the two. It contains a large lagoon holding stagnant water. There is a chain of these parks reaching from the northern end of De Motte's southward, a distance of 25 miles, separated only by necks of forest.

Our first objective point is a spring situated in one of the large ravines which head in the heights overlooking these two parks. Without some foreknowledge of the way to reach it, or without a guide, it would be impossible to find it, and the same is true of any other spring on the summit, but with this foreknowledge we seek the southwestern border of Little De Motte and enter the timber. During half an hour there is a miserable struggle with fallen trees and thick set branches of spruce and aspen, but at length the heights are gained, and we descend into a shallow ravine where the way is once more open. The winding glade with smooth bottom richly carpeted with long green grass, aglow with myriads of beautiful blossoms is before us, and the tall trees are on either hand. Soon it leads into a larger one, and this into another, until at last the main ravine is reached. Very sweet and touching now are the influences of nature. The balmy air, the dark and somber spruces, the pale green aspens, the golden shafts of sunlight shot through their foliage, the velvet sward—surely this is the home of the woodland nymphs, and at every turn of the way we can fancy we are about to see them flying at our approach, or peeping at us from the flowery banks.

By half-past ten the spring is reached. Next to the Big Spring, in Stewart's Cañon, it is the largest on the summit of the plateau. Here, too, is the only semblance of running water, for the stream flows a little more than half a mile before it sinks. The water is cold and delicious. It has a faint whitish cast like that which would be produced by putting a drop or two of milk into a bucket of pure water. I presume it is caused by a fine precipitate of lime. We called it the "Milk Spring." Pausing here for a hasty lunch, and to fill the kegs (for to-night we may make a "dry" camp), we push on. We climb out of the ravine, and in fact we only came here to obtain water, as it is the only place near to the point of destination at which water can be procured. The route now becomes more rugged, leading across ravines and over intervening ridges, crossing the grain of the country, so to speak. But it is not difficult, for the pines have taken place of the spruces, and where the pines predominate the forest is very open. For eight miles from the Milk Spring we continue to cross hills and valleys, then follow a low swale shaded by giant pines with trunks three to four feet in thickness. The banks are a parterre of flowers. On yonder hillside, beneath one of these kingly trees, is a spot which seems to glow with an unwonted wealth of floral beauty. It is scarcely a hundred yards distant; let us pluck a bouquet from it. We ride up the slope.

The earth suddenly sinks at our feet to illimitable depths. In an instant, in the twinkling of an eye, the awful scene is before us.

CHAPTER VII.

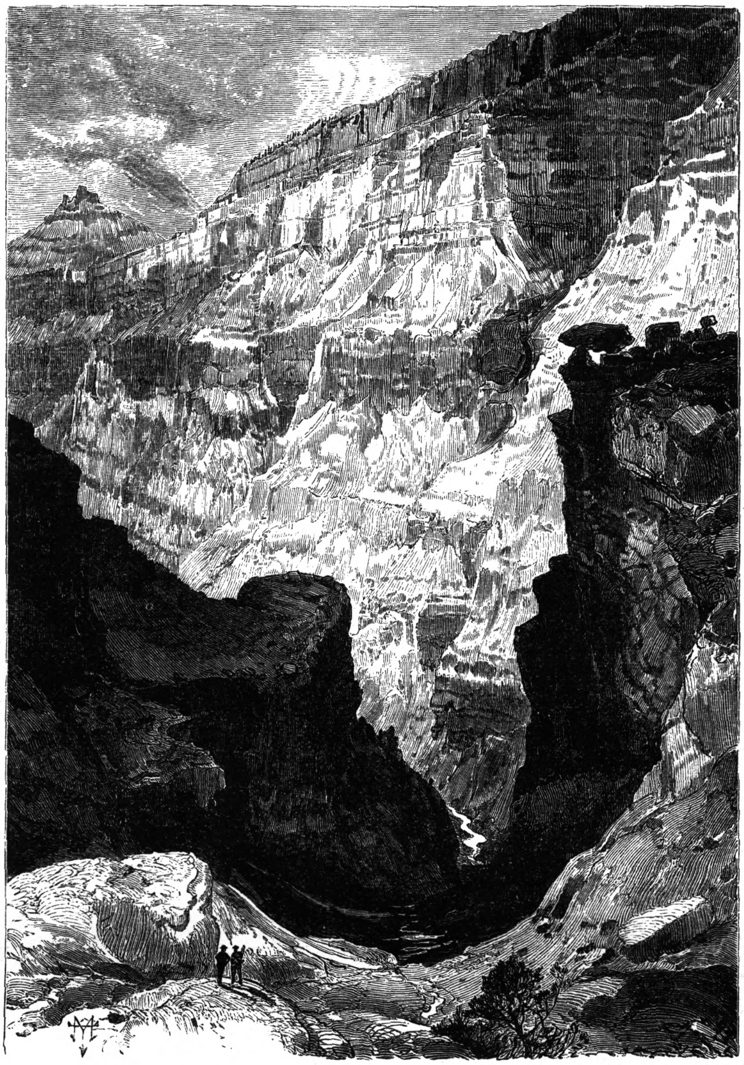
POINT SUBLIME.

Wherever we reach the Grand Cañon in the Kaibab it bursts upon the vision in a moment. Seldom is any warning given that we are near the brink. At the Toroweap it is quite otherwise. There we are notified that we are near it a day before we reach it. As the final march to that portion of the chasm is made the scene gradually develops, growing by insensible degrees more grand until at last we stand upon the brink of the inner gorge, where all is before us. In the Kaibab the forest reaches to the sharp edge of the cliff and the pine trees shed their cones into the fathomless depths below.

If the approach is made at random, with no idea of reaching any particular point by a known route, the probabilities are that it is first seen from the rim of one of the vast amphitheaters which set back from the main chasm far into the mass of the plateau. It is such a point to which the reader has been brought in the preceding chapter. Of course there are degrees in the magnitude and power of the pictures presented, but the smallest and least powerful is tremendous and too great for comprehension. The scenery of the amphitheaters far surpasses in grandeur and nobility anything else of the kind in any other region, but it is mere by-play in comparison with the panorama displayed in the heart of the cañon. The supreme views are to be obtained at the extremities of the long promontories, which jut out between these recesses far into the gulf. Towards such a point we now direct our steps. The one we have chosen is on the whole the most commanding on the Kaibab front, though there are several others which might be regarded as very nearly equal to it, or as even more imposing in some respects. We named it *Point Sublime.*

The route is of the same character as that we have already traversed—open pine forest, with smooth and gently rolling ground. The distance from the point where we first touched the rim of the amphitheater is about five miles. Nothing is seen of the chasm until about a mile from the end we come once more upon the brink. Reaching the extreme verge the packs are cast off and sitting upon the edge we contemplate the most sublime and awe inspiring spectacle in the world.

The Grand Cañon of the Colorado is a great innovation in modern ideas of scenery, and in our conceptions of the grandeur, beauty, and power of nature. As with all great innovations it is not to be comprehended in a day or a week, nor even in a month. It must be dwelt upon and studied, and the study must comprise the slow acquisition of



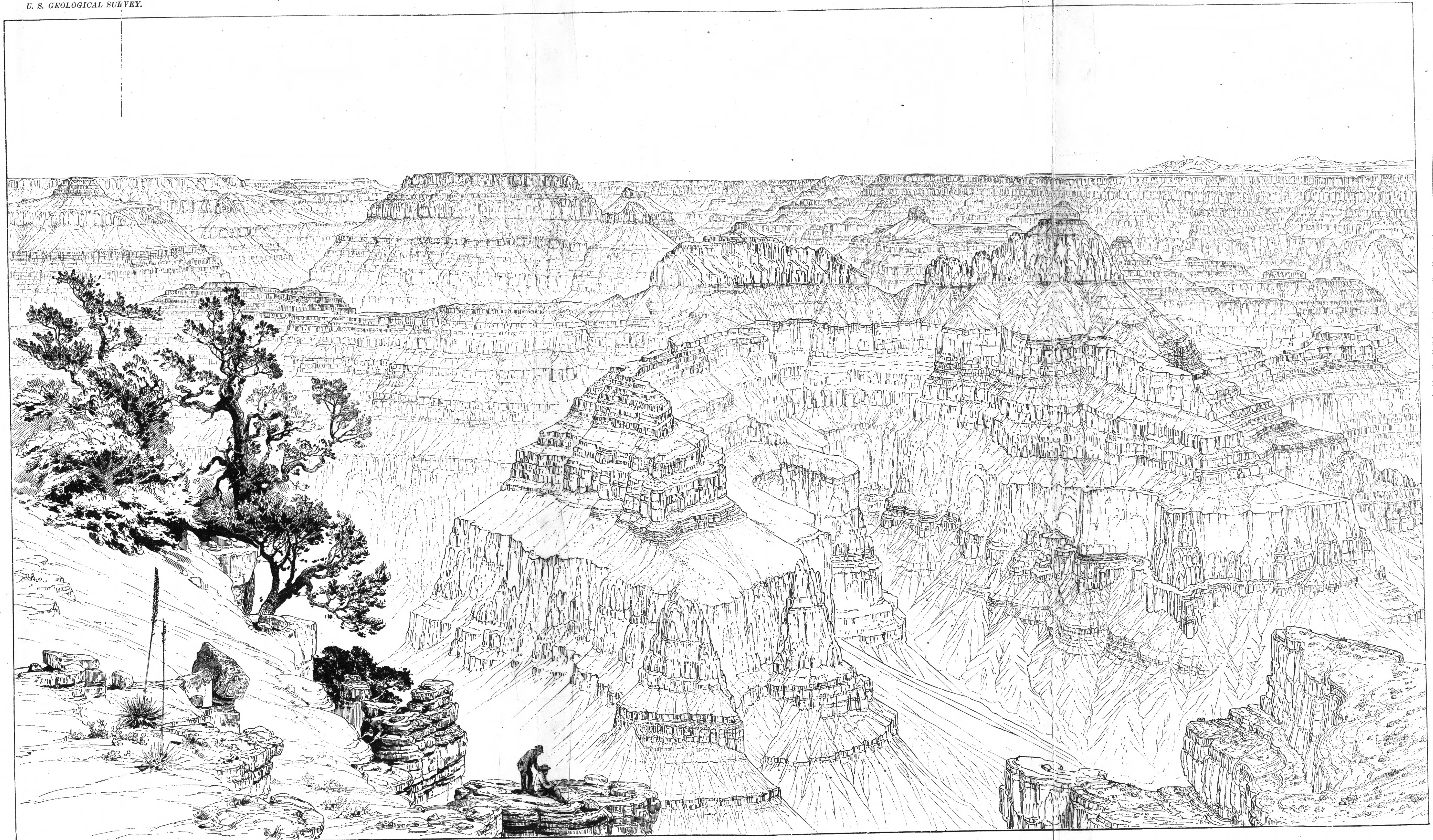
·14.—A lateral amphitheater of the second order.

the meaning and spirit of that marvelous scenery which characterizes the Plateau country, and of which the great chasm is the superlative manifestation. The study and slow mastery of the influences of that class of scenery and its full appreciation is a special culture, requiring time, patience, and long familiarity for its consummation. The lover of nature, whose perceptions have been trained in the Alps, in Italy, Germany, or New England, in the Appalachians or Cordilleras, in Scotland or Colorado, would enter this strange region with a shock, and dwell there for a time with a sense of oppression, and perhaps with horror.

Whatsoever things he had learned to regard as beautiful and noble he would seldom or never see, and whatsoever he might see would appear to him as anything but beautiful and noble. Whatsoever might be bold and striking would at first seem only grotesque. The colors would be the very ones he had learned to shun as tawdry and bizarre. The tones and shades modest and tender, subdued yet rich, in which his fancy had always taken special delight, would be the ones which are conspicuously absent. But time would bring a gradual change. Some day he would suddenly become conscious that outlines which at first seemed harsh and trivial have grace and meaning; that forms which seemed grotesque are full of dignity; that magnitudes which had added enormity to coarseness have become replete with strength and even majesty; that colors which had been esteemed unrefined, immodest, and glaring, are as expressive, tender, changeful, and capacious of effects as any others. Great innovations, whether in art or literature, in science or in nature, seldom take the world by storm. They must be understood before they can be estimated, and must be cultivated before they can be understood.

It is so with the Grand Cañon. The observer who visits its commanding points with the expectation of experiencing forthwith a rapturous exaltation, an ecstacy arising from the realization of a degree of grandeur and sublimity never felt before, is doomed to disappointment. Supposing him to be but little familiar with plateau scenery, he will be simply bewildered. Must he therefore pronounce it a failure, an overpraised thing? Must he entertain a just resentment towards those who may have raised his expectations too high? The answer is that subjects which disclose their full power, meaning, and beauty as soon as they are presented to the mind have very little of those qualities to disclose. Moreover a visitor to the chasm or to any other famous scene must necessarily come there (for so is the human mind constituted) with a picture of it created by his own imagination. He reaches the spot, the conjured picture vanishes in an instant, and the place of it must be filled anew. Surely no imagination can construct out of its own material any picture having the remotest resemblance to the Grand Cañon. In truth the first step in attempting a description is to beg the reader to dismiss from his mind, so far as practicable, any preconceived notion of it.

Those who have long and carefully studied the Grand Cañon of the Colorado do not hesitate for a moment to pronounce it by far the most sublime of all earthly spectacles. If its sublimity consisted only in its dimensions, it could be sufficiently set forth in a single sentence. It is more than 200 miles long, from 5 to 12 miles wide, and from 5,000 to 6,000 feet deep. There are in the world valleys which are longer and a few which are deeper. There are valleys flanked by summits loftier than the palisades of the Kaibab. Still the Grand Cañon is the sublimest thing on earth. It is so not alone by virtue of its magnitudes, but by virtue of the whole—its *ensemble*.



THE PANORAMA FROM POINT SUBLIME—LOOKING EAST.

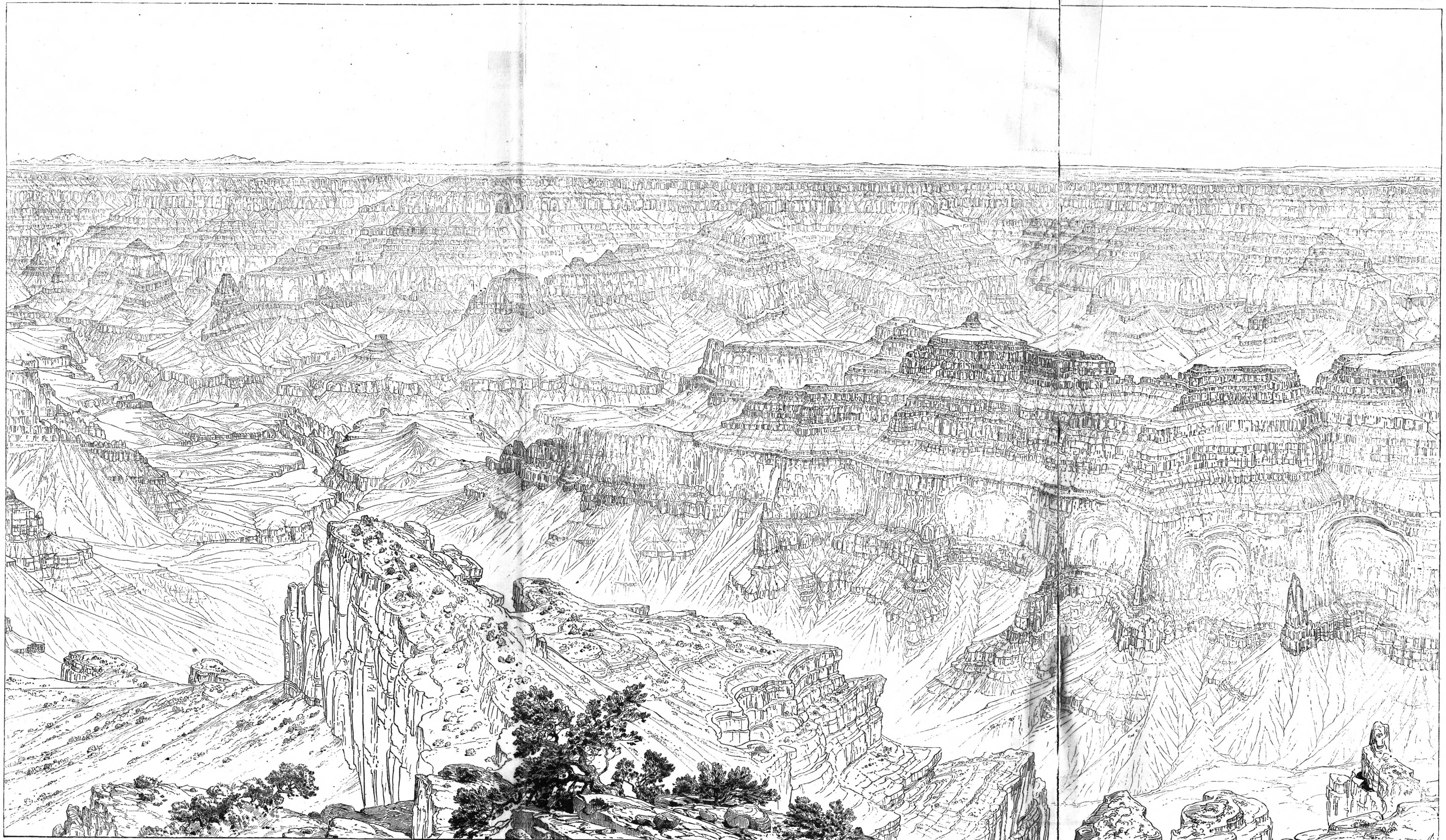
The common notion of a cañon is that of a deep, narrow gash in the earth, with nearly vertical walls like a great and neatly cut trench. There are hundreds of chasms in the Plateau country which answer very well to this notion. Many of them are sunk to frightful depths and are fifty to a hundred miles in length. Some are exceedingly narrow, as the cañons of the forks of the Virgen, where the overhanging walls shut out the sky. Some are intricately sculptured, and illuminated with brilliant colors; others are picturesque by reason of their bold and striking sculpture. A few of them are most solemn and impressive by reason of their profundity and the majesty of their walls. But as a rule the common cañons are neither grand nor even attractive. Upon first acquaintance they are curious and awaken interest as a new sensation, but they soon grow tiresome for want of diversity, and become at last mere bores. The impressions they produce are very transient, because of their great simplicity and the limited range of ideas they present. But there are some which are highly diversified, presenting many attractive features. These seldom grow stale or wearisome, and their presence is generally greeted with pleasure.

It is perhaps in some respects unfortunate that the stupendous pathway of the Colorado River through the Kaibabs was ever called a cañon, for the name identifies it with the baser conception. But the name presents as wide a range of signification as the word house. The log cabin of the rancher, the painted and vine-clad cottage of the mechanic, the home of the millionnaire, the places where parliaments assemble, and the grandest temples of worship, are all houses. Yet the contrast between Saint Marc's and the rude dwelling of the frontiersman is not greater than that between the chasm of the Colorado and the trenches in the rocks which answer to the ordinary conception of a cañon. And as a great cathedral is an immense development of the rudimentary idea involved in the four walls and roof of a cabin, so is the chasm an expansion of the simple type of drainage channels peculiar to the Plateau country. To the conception of its vast proportions must be added some notion of its intricate plan, the nobility of its architecture, its colossal buttes, its wealth of ornamentation, the splendor of its colors, and its wonderful atmosphere. All of these attributes combine with infinite complexity to produce a whole which at first bewilders and at length overpowers.

From the end of Point Sublime, the distance across the chasm to the nearest point in the summit of the opposite wall, is about 7 miles. This, however does not fairly express the width of the chasm, for both walls are recessed by wide amphitheaters, setting far back into the platform of the country and the promontories are comparatively narrow strips between them. A more correct statement of the general width would be from 11 to 12 miles This must dispose at once of the idea that the chasm is a narrow gorge of immense depth and simple form. It is somewhat unfortunate that there is a prevalent idea that in some way an essential part of the grandeur of the Grand Cañon is the narrowness of its defiles. Much color has been given to this notion by the first illustrations of the cañon from the pencil of Egloffstein in the celebrated report of Lieutenant Ives. Never was a great subject more artistically misrepresented or more charmingly belittled. Nowhere in the Kaibab section is any such extreme narrowness observable, and even in the Uinkaret section the width of the great inner gorge is a little greater than the depth. In truth a little reflection will show that such a character would be inconsistent with the highest and strongest effects. For it is obvious that some notable width is necessary to enable the eye to see the full extent of the walls. In a chasm one mile deep, and only a thousand feet wide, this would be quite impossible. If we compare the Marble Cañon or the gorge at the Toroweap with wider sections it will at once be seen that the wider ones are much stronger. If we compare one of the longer alcoves having a width of 3 or 4 miles with the view across the main chasm the advantage will be very decidedly with the latter. It is evident that for the display of wall surface of given dimensions a certain amount of distance is necessary. We may be too near or too far for the right appreciation of its magnitude and proportions. The distance must bear some ratio to the magnitude. But at what precise limit this distance must in the present case be fixed is not easy to determine. It can hardly be doubted that if the cañon were materially narrower it would suffer a loss of grandeur and effect.

The length of cañon revealed clearly and in detail at Point Sublime is about 25 miles in each direction. Towards the northwest the vista terminates behind the projecting mass of Powell's Plateau. But again to the westward may be seen the crests of the upper walls reaching through the Kanab and Uinkaret Plateaus, and finally disappearing in the haze about 75 miles away.

The space under immediate view from our stand-point, 50 miles long and 10 to 12 wide, is thronged with a great multitude of objects so vast in size, so bold and majestic in form, so infinite in their details, that as the truth gradually reveals itself to the perceptions it arouses the strongest emotions. Unquestionably the overruling feature is the colossal wall on the opposite side of the gulf. Can mortal fancy create a picture of a mural front a mile in height, 7 to 10 miles distant, and receding into space indefinitely in either direction? As the mind strives to realize its proportions its spirit is broken and its imagination completely crushed. If the wall were simple in its character, if it were only blank and sheer, some rest might be found in contemplating it; but it is full of diversity and eloquent with grand suggestions. It is deeply recessed by alcoves and amphitheaters receding far into the plateau beyond, and usually disclosing only the portals by which they open into the main chasm. Between them the promontories jut out, ending in magnificent gables with sharp mitered angles. Thus the wall rambles in and out, turning numberless corners. Many of the angles are acute and descend as sharp



THE PANORAMA FROM POINT SUBLIME—LOOKING SOUTH.

spurs like the forward edge of a plowshare. Only those alcoves which are directly opposite to us can be seen in their full length and depth. Yet so excessive, nay so prodigious, is the effect of foreshortening, that it is impossible to realize their full extensions. We have already noted this effect in the Vermilion Cliffs, but here it is much more exaggerated. At many points the profile of the façade is thrown into view by the change of trend, and its complex character is fully revealed. Like that of the Vermilion Cliffs, it is a series of many ledges and slopes, like a molded plinth, in which every stratum is disclosed as a line or a course of masonry. The Red Wall limestone is the most conspicuous member, presenting its vertical face eight hundred to a thousand feet high, and everywhere unbroken. The thinner beds more often appear in the slopes as a succession of ledges projecting through the scanty talus which never conceals them.

Numerous detached masses are also seen flanking the ends of the long promontories. These buttes are of gigantic proportions, and yet so overwhelming is the effect of the wall against which they are projected that they seem insignificant in mass, and the observer is often deluded by them, failing to perceive that they are really detached from the wall and perhaps separated from it by an interval of a mile or two.

At the foot of this palisade is a platform through which meanders the inner gorge in whose dark and somber depths flows the river. Only in one place can the water surface be seen. In its windings the abyss, which holds it extends for a short distance towards us and the line of vision enters the gorge lengthwise. Above and below this short reach the gorge swings its course in other directions and reveals only a dark, narrow opening, while its nearer wall hides its depths. This inner chasm is 1,000 to 1,200 feet deep. Its upper 200 feet is a vertical ledge of sandstone of a dark rich brownish color. Beneath it lies the granite of a dark iron-gray shade, verging towards black, and lending a gloomy aspect to the lowest deeps. Perhaps a half mile of the river is disclosed. A pale, dirty red, without glimmer or sheen, a motionless surface, a small featureless spot, inclosed in the dark shade of the granite, is all of it that is here visible. Yet we know it is a large river, a hundred and fifty yards wide, with a headlong torrent foaming and plunging over rocky rapids.

A little, and only a little, less impressive than the great wall across the chasm are the buttes upon this side. And such buttes! All others in the West, saving only the peerless Temples of the Virgen, are mere trifles in comparison with those of the Grand Cañon. In nobility of form, beauty of decoration, and splendor of color, the Temples of the Virgen must, on the whole, be awarded the palm; but those of the Grand Cañon, while barely inferior to them in those respects, surpass them in magnitude and fully equal them in majesty. But while the Valley of the Virgen presents a few of these superlative creations, the Grand Cañon presents them by dozens. In this relation the comparison would be analogous to one between a fine cathedral town and a metropolis like London or Paris. In truth, there is only a very limited ground of comparison between the two localities, for in style and effects their respective structures differ as decidedly as the works of any two well developed and strongly contrasted styles of human architecture.

Whatsoever is forcible, characteristic, and picturesque in the rock-forms of the Plateau country is concentrated and intensified to the uttermost in the buttes. Wherever we find them, whether fringing the long escarpments of terraces or planted upon broad mesas, whether in cañons or upon expansive plains, they are always bold and striking in outline and ornate in architecture. Upon their flanks and entablatures the decoration peculiar to the formation out of which they have been carved is most strongly portrayed and the profiles are most sharply cut. They command the attention with special force and quicken the imagination

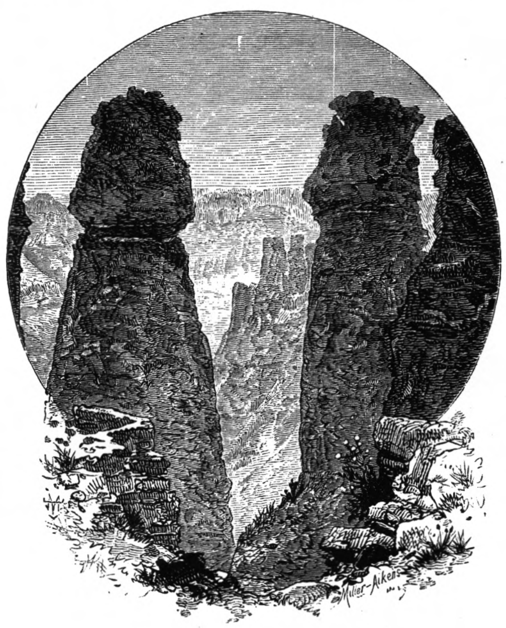
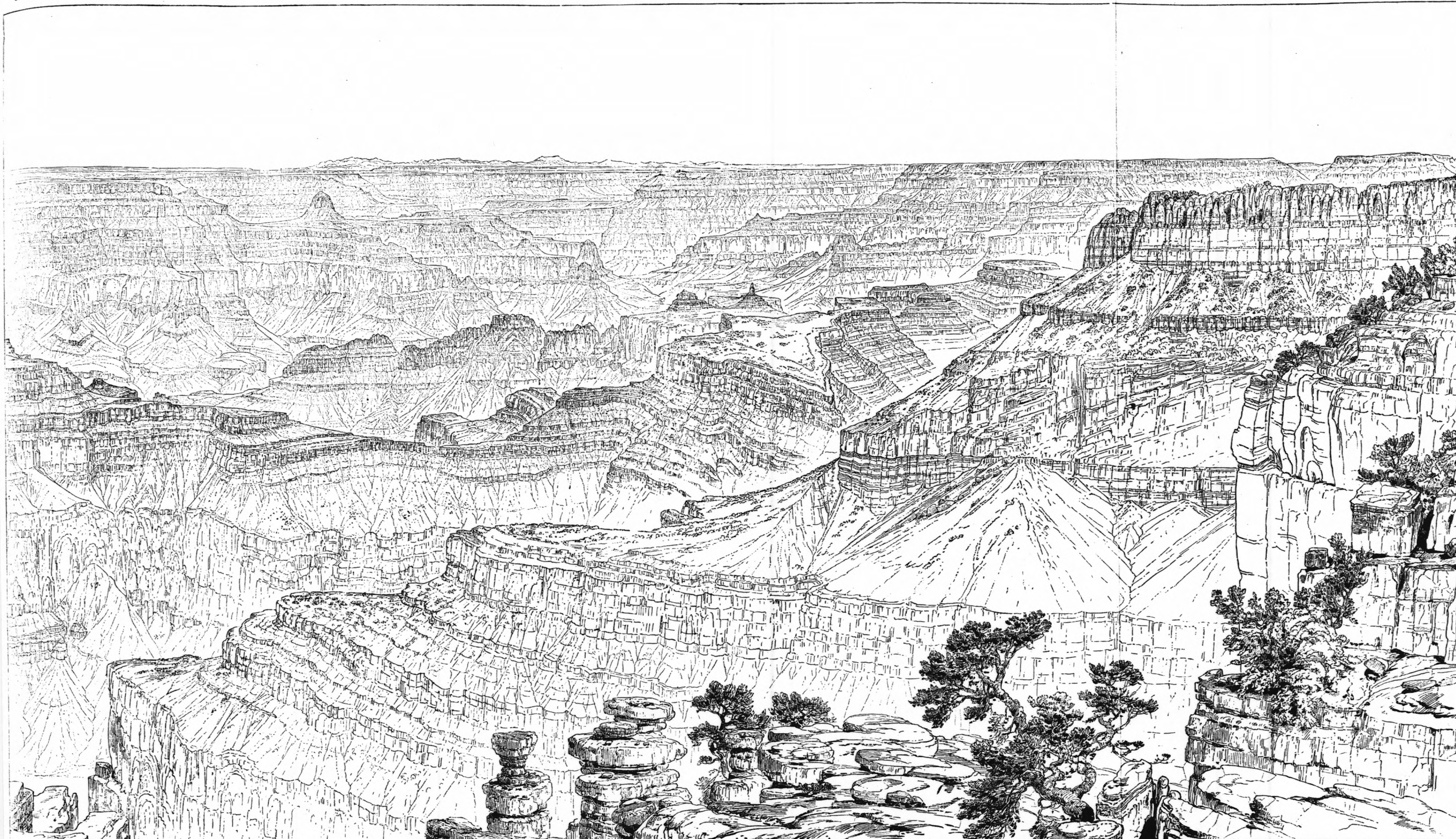


FIG. 15.—Pinnacles on the brink.

with a singular power. The secret of their impressiveness is doubtless obscure. Why one form should be beautiful and another unattractive; why one should be powerful, animated, and suggestive, while another is meaningless, are questions for the psychologist rather than the geologist. Sufficient here is the fact. Yet there are some elements of impressiveness which are too patent to escape recognition. In nearly all buttes there is a certain *definiteness* of form which is peculiarly emphatic, and this is seen in their profiles. Their ground-plans are almost always indefinite and capricious, but the profiles are rarely so. These are usually composed of lines which have an approximate and sometimes



THE PANORAMA FROM POINT SUBLIME—LOOKING WEST.

a sensibly perfect geometrical definition. They are usually few and simple in their ultimate analysis, though by combination they give rise to much variety. The ledges are vertical, the summits are horizontal, and the taluses are segments of hyperbolas of long curvature and concave upwards. These lines greatly preponderate in all cases, and though others sometimes intrude they seldom blemish greatly the effects produced by the normal ones. All this is in striking contrast with the ever-varying, indefinite profiles displayed in mountains and hills or on the slopes of valleys. The profiles generated by the combinations of these geometric lines persist along an indefinite extent of front. Such variations as occur arise not from changes in the nature of the lines, but in the modes of combination and proportions. These are never great in any front of moderate extent, but are just sufficient to relieve it from a certain monotony which would otherwise prevail. The same type and general form is persistent. Like the key-note of a song, the mind carries it in its consciousness wherever the harmony wanders.

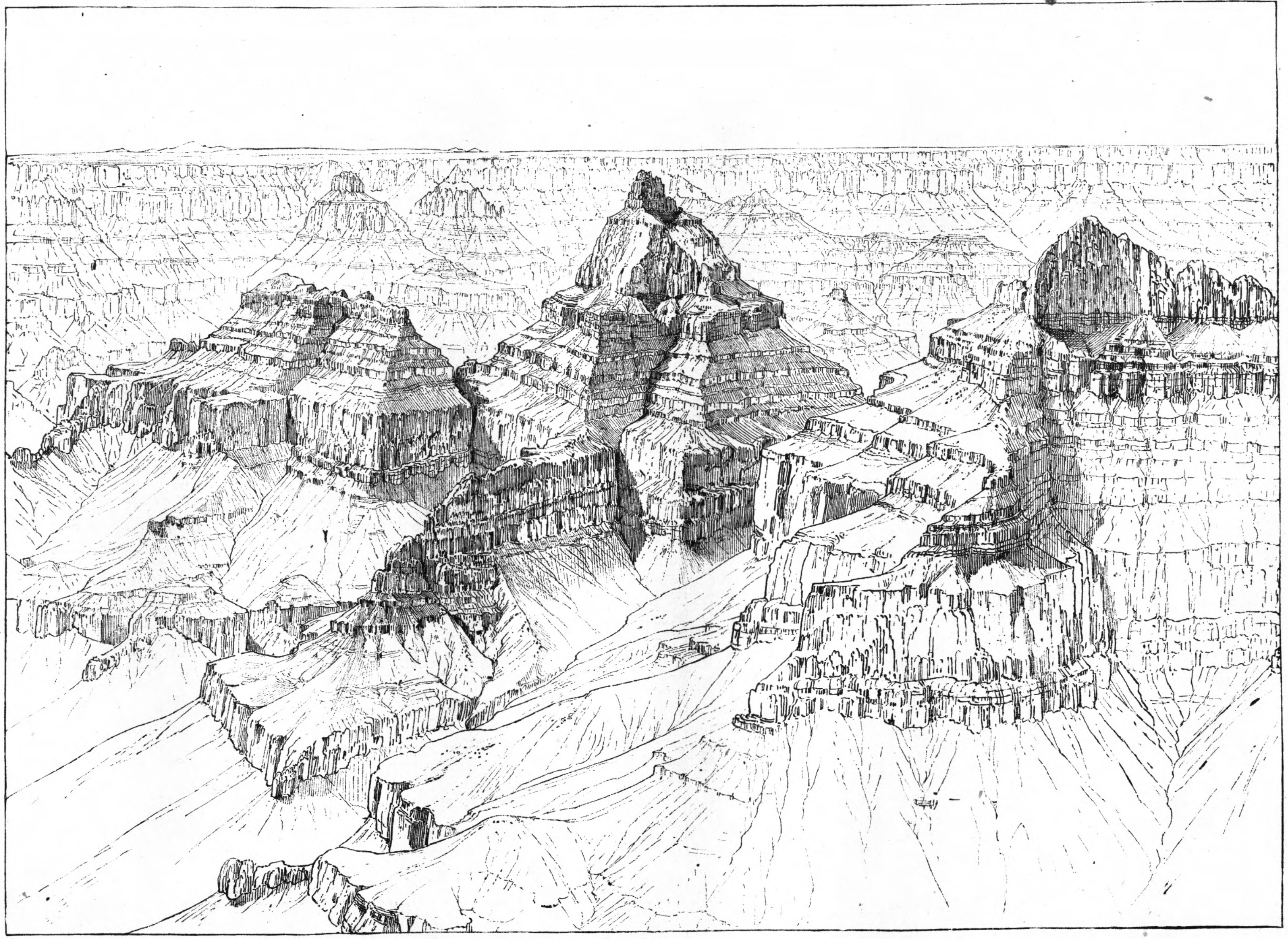
The horizontal lines or courses are equally strong. These are the edges of the strata, and the deeply eroded seams where the superposed beds touch each other. Here the uniformity as we pass from place to place is conspicuous. The Carboniferous strata are quite the same in every section, showing no perceptible variation in thickness through great distances and only a slight dip.

It is readily apparent, therefore, that the effect of these profiles and horizontal courses so persistent in their character is highly architectural. The relation is more than a mere analogy or suggestion; it is a vivid resemblance. Its failure or discordance is only in the ground plan, though it is not uncommon to find a resemblance, even in this respect, among the Permian buttes. Among the buttes of the Grand Cañon there are few striking instances of definiteness in ground plan. The finest butte of the chasm is situated near the upper end of the Kaibab division; but it is not visible from Point Sublime. It is more than 5,000 feet high, and has a surprising resemblance to an Oriental pagoda. We named it Vishnu's Temple.

On either side of the promontory on which we stand is a side gorge sinking nearly 4,000 feet below us. The two unite in front of the point, and, ever deepening, their trunk opens into the lowest abyss in the granite at the river. Across either branch is a long rambling mass, one on the right of us the other on the left. We named them the Cloisters. They are excellent types of a whole class of buttes which stand in close proximity to each other upon the north side of the chasm throughout the entire extent of the Kaibab division. A far better conception of their forms and features can be gained by an examination of Mr. Holmes's panoramic picture than by reading a whole volume of verbal description. The whole prospect, indeed, is filled with a great throng of similar objects, which, as much by their multitude as by their colossal size, confuse the senses; but these, on account of their proximity, may be most satisfactorily studied. The infinity of sharply defined detail is amazing. The eye is instantly caught and the attention firmly held by its systematic character. The parallelism of the lines of bedding is most forcibly displayed in all the windings of the facades, and these lines are crossed by the vertical scorings of numberless water-ways. Here, too, are distinctly seen those details which constitute the peculiar style of decoration prevailing throughout all the buttes and amphitheaters of the Kaibab. The course of the walls is never for a moment straight, but extends as a series of cusps and re-entrant curves. Elsewhere the reverse is more frequently seen; the projections of the wall are rounded and are convex towards the front, while the re-entrant portions are cusp-like recesses. This latter style of decoration is common in the Permian buttes and is not rare in the Jurassic. It produces the effect of a thickly set row of pilasters. In the Grand Cañon the reversal of this mode produces the effect of panels and niches. In the western Cloister may be seen a succession of these niches, and though they are mere details among myriads, they are really vast in dimensions. Those seen in the Red Wall limestone are over 700 feet high, and are overhung by arched lintels with spandrels.

As we contemplate these objects we find it quite impossible to realize their magnitude. Not only are we deceived, but we are conscious that we are deceived, and yet we cannot conquer the deception. We cannot long study our surroundings without becoming aware of an enormous disparity in the effects produced upon the senses by objects which are immediate and equivalent ones which are more remote. The depth of the gulf which separates us from the Cloisters cannot be realized. We crane over the brink, and about 700 feet below is a talus, which ends at the summit of the cross-bedded sandstone. We may see the bottom of the gorge, which is about 3,800 feet beneath us, and yet the talus seems at least half way down. Looking across the side gorge the cross-bedded sandstone is seen as a mere band at the summit of the Cloister, forming but a very small portion of its vertical extent, and whatever the reason may conclude, it is useless to attempt to persuade the imagination that the two edges of the sandstone lie in the same horizontal plane. The eastern Cloister is nearer than the western, its distance being about a mile and a half. It seems incredible that it can be so much as one-third that distance. Its altitude is from 3,500 to 4,000 feet, but any attempt to estimate the altitude by means of visual impressions is felt at once to be hopeless. There is no stadium. Dimensions mean nothing to the senses, and all that we are conscious of in this respect is a troubled sense of immensity.

Beyond the eastern Cloister, five or six miles distant, rises a gigantic mass which we named Shiva's Temple. It is the grandest of all the buttes, and the most majestic in aspect, though not the most ornate. Its mass is as great as the mountainous part of Mount Washington. That summit looks down 6,000 feet into the dark depths of the inner



VISHNU'S TEMPLE—HEAD OF THE GRAND CAÑON.

abyss, over a succession of ledges as impracticable as the face of Bunker Hill Monument. All around it are side gorges sunk to a depth nearly as profound as that of the main channel. It stands in the midst of a great throng of cloister-like buttes, with the same noble profiles and strong lineaments as those immediately before us, with a plexus of awful chasms between them. In such a stupendous scene of wreck it seemed as if the fabled "Destroyer" might find an abode not wholly uncongenial.

In all the vast space beneath and around us there is very little upon which the mind can linger restfully. It is completely filled with objects of gigantic size and amazing form, and as the mind wanders over them it is hopelessly bewildered and lost. It is useless to select special points of contemplation. The instant the attention lays hold of them it is drawn to something else, and if it seeks to recur to them it cannot find them. Everything is superlative, transcending the power of the intelligence to comprehend it. There is no central point or object around which the other elements are grouped and to which they are tributary. The grandest objects are merged in a congregation of others equally grand. Hundreds of these mighty structures, miles in length, and thousands of feet in height, rear their majestic heads out of the abyss, displaying their richly-molded plinths and friezes, thrusting out their gables, wing-walls, buttresses, and pilasters, and recessed with alcoves and panels. If any one of these stupendous creations had been planted upon the plains of Central Europe it would have influenced modern art as profoundly as Fusiyama has influenced the decorative art of Japan. Yet here they are all swallowed up in the confusion of multitude. It is not alone the magnitude of the individual objects that makes this spectacle so portentous, but it is still more the extravagant profusion with which they are arrayed along the whole visible extent of the broad chasm.

The color effects are rich and wonderful. They are due to the inherent colors of the rocks, modified by the atmosphere. Like any other great series of strata in the Plateau Province, the Carboniferous has its own range of characteristic colors, which might serve to distinguish it even if we had no other criterion. The summit strata are pale gray, with a, faint yellowish cast. Beneath them the cross-bedded sandstone appears showing a mottled surface of pale pinkish hue. Underneath this member are nearly 1,000 feet of the lower Aubrey sandstones, displaying an intensely brilliant red, which is somewhat masked by the talus shot down from the grey, cherty limestones at the summit. Beneath the lower Aubrey is the face of the Red Wall limestone, from 2,000 to 3,000 feet high. It has a strong red color, but a very peculiar one. Most of the red strata of the west have the brownish or vermilion tones, but these are rather purplish-red, as if the pigment had been treated to a dash of blue. It is not quite certain that this may not arise in part from the intervention of the blue haze, and probably it is rendered more conspicuous by this cause; but, on the whole, the purplish cast seems to be inherent. This is the dominant color-mass of the cañon, for the expanse of rock surface displayed is more than half in the Red Wall group. It is less brilliant than the fiery red of the Aubrey sandstones, but is still quite strong and rich. Beneath are the deep browns of the lower Carboniferous. The dark iron-black of the hornblendic schists revealed in the lower gorge makes but little impression upon the boundless expanse of bright colors above.

The total effect of the entire color-mass is bright and glowing. There is nothing gloomy or dark in the picture except the opening of the inner gorge, which is too small a feature to influence materially the prevailing tone. Although the colors are bright when contrasted with normal landscapes, they are decidedly less intense than the flaming hues of the Trias or the dense cloying colors of the Permian; nor have they the refinement of those revealed in the Eocene. The intense luster which gleams from the rocks of the Plateau country is by no means lost here but is merely subdued and kept under some restraint. It is toned down and softened without being deprived of its character. Enough of it is left to produce color effects not far below those that are yielded by the Jura-Trias.

But though the inherent colors are less intense than some others, yet under the quickening influence of the atmosphere they produce effects to which all others are far inferior. And here language fails and description becomes impossible. Not only are their qualities exceedingly subtle, but they have little counterpart in common experience. If such are presented elsewhere they are presented so feebly and obscurely that only the most discriminating and closest observers of nature ever seize them, and they so imperfectly that their ideas of them are vague and but half real. There are no concrete notions founded in experience upon which a conception of these color effects and optical delusions can be constructed and made intelligible. A perpetual glamour envelops the landscape. Thing are not what they seem, and the perceptions cannot tell us what they are. It is not probable that these effects are different in kind in the Grand Cañon from what they are in other portions of the Plateau country. But the difference in degree is immense, and being greatly magnified and intensified many characteristics become palpable which elsewhere elude the closest observation.

In truth, the tone and temper of the landscape are constantly varying, and the changes in its aspect are very great. It is never the same, even from day to day, or even from hour to hour. In the early morning its mood and subjective influences are usually calmer and more full of repose than at other times, but as the sun rises higher the whole scene is so changed that we cannot recall our first impressions. Every passing cloud, every change in the position of the sun recasts the whole. At sunset the pageant closes amid splendors that seem more than earthly. The direction of the full sunlight, the massing of the shadows, the manner in which the side-lights are thrown in from the clouds determine these modulations, and the sensitiveness of the picture to the slightest variations in these conditions is very wonderful.

The shadows thrown by the bold abrupt forms are exceedingly dark. It is almost impossible at the distance of a very few miles to distinguish even broad details in these shadows. They are like remnants of midnight unconquered by the blaze of noonday. The want of half tones and gradations in the light and shade, which has already been noted in the Vermilion Cliffs, is apparent here, and is far more conspicuous. Our thoughts in this connection may suggest to us a still more extreme case of a similar phenomenon presented by the half-illuminated moon when viewed through a large telescope. The portions which catch the sunlight shine with great luster but the shadows of mountains and cliffs are black and impenetrable. But there is one feature in the cañon which is certainly extraordinary. It is the appearance of the atmosphere against the background of shadow. It has a metallic luster which must be seen to be appreciated. The great wall across the chasm presents at noonday, under a cloudless sky, a singularly weird and unearthly aspect. The color is for the most part gone. In place of it comes this metallic glare of the haze. The southern wall is never so poorly lighted as at noon. Since its face consists of a series of promontories projecting towards the north, these projections catch the sunlight on their eastern sides in the forenoon, and upon their western sides in the afternoon; but near meridian the rays fall upon a few points only, and even upon these with very great obliquity. Thus at the hours of greatest general illumination the wall is most obscure and the abnormal effects are then presented most forcibly. They give rise to strange delusions. The rocks then look nearly black, or very dark grey and covered with feebly shining spots. The haze is strongly luminous, and so dense as to obscure the details already enfeebled by shade as if a leaden or mercurial vapor intervened. The shadows antagonize the perspective, and everything seems awry. The lines of stratification, dimly seen in one place and wholly effaced in another, are strangely belied and the strata are given apparent attitudes which are sometimes grotesque and sometimes impossible.

Those who are familiar with western scenery have, no doubt, been impressed with the peculiar character of its haze, or atmosphere in the artistic sense of the word, and have noted its more prominent qualities. When the air is free from common smoke it has a pale blue color which is quite unlike the neutral gray of the east. It is always apparently more dense when we look towards the sun than when we look away from it, and this difference in the two directions, respectively, is a maximum near sunrise and sunset. This property is universal, but its peculiarities in the Plateau Province become conspicuous when the strong rich colors of the rocks are seen through it. The very air is then visible. We see it, palpably, as a tenuous fluid and the rocks beyond it do not appear to be colored blue as they do in other regions but reveal themselves clothed in colors of their own. The Grand Cañon is ever full of this haze. It fills it to the brim. Its apparent density, as elsewhere, is varied according to the direction in which it is viewed and the position of the sun; but it seems also to be denser and more concentrated than elsewhere. This is really a delusion arising from the fact that the enormous magnitude of the chasm and of its component masses dwarfs the distances; we are really looking through miles of atmosphere under the impression that they are only so many furlongs. This apparent concentration of haze, however, greatly intensifies all the beautiful or mysterious optical effects which are dependent upon the intervention of the atmosphere.

Whenever the brink of the chasm is reached the chances are that the sun is high and these abnormal effects in full force. The cañon is asleep. Or it is under a spell of enchantment which gives its bewildering mazes an aspect still more bewildering. Throughout the long summer forenoon the charm which binds it grows in potency. At midday the clouds begin to gather, first in fleecy flecks, then in cumuli and throw their shadows into the gulf. At once the scene changes. The slumber of the chasm is disturbed. The temples and cloisters seem to raise themselves half awake to greet the passing shadow. Their wilted, drooping, flattened faces expand into relief. The long promontories reach out from the distant wall as if to catch a moment's refreshment from the shade. The colors begin to glow; the haze loses its opaque density and becomes more tenuous. The shadows pass, and the chasm relapses into its dull sleep again. Thus through the midday hours it lies in fitful slumber, overcome by the blinding glare and withering heat, yet responsive to every fluctuation of light and shadow like a delicate organism.

As the sun moves far into the west the scene again changes, slowly and imperceptibly at first, but afterwards more rapidly. In the hot summer afternoons the sky is full of cloud-play and the deep flushes with ready answers. The banks of snowy clouds pour a flood of light sidewise into the shadows and light up the gloom of the amphitheaters and alcoves, weakening the glow of the haze and rendering visible the details of the wall faces. At length as the sun draws near the horizon the great drama of the day begins.

Throughout the afternoon the prospect has been gradually growing clearer. The haze has relaxed its steely glare and has changed to a veil of transparent blue. Slowly the myriads of details have come out and the walls are flecked with lines of minute tracery, forming a diaper of light and shade. Stronger and sharper becomes the relief of each projection. The promontories come forth from the opposite wall. The sinuous lines of stratification which once seemed meaningless, distorted, and even chaotic, now range themselves into a true perspective of graceful curves, threading the scallop edges of the strata. The colossal buttes expand in every dimension. Their long narrow wings, which once were folded together and flattened against each other, open out, disclosing between them vast alcoves illumined with Rembrandt lights tinged with the pale refined blue of the ever-present haze. A thousand forms, hitherto unseen or obscure, start up within the abyss, and stand forth in strength and animation. All things seem to grow in beauty, power, and dimensions. What was grand before has become majestic, the majestic becomes sublime, and, ever expanding and developing, the sublime passes beyond the reach of our faculties and becomes transcendent. The colors have come back. Inherently rich and strong, though not superlative under ordinary lights, they now begin to display an adventitious brilliancy. The western sky is all aflame. The scattered banks of cloud and wavy cirrhus have caught the waning splendor, and shine with orange and crimson. Broad slant beams of yellow light, shot through the glory-rifts, fall on turret and tower, on pinnacled crest, and winding ledge, suffusing them with a radiance less fulsome, but akin to that which flames in the western clouds. The summit band is brilliant yellow; the next below is pale rose. But the grand expanse within is a deep, luminous, resplendent red. The climax has now come. The blaze of sunlight poured over an illimitable surface of glowing red is flung back into the gulf, and, commingling with the blue haze, turns it into a sea of purple of most imperial hue—so rich, so strong, so pure that it makes the heart ache and the throat tighten. However vast the magnitudes, however majestic the forms, or sumptuous the decoration, it is in these kingly colors that the highest glory of the Grand Cañon is revealed.

At length the sum sinks and the colors cease to burn. The abyss lapses back into repose. But its glory mounts upward and diffuses itself in the sky above. Long streamers of rosy light, rayed out from the west, cross the firmament and converge again in the east ending in a pale rosy arch, which rises like a low aurora just above the eastern horizon. Below it is the dead gray shadow of the world. Higher and higher climbs the arch followed by the darkening pall of gray, and as it ascends it fades and disappears, leaving no color except the after-glow of the western clouds, and the lusterless red of the chasm below. Within the abyss the darkness gathers Gradually the shades deepen and ascend, hiding the opposite wall and enveloping the great temples. For a few moments the summits of these majestic piles seem to float upon a sea of blackness, then vanish in the darkness, and, wrapped in the impenetrable mantle of the night, they await the glory of the coming dawn.

CHAPTER VIII.

THE EXCAVATION OF THE CHASM.

The excavation of the Grand Cañon and the sculpture of its walls and buttes are the results of two processes acting in concert—*corrasion* and *weathering*. In discussing them it is necessary to take into the account the peculiar conditions under which they have operated; conditions which have no parallel in any other part of the world.

In common parlance it is customary to say, for brevity's sake, that the rivers have cut their cañons; but the expression states only a part of the truth. The river has in reality cut only a narrow trench no wider than the river's water surface. It has been the vehicle which has carried away to another part of the world the materials which have been torn from the strata by corrasion and weathering. Opening laterally into the main chasm are many amphitheaters excavated back into the platform of the country. At the bottom of each of them is a stream-bed over which in some cases a perennial river flows, while in other cases the flows are spasmodic. Like the trunk river these streams have corraded their channels to depths varying somewhat among themselves, but generally a little less than the depth of the central chasm. These tributaries often fork, and the forks are in the foregoing respects quite homologous to the main amphitheaters. Down the faces of the walls and down the steep slopes of the taluses run thousands of rain gullies. When the rain comes freely it gathers into rills which cascade down the wall clefts and rush headlong through the troughs in the talus carrying an abundance of sand and grit. These waters scour out their little channels in much the same way as their united waters cut down their beds in the amphitheaters of the second and first orders, and in the main chasm itself. But the work of flowing water, whether in the main channel or in an amphitheater, or in a gully or cranny of the cliff, is limited to two functions. The first is the cutting of a channel no wider than the surface of the stream; the second is the transportation of the débris. Corrasion alone then could never have made the Grand Cañon what it is. Another process, acting conjointly with corrasion and dependent upon it, has effected by far the greater part of the excavation. This other process is weathering. In order to comprehend their combined action it is necessary to study their action in detail, and to study also the special conditions under which they have operated here. We shall find the subject a very complicated one.

CORRASION.

Mr. G. K. Gilbert has embodied in his admirable monograph on the Henry Mountains, a chapter on Land Sculpture, which sets forth in most logical and condensed form the mechanical principles which enter into the problems of erosion. In his analysis may be found a discussion of the conditions under which the sculpturing forces and processes achieve such peculiar results as we observe in the Plateau country.

The perusal of that chapter will give to the geologist's comprehension of the subject a most delightful definiteness and precision, and the reader, however learned he may be, will take great satisfaction in finding a subject so complex made so intelligible. The principles laid down by Mr. Gilbert will be adopted here and applied. For that purpose I quote from the chapter referred to such statements as are of immediate service.

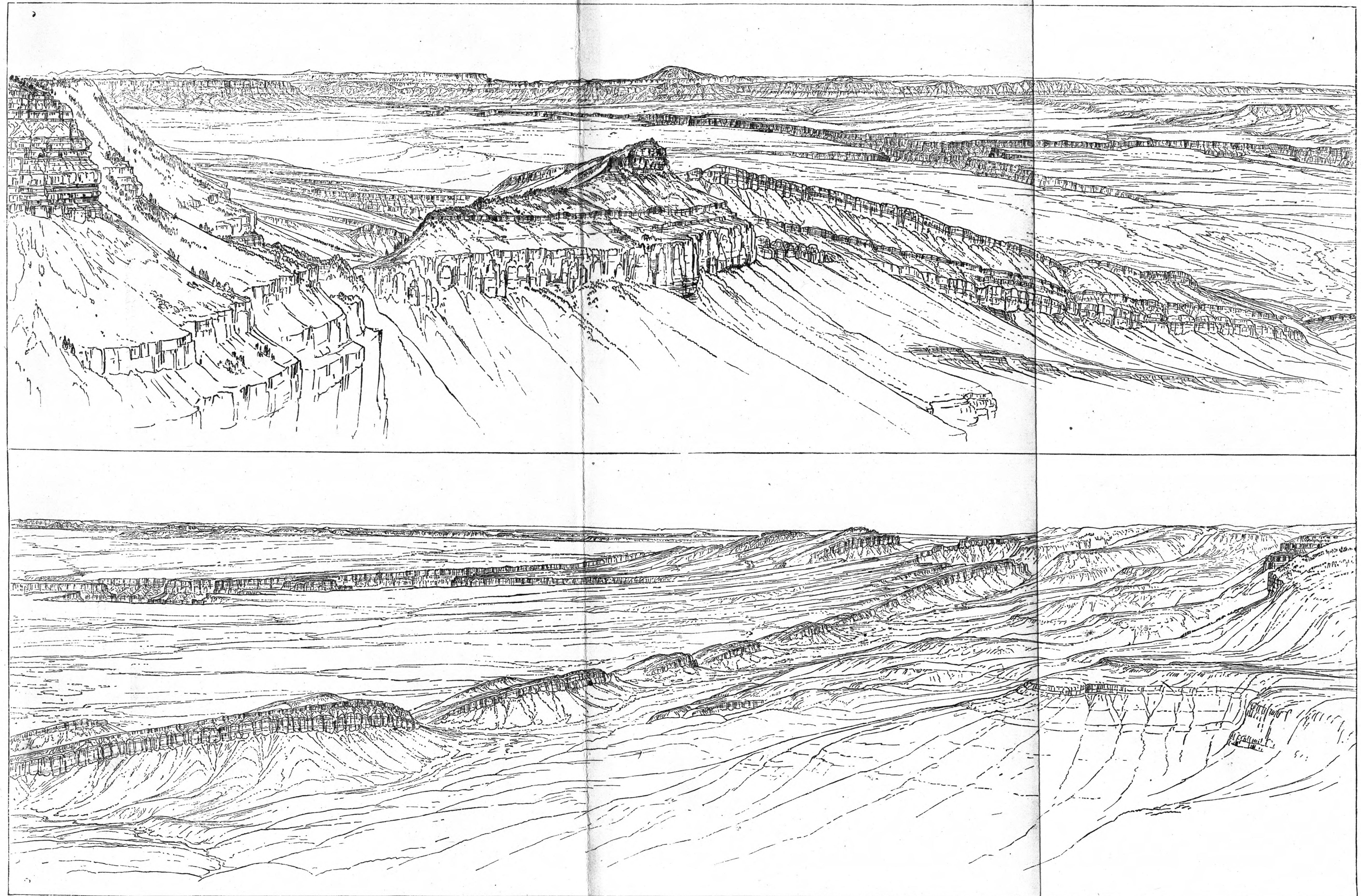
> The mechanical wear of streams is performed by the aid of hard mineral fragments carried along by the current. The effective force is that of the current; the tools are mud, sand, and bowlders. The most important of them is sand; it is chiefly by the impact and friction of grains of sand that the rocky beds of streams are disintegrated.
>
> Where a stream has all the load of a given degree of comminution which it is capable of carrying, the entire energy of the descending water and load is consumed in the translation of the water and load, and there is none applied to corrasion. If it has an excess of load, its velocity is thereby diminished so as to lessen its competence and a portion is dropped. If it has less than a full load, it is in condition to receive more, and it corrades its bottom. A fully-loaded stream is on the verge between corrasion and deposition. * * * The work of transportation may thus monopolize a stream to the exclusion of corrasion, or the two works may be carried forward at the same time.
>
> The rapidity of mechanical corrasion depends on the hardness, size, and number of the transient fragments, on the hardness of the rock-bed, and on the velocity of the stream. * * * The element of velocity is of double importance, since it determines not only the speed, but, to a great extent, the size of the pestles which grind the rocks. The co-efficients upon which it [velocity] in turn depends, namely, declivity and quantity of water, have the same importance in corrasion that they have in transportation.
>
> Let us suppose that a stream endowed with a constant volume of water is at some point continuously supplied with as great a load as it is capable of carrying. For so great a distance as its velocity remains the same, it will neither corrade nor deposit, but will leave the declivity of its bed unchanged. But if in its progress it reaches a place where a less declivity of bed gives a diminished velocity, its capacity for transportation will become less than the load, and a part of the load will be deposited. Or if in its progress it reaches a place where a greater declivity of bed gives an increased velocity, the capacity for transportation will become greater than the load and there will be corrasion of the bed. In this way a stream which has a supply of débris equal to its capacity tends to build up the gentler slopes of its bed and to cut away the steeper. It tends to establish a single uniform grade.
>
> Let us now suppose that the stream, after having obliterated all of the inequalities of the grade of its bed, loses nearly the whole of its load. Its velocity is at once accelerated and vertical corrasion begins through its whole length. Since the stream has the same declivity, and consequently the same velocity, at all points, its capacity for corrasion is everywhere the same. Its rate of corrasion, however, will depend upon the character of its bed. Where the rock is hard, corrasion will be less rapid than where

it is soft, and there will result inequalities of grade. But so soon as there is inequality of grade there is inequality of velocity and inequality of capacity for corrasion; and where hard rocks have produced declivities, there the capacity for corrasion will be increased. The differentiation will proceed until the capacity for corrasion is everywhere proportional to the resistance to be encountered; that is, until there is equilibrium of action

In general we may say that a stream tends to equalize its work in all parts of its course. Its power inheres in its fall, and each foot of fall has the same power. When its work is to corrade and the resistance unequal, it concentrates its energy where the resistance is great by crowding many feet of descent into a small space, and diffuses it where the resistance is small by using but a small fall in a long distance. When its work is to transport, the resistance is constant and the fall is evenly distributed by a uniform grade. When its work includes both transportation and corrasion, as in the usual case, its grades are somewhat unequal and the inequality is greatest when the load is least.

The foregoing analysis is applicable to the Colorado. It is, in respect to corrasion, an exceptional river. Nearly all the large rivers of the world along their lower and middle courses have either reached, or closely approximated to, that condition of equilibrium which Mr. Gilbert speaks of, in which the transporting power is nearly adjusted without excess to the load to be carried. They have little or no surplus energy to spare for corrasion, and therefore neither corrade nor deposit. But the Colorado is corrading rapidly, and has doubtless done so with little interruption throughout the entire period of its existence. The cause may be discerned in one important fact already brought out. The region it traverses has been throughout Tertiary time steadily rising, and the total elevation has been enormous. This progressive elevation has antagonized the tendency of the river to reach that adjustment of its energy to the work of transportation alone, and has kept alive its corrasive power. There have been probably some limited periods in the history of the river in which, for the time being, it had sunk its channel until it reached a "base-level"—a grade below which it could not corrade. But this state of affairs was afterwards subverted by a further elevation which increased the declivities of the channel, restoring the corrasive power. The last great upheaval, exceeding in amount 3,000 feet, was of comparatively recent occurrence, and the river has not yet reached the new equilibrium of action and the new adjustment of its energy to the work of simple transportation.

The reader who for the first time is brought to consider the enormous depth of the gash which the Colorado has cut would naturally turn to the rivers with which he is familiar to inquire whether they disclosed evidence of similar and commensurate action. He would rarely find any such evidence. It is only by examining the physical conditions of the Colorado and comparing them with other rivers in the light of such principles as Mr. Gilbert has laid down that the facts become intelligible. The first and most important factor to be considered is its declivity. The fall of the Colorado and its principal fork, the Green River, from Green River Station, on the Pacific Railway, to the end of the Grand Cañon, a



VIEW FROM THE EASTERN BRINK OF THE KAIBAB—OVERLOOKING THE MARBLE CAÑON PLATFORM.

distance, as the river runs, of about 1,050 miles, is about 5,150 feet, or very nearly five feet to the mile. The fall through the Grand Cañon is on an average 7.56 feet to the mile. Taking the several divisions of the Grand Cañon, the declivity may thus be tabulated:

Declivity of the Colorado in the Grand Cañon.

Subdivisions	Distance in miles.	Fall in feet	Fall in feet per mile
From Little Colorado to Kaibab division	9 6	60	6 25
Kaibab division	58	700	12 07
Kanab division	47 6	240	5 01
Uinkaret division	19 2	100	5 21
Sheavwits division	84	540	6 43
Totals	218 4	1,640	7.56

The Marble Cañon, with a length of 65.2 miles, has a descent of 510 feet, or an average fall of 7.82 feet per mile. When compared with the declivities in the middle and lower courses of other large rivers, that of the Colorado in the cañons is seen to be very excessive. It falls about as many feet as the others fall in inches. The flow of other large rivers which are usually considered swift is calm and easy in comparison with the rush of the waters of the Colorado.

There is another factor which would be fatal to corrasion in other rivers, but which in this one greatly augments its corrasive power. Not only are few rivers so swift, but fewer still are so continuously turbid and so heavily charged with sediment. Rarely is the river clear, even in the droughts of midsummer. Immense quantities of sand and clay are swept along at all parts of the year. Ordinary rivers, and even most of the exceptional ones, would be gorged with such quantities of sand, and instead of corrading would have their energies fully taxed in carrying the load which the Colorado bears easily. This sand is the tool which it employs for its work, and it uses it with great effect. Though the river is heavily loaded, it is still underloaded, and has great power to corrade.*

To show how efficient the corrasive action may become under extremely favorable circumstances, we may cite the case of some of the great hydraulic mines in California. In these mines powerful streams of water are discharged against the gravel banks, and the spent water is gathered into a brook which finds its way over the "bed-rock" into a tunnel, and finally escapes into some deep natural gorge below the level of the workings. As the water flows away it carries with it all the débris washed from the banks, whether coarse or fine. In the well-known Bloomfield mine I saw a gash in the solid basaltic bed-rock 12 feet in depth, which I was assured had been cut by the escaping water and gravel in a period of about sixteen months. The actual running

* The details of corrasion in the cañon will be much more fully discussed in the monograph on the Grand Cañon District.

time of the water, however, had been equivalent to about 145 days of twenty-four hours each. This case is indeed a most extreme one, and no natural river can show any such rapid corrasion of any considerable length of its bed. It is not cited to support an inference of phenomenal rapidity in the corrasion of the Grand Cañon, but rather to illustrate the efficiency of corrasive action when all the attendant conditions are extremely favorable and no countervailing condition is present. But although the Colorado is far from being such an extreme case as the one just mentioned, it is still a very strong one. Yet there are some stretches in the river where the corrasion must be proceeding at a very rapid rate—at a rate not very many times slower than in the Bloomfield mine. These portions are in the hardest rocks, and they illustrate well the law which Mr. Gilbert has so clearly enunciated (p. 157, line 44).

The course of the Colorado in the Grand Cañon is a succession of headlong rapids or cataracts and of smooth but swiftly-flowing reaches. In the Kaibab division the rapids are very numerous, very long, and very frequent, while the still reaches are short. In the Kanab division the rapids are fewer and less formidable, while the still reaches are longer. In the Sheavwits, the condition is intermediate between those of the Kaibab and Kanab divisions. The rapids, however, are of two kinds and are the results of two wholly independent causes. (1.) When the stream lies in the hard rocks, the declivity is much greater, and the rapid is then due to the greater slope of the bed. (2.) At the opening of every side-gorge, a pile of large bowlders and rubble is pushed out into the stream. Most of the side-gorges are dry throughout the greater part of the year. But when the rains do come, their effects are prodigious.* In the vast amphitheaters the water is quickly shot down into the channel and rushes with frightful velocity along the bed, which has a slope of 200 feet or more to the mile. Nothing which is loose and which lies in the way of it can resist its terrible rush. Bowlders of many tons' weight are swept along like chaff, and go thundling down the side gorges into the main river. When the torrents reach the river the large fragments are dropped; for the maximum slope of the main stream (reckoned throughout any stretch exceeding four or five miles) never exceeds 25 feet to the mile; and the water, though great in volume at flood-time, has much less velocity than the torrents of the side chasms. The river has, however, abundant power to sweep along fragments of considerable size, which are ground up as they move onward. The coarse material, the large bowlders and rubble washed out of a lateral chasm, form a dam where the river becomes a cataract. They are also strung out for considerable distances below the dam, and thus the tendency is to build up and increase the grade of the river

* It is well to remember here the grand scale on which these lateral features of the chasm are laid out. The watersheds of these amphitheaters cover each from 10 to 50 square miles! And when a heavy rain comes, whatever water is not soaked up by the rocks and soil is in the bottom of the amphitheater in less than ten minutes!!

just beyond the rapid. But this tendency is quickly checked and brought to a stop by the increased power of the current due to the increased slope. The body of fragments brought into the river laterally is vast in amount. But on the whole it is insufficient at the present epoch to prevent the river from corrading its channel, though corrasion is greatly retarded by it. There are many stretches where there is an equilibrium between the tendency to cut deeper and the tendency to build up the bottom by the accumulation of débris; where the whole energy of the river is consumed in dissipating the fragments brought into it. But there are other portions where the river bed is in the bare rock of Palæozoic and Archæan strata, and wherever it is so corrasion is proceeding rapidly.

WEATHERING.

The work of corrasion is limited to the cutting of narrow gashes in the strata, and the grinding up of the fragments brought into the river channels. The widening of these cuts into the present configuration of the chasm is the work of weathering. The common notion is that "solid rock" is but little affected by any natural agents such as water and air, and though it is acknowledged that water and carbonic acid exert a certain nominal solvent and chemical action upon rock material, yet these are usually esteemed so feeble that even the enormous periods of time which the geologist invokes seem quite insufficient to warrant us in ascribing to them any very important effects. Our observation upon the works of human construction which have been exposed for many centuries to the action of the elements confirms this notion. The structures of Egypt, Greece, and Italy have been thus exposed for periods which are nearly or even exactly known. They bear evidence that this action is a real one, and that their final dissipation would, in the event of indefinite exposure, be a mere question of time. But they also indicate that so far as their own materials are concerned the process is exceedingly slow. Their rate of decay by solution, if applied as a factor to the recession of the walls of the Grand Cañon, would give a period of time so vast that the mind would promptly reject it because of its very enormity. But we shall find that the recession of those walls goes on, slowly indeed, but at a rate very much greater than would be inferred from an inspection and comparison of the works of human antiquity.

It is at once obvious that the building-stones are not a fair criterion. They are selected for their durability, and of all rocks they represent those which offer the greatest possible resistance to weathering. Taking the common rocks only—those of frequent and world-wide occurrence—there is reason to believe that their rates of decay under equal conditions vary among themselves enormously. Leaving out of the account the unconsolidated or loosely consolidated strata, it cannot be doubted that some indurated rocks decay fifty times faster than others, the conditions being identical as to climate and exposure. We have, it is true, no experimental or laboratory data upon which this assertion can be based, but it is, I am confident, quite defensible, and will appear to be so when we examine the results of weathering in the rocks in place. For there is another consideration which is not apparent in the decay of building-stones. The strata are disintegrated by a process which includes something far more efficient than mere solution or chemical decomposition.

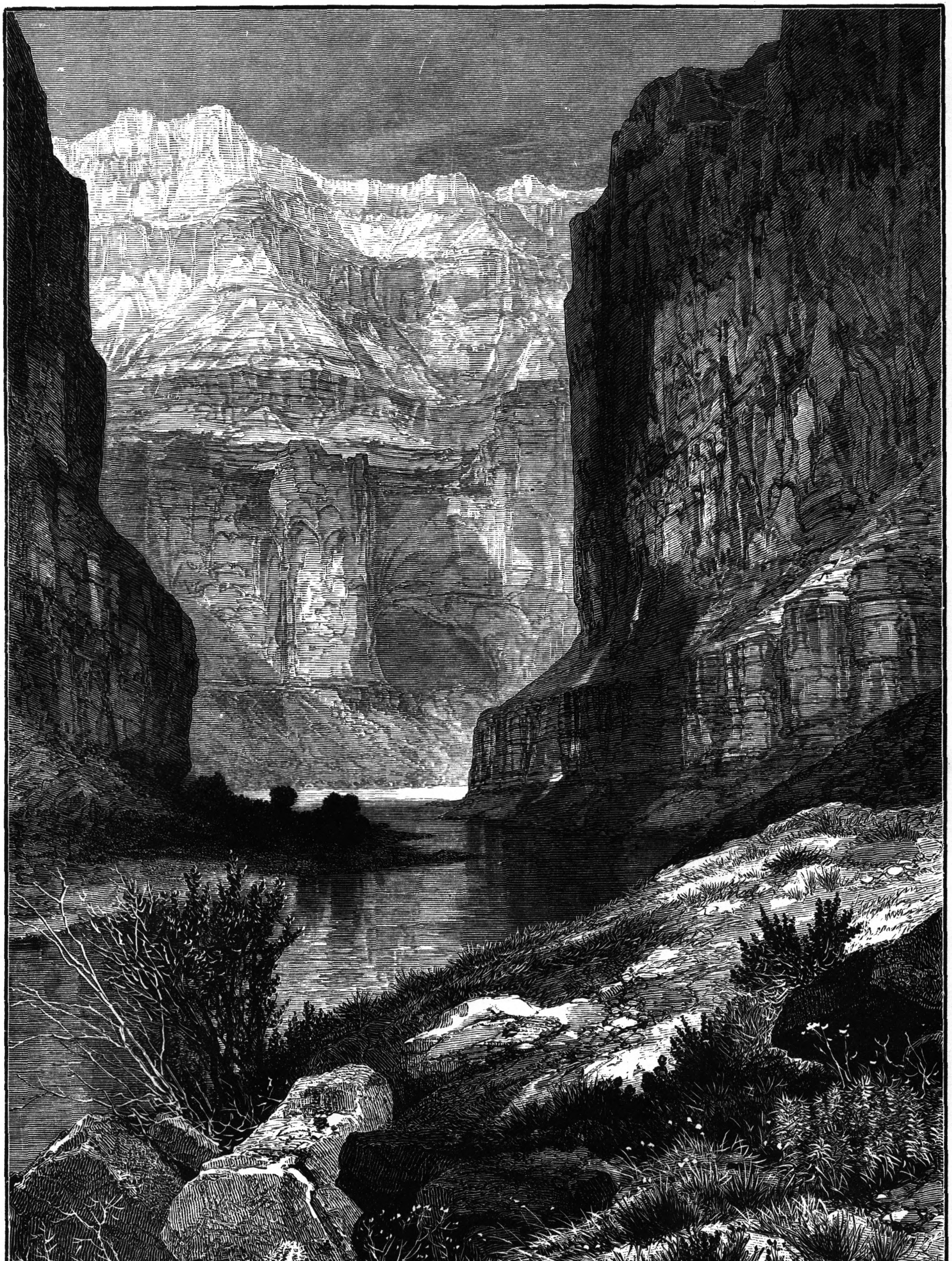
At the base of every cliff in the Plateau country we find a large talus consisting of fragments fallen from the rock faces above. The fragments vary in size from bowlders of many tons' weight down to the finest gravel, sand, and clay. Here is proof at once that the decay of cliffs goes on chiefly through the breaking off of fragments. It soon appears that the amount of material removed from the wall in solution is but a very trifling fraction of the quantity which has spalled off from the face of the wall. As the large fragments fall off from the vertical front they are dashed to pieces below. In this fragmental condition they expose a much greater surface to weathering and are dissipated with correspondingly increased rapidity. And now we come to the key of the problem. The explanation of those persistent profiles of the Grand Cañon is found when we analyze the formation and decay of talus. It is one of the most charming studies in the whole range of physical geology.

In the Carboniferous strata of the Grand Cañon we have a mass of rocks widely varying in lithological characters, but which on the average are just about as obdurate to weathering as the average of rocks found in other regions. So far as can be seen or inferred, in this respect they differ not at all from the strata of other regions. Some of them weather easily, some are very obdurate. Perhaps the only qualification to this comparative statement is that there are no extremely perishable strata in the whole series. The softest beds are still firm and perfectly indurated. The degrees of obduracy, however, appear to vary greatly in the series.

The upper stratum in the cañon wall is a cherty limestone, which is harder* than the average, though not extreme in that respect. It forms usually a precipitous face, though it is frequently breached and broken down. It is out of this series that the rows of pinnacles in the crest of the cañon are carved.† Beneath it is another series of limestones of less than average hardness. They are sometimes a little cherty

* In speaking here of relative hardness and softness, I wish to be understood as meaning the resistance which the rock opposes to destruction by direct weathering, and not hardness in the mineralogical sense, nor the resistance which the rocks might offer to the tools of the stone-cutter.

† The cherty limestones are full of silicious nodules. They occur in vast numbers and show a tendency to arrange themselves in bands parallel with the bedding. The inclosing matrix, though mainly calcareous, has much disseminated silica in the cherty form. In the weathering the nodules are dissolved out of the matrix and fall down the cliffs.



THE MARBLE CAÑON.

but far less so than the overlying beds. They break down always into a steep slope, covered with a talus partly of their own débris and partly of the cherty nodules weathered out from above. Beneath the limestones lies the cross-bedded sandstone, one of the most conspicuous members of the cañon. Of all the strata it is the hardest; in truth, is about as adamantine as any rock to be found in the world. It forms everywhere the vertical frieze of the upper wall and is very seldom broken down into a slope. Underneath it comes the great series of Lower Aubrey sandstones, a thousand feet thick, made up of very many individual beds. They are similar in character, and all of them weather rapidly. We have, then, in the Upper and Lower Aubrey Groups, which form the outer chasm wall at the Toroweap (and which are almost exactly the same elsewhere throughout the Grand Cañon), four groups of strata which are alternately hard and soft (Fig. 16), (1) a hard cherty limestone, (2) a softer limestone, (3) an extremely hard sandstone, (4) a great thickness of much softer sandstones.

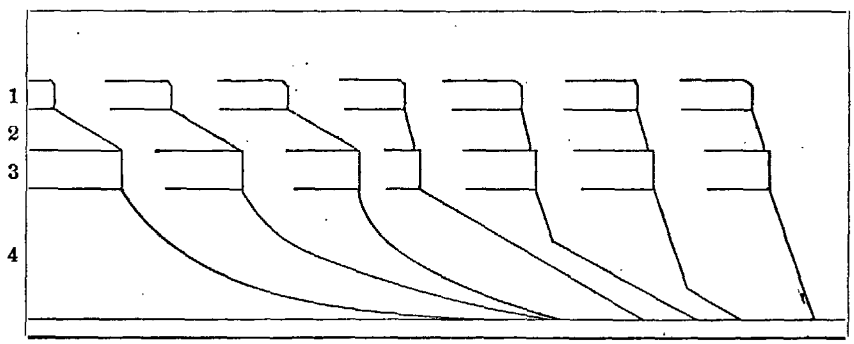


FIG. 16.—Development of cliff profiles by recession in the upper wall of the chasm.

It has already been explained that the attack of erosion is made chiefly upon the scarp walls and steep slopes of a country and only feebly upon level surfaces. Imagine, now, a cut made by a corrading stream into such a series of strata as that which has just been described. It will soon appear that it is quite immaterial whether the cut be made very gradually or instantly,—by a miracle, as we may suppose. Weathering at once attacks the face of the wall. The softer beds yielding much more rapidly, gradually undermine the harder ones above, and the latter cleave off by their joints and great fragments fall down. If we suppose the corraded cut to have been made instantly and the river to be flowing in it, the fragments would at first fall into the stream and be devoured by corrasion as fast as they fall. But after a time the widening of the cut so produced would leave a platform on the margin of the stream where the fragments would begin to form a talus. As the recession by waste goes on, the talus grows larger and larger, and gradually mounts up on the breast of the lower wall. Now the effect of a talus is to protect the beds upon whose edges it lies, and to retard their rate of decay by virtue of that protection. At first, then, the talus causes the lowest beds to lag behind in the recession. As it mounts up the wall, higher and higher beds gain protection, and they, too, begin to lag behind, until at last the talus mounts up very nearly to the base of the extremely hard, cross-bedded sandstone. Thus the entire lower series of soft strata becomes converted into a slope covered with talus, and at this stage all the beds above stand as a single vertical face. But immediately a second cliff and talus begin to form above the hard sandstone; for since the lower soft beds are protected and their rate of recession reduced by the talus, the upper soft beds, being naked, must recede at a more rapid rate, until they, too, become a slope and receive the protection of a talus from the hard limestone at the summit.

It appears, then, that the recession of the hard beds is accelerated by undermining, while the recession of the soft beds is retarded by the protection of the talus. The result is the final establishment of a definite profile, which thereafter remains very nearly constant as the cliff continues to recede. *Thus the talus is the regulator of the cliff profile.* There are many minor features which may be explained as satisfactorily, and one of them is the curvature of the Lower Aubrey profile.

Throughout the greater part of the chasm the slope of the Lower Aubrey is a very graceful curve, but in the Kaibab division it is usually straight and descends at an inclination of about 30 degrees, the angle of repose, or very nearly so, for the débris which occurs here. Taking first the Toroweap section, we remark that at the base of the main palisade is the broad esplanade or plain which forms the floor of the upper chasm. It is from a mile to three miles in width. In a great talus the fragments are slowly and continually creeping down by the action of rain and frost. The plain at the base acts as a check to the descent. Nowhere except, perhaps, at a notable distance away from the base or in the very lowest part of the stratigraphic series are the beds wholly buried in talus. Considerable areas of rock surface project through the covering. The tendency of the descent of talus under the conditions here considered is to give more protection to the lower beds than to the higher. The check given to the descent of the talus by the level plain is felt more strongly at the base of the slope than higher up. Moreover, the finer débris is more readily washed down a slope of given declivity than the coarse, and thus the débris at the base of the talus is finer than that above; and fine débris is a more efficient protection than coarse. In consequence of this greater protection, the recession of the lower beds is less rapid than that of the higher ones, and in general terms the protection of any given bed in the slope is inversely proportional to the square or some other complex function of its height above the base. The curved profile at once follows, and it is demonstrably of the hyperbolic class.

In the Kaibab the case is different. Here the mighty plinth of the Red Wall limestone cuts off the foot of the Lower Aubrey slope, giving a free discharge to the fragments into the depth below. There is no check to the descent of the talus; the amount of protection given by it to all the beds of the Lower Aubrey is very nearly uniform, and the slope becomes straight. But whenever, as sometimes happens, the top of the Red Wall precipice stands at an unusual distance from the Lower Aubrey, the curvature of the profile of the latter appears, and its emphasis is proportional to the distance which separates the vertical planes of the Red Wall and of the cross-bedded sandstone.

Many details of repetitive or systematic sculpture are presented in the great chasm, and they may be explained as readily as the profiles. Only one other feature can be alluded to here, and the allusion will be brief. It concerns the plan or horizontal projections of the component features of the Kaibab division, the blocking out of the cloister buttes and the temples, and their reduction to their present forms. In a general way it is apparent that these have been originated by the profound corrasion of short lateral tributaries of the Colorado and the subsequent widening of the cuts into the present amphitheaters and alcoves; the buttes and temples being the residual masses between them. But the contours of the latter are striking and peculiar in the extreme. They are explained by observing that wherever recession of the cliffs takes place it proceeds with great uniformity along the entire front. It starts along the line of a stream which is tortuous, but as it proceeds it carries back the cliff in a succession of curves, and in process of time minor inequalities are obliterated. Each larger bend of the stream gives rise to its own curve in the trend of the wall, and where successive curves intersect they form very sharp cusps. Everything here depends upon uniformity in the rate of the recession of all parts of the cliff. Where the outward spreading circles of erosion from two distinct alcoves or amphitheaters meet by recession in opposite directions, a butte is cut off and a saddle or "col" is formed. The cusps between two intersecting circles are exceedingly sharp and well formed, and three circles generally give rise to a fine gable.

The peculiar cliff-forms of the Plateau country would hardly be possible in any other, for no other presents those conditions which are necessary for them. These conditions may be summarized as follows: (1.) The great elevation of the region. (2.) The horizontality of the strata. (3.) A series of strata containing very massive beds which differ greatly among themselves in respect to hardness, but each member being very homogeneous in all its horizontal extent; in a word, heterogeneity in vertical range and homogeneity in horizontal range. (4.) An arid climate. The great elevation is essential to high reliefs in the topography. Only in a high country can the streams corrade deeply, and it is by corrasion of streams that the features are originated and blocked out. The effect of horizontality of the strata is self-evident. With regard to vertical heterogeneity, it is apparent that it is essential to give diversity to profiles. If the rocks were homogeneous in vertical range, the cliffs would all be like the Jurassic sandstone, stolid and formless. Horizontal homogeneity is essential to that rigorous uniformity in the rate of weathering which gives to the cliffs their systematic character. The effect of the arid climate of the region cannot be explained without a preliminary statement in great detail of the fundamental principles and laws of erosion. These are highly complex, and require an analysis which is more suitable to a monograph than to the present essay. Such an analysis will be attempted in my work upon the geology of the Grand Cañon District.

No doubt the question will often be asked, how long has been the time occupied in the excavation of the Grand Cañon? Unfortunately there is no mystery more inscrutable than the duration of geological time. On this point geologists have obtained no satisfactory results in any part of the world. Whatever periods may have been assigned to the antiquity of past events have been assigned provisionally only, and the inferences are almost purely hypothetical. In the Plateau country, Nature has, in some respects, been far more communicative than in other regions, and has answered many questions far more fully and graciously. But here, as elsewhere, whenever we interrogate her about time other than relative, her lips are sternly closed, and her face becomes as the face of the Sphinx.

CONTRIBUTIONS

TO THE

HISTORY OF LAKE BONNEVILLE.

BY

G. K. GILBERT.

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I. INTRODUCTION.

In the organization of the Geological Survey by Mr. King, the territory subject to its operation was apportioned in a number of divisions. To each division a scientific corps was assigned, and in order that the labors and results of each corps might be characterized in the highest practicable degree by unity each geographic district was made to correspond to a great geologic province. The Division of the Great Basin is a province characterized by numerous small mountain ranges, and is thereby distinguished from its western neighbor, the Division of the Pacific, which contains a comparatively great mountain chain, the Sierra Nevada, and from its eastern neighbor, the Division of the Colorado, which includes as its chief feature the great group of plateaus of the Colorado Basin. At the north it is limited by the British Possessions, and at the south by the Mexican boundary, and it has an extent nearly twice as great as the Eastern and Middle States combined. Nearly the whole of this area is studded by mountain ridges, which are approximately parallel and have a meridional trend. None of them are of great height nor of great extent, and they are so numerous that many have no individual names known to the whites. Between them lie valleys filled by the alluvium that in past ages has been worn from their summits and sides, and in a few districts these valleys grow broad and blend together so as to constitute plains of some extent. The rainfall of the region is scant and the streams are few and small. Two great rivers traverse it, but their sources are beyond its limits. The Columbia, fed by the abundant precipitation of the uplands rising to the eastward, crosses in a northwest direction to the Pacific Ocean; the Colorado, rising in the same uplands, flows southward and westward to the Gulf of California. From the arid tract they receive a few small affluents, but except for the avenues opened by their waters it is scarcely probable that any streams rising within the district would find their way to the ocean. In the interval between the drainage basins of the two rivers there is a large district which gives rise to no outflowing streams, but returns to the air by evaporation all the moisture received from it as rain. It is this district of continental drainage to which the title "Great Basin" is specifically applied, and it is from it that the Division receives its name. The geological survey of the Division involves the study of a wide range of topics. Not only does each mountain consist of a variety of geologic strata and embody a history of its own, but the district as a whole contains every great known group of formations, and their study cannot be conducted without a coincident study of the greater dynamic problems of geologic science. The Archæan, the Paleozoic, the Mesozoic, and the Tertiary systems are each developed in so many localities that no one of them can be studied fully without traversing a large portion of the entire area. Volcanic rocks abound in all parts, and phenomena pertinent to the study of the growth of mountains and the decay of mountains are everywhere present.

With the limited means at the disposal of the Survey it was manifestly impossible to occupy the entire field at once and carry on the work in a way that would be both geologically and geographically symmetric. It was necessary to restrict attention, and the question arose whether this should be done by selecting a limited district for initial work and beginning in it the study of every topic to which it might contribute, or by choosing a specific line of inquiry and carrying it through the entire area. The latter course was decided on, and the theme of study selected was the Quaternary history of the valleys of the Great Basin. It was already known that many of these valleys which are now destitute or nearly destitute of water, had contained, at a period of time geologically very late, a series of lakes, some of which were salt and some fresh; and it had been more than surmised that these lakes were the contemporaries of the glaciers of the Ice Epoch. The study of their history was therefore nearly identical with the study of the Quaternary history of the valleys, and it was to them that attention was chiefly directed.

The lowlands of the Great Basin are valleys without drainage to the ocean, and when the climate of the Glacial Epoch gave them a more generous supply of moisture the surplus was accumulated in their lower parts in quantities which bore a definite relation to the climate. When for centuries the climate became more humid the lakes rose and encroached upon the land, and when the reverse was true and aridity prevailed they dried away and the land was laid bare. The extent of the lakes was therefore the measure of the climate, and if we can rightly interpret the traces the lake margins have left of their successive positions we shall be furnished with a detailed history of the oscillations of climate in this region of the earth during that epoch. The problem of Glacial climate is one of the most interesting which now claims the attention of geologists, and if these Quaternary lakes can afford an independent history of the climatal changes by which the accumulations of ice were made and dissipated, they will make a most acceptable contribution to the subject.

Closely interwoven with the history of the oscillations of the water is the history of the sediments deposited by it, and the general study cannot be carried forward without at the same time investigating the conditions of sedimentation in inland seas. It is therefore hoped that the progress of the investigation will add something to our means of distinguishing, among the older geologic formations, strata which were formed under similar conditions, and will thus enable us to read more clearly some of the earlier pages of the geologic record which are now obscure.

Another collateral subject of investigation is the process of shore formation—the process, that is, by which the waves of a lake modify the configuration of the land upon which they break, and produce the peculiar topographic features characteristic of shores. This study has already been successfully pursued by others on the margins of existing bodies of water, but there are some details in the anatomy of shores which are necessarily concealed by living bodies of water, and can only be revealed by the dissection of the denuded remains of dead lakes.

The desiccation of the old lakes caused the concentration of their mineral contents, so that all of them which survive with diminished area are saline, and the positions of those which have entirely disappeared are marked by deposits of salt and other soluble minerals. The study of the Quaternary lakes is therefore inseparable from the study of the modern salines, and it may reasonably be anticipated that the final discussion of the results will throw new light upon the saliferous deposits of the older rocks.

At the time of the organization of the Survey it chanced that there was in the possession of the writer a considerable body of unpublished material bearing upon Lake Bonneville, and that lake was therefore selected as the first individual subject of study. Its investigation in the field has now been completed, and a full account of its history, so far as it has been found practicable to deduce it, is in preparation. But while this history will be monographic as regards Lake Bonneville, it will in another sense be only one of a series—to be followed in time by similar accounts of other Quaternary lakes, and eventually by general discussions of the various collateral topics developed by the investigation.

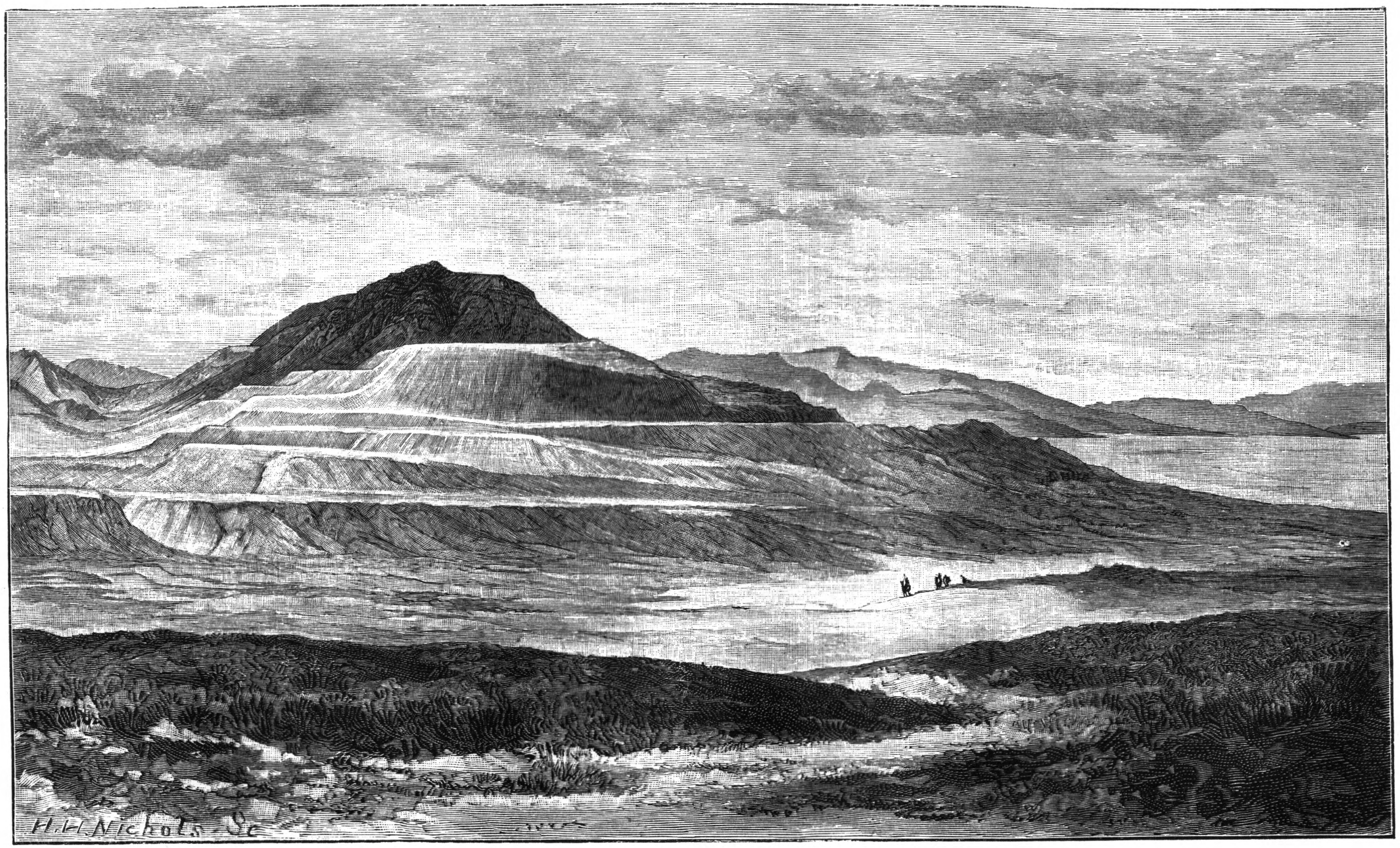
In the present paper it is proposed to give in brief the principal results of the year's work, reserving for the monograph the full presentation of the facts from which they are derived. They will be prefaced, however, by an outline of the subject as previously known, for the literature of Lake Bonneville is so scattered that a general familiarity with it cannot be assumed.

Whoever makes a careful examination of a tract of sea coast, first before a great storm and again after the storm has passed, cannot fail to discover various modifications wrought by the storm in the form or character of the coast. Wherever the water margin is overlooked by a cliff it will be found that some portion of the rock or earth of the cliff has been washed away, and probably that fragments great or small have fallen from above. Wherever the shore is constituted by a beach or spit it will be found that additions have somewhere been made to the sand or shingle, and possibly that at other points losses have been sustained. It is universally recognized that these changes are the result of the conjoined action of waves and currents set in motion by the storm, and that they are limited to the immediate vicinity of the shore and to shallow water. There is a horizontal zone of activity practically corresponding with the zone which receives the force of the breakers, but extending somewhat farther downward, and along this zone nearly every portion of the coast either suffers abrasion or else grows by additions to its banks and bars. Where the coast is abraded, the zone of wave beating is carried progressively landward, and two features are wrought: the paring away of the land leaves a fringing terrace or shelf just beneath the water; and the same excavation produces a cliff at the landward margin of the terrace. Where the coast grows, its banks and bars are not merely enlarged, but if they did not before exist they are created. The sea-cliff and the terrace at its foot are the creatures of the wave and mark the spot where the nature of its action is destructive. The spit, the beach, and the bar are equally the creatures of the wave, and testify to its constructive energy.

In this way there arises a special topography of coasts, and when the waters of a sea or lake recede or disappear, the topographic features which were wrought by the waves survive, constituting a conspicuous and almost unmistakable record. Every element of this record is characterized by horizontality; the landward edge of the wave-cut terrace is a horizontal line coincident with the level base of the sea-cliff; the beach and the spit and all other constructive works are level-topped, having been built upward to a limit regulated by the force of the storm waves. When, therefore, one views a slope from which an ancient lake has been withdrawn he recognizes its shore trace in a series of features which embody a horizontal line. Here the line is the meeting of a terrace and a cliff, there it is the crest of an embankment, and elsewhere it is the brow of a delta plain; its manifestations are diverse, but it is never wanting. To an eye placed at the proper height and distance all its elements blend together and it stands forth as a continuous, horizontal, indubitable *shoreline.*

It is by records of this character that Lake Bonneville is chiefly known. All about the great basin of Utah the lower slopes of the mountains are skirted by these level tracings—not a single line merely at a single level, but a series of lines at many levels, testifying to a system of oscillations of an ancient lake.

The highest water line is 1,000 feet above the level of Great Salt Lake, and over every foot of the intervening profile can be traced evidence of the action of waves. There is, however, a great inequality of the record,



RESERVOIR BUTTE, SHOWING TERRACES OF THE BONNEVILLE SHORELINES.

and the most casual observation shows that the water lingered much longer at some stages than at others. One of the most conspicuous water lines is the highest of all, but its prominence is largely due to the fact that it marks the limit between the wave-wrought surface below and the rain-sculptured forms which rise above. Of the lower lines there is one lying about 400 feet below the highest, which is far more conspicuous than any other and has for this reason been given a special name—the Provo shoreline. The highest is distinctively known as the Bonneville shoreline. Between the Bonneville and the Provo four or five prominent lines can usually be seen, to which no individual names have been given, and it will be convenient to call these in this place the Intermediate shorelines. On the slopes below the Provo shore the water lines are less conspicuously drawn, and only a single one is so accentuated as to have been identified at numerous localities.

A lake without outlet cannot maintain a constant level, because its quantity of water depends upon the relation of the rainfall to the superficial evaporation, and these elements of climate are notoriously variable. A series of moist seasons increases its contents and causes its margin to advance upon the land, while a succession of dry seasons produces the reverse effect and makes it shrink from its borders. With a lake having a discharge the case is different, for every increase or diminution of supply, by slightly raising or lowering the surface, increases or diminishes the discharge, and thus a practical equilibrium is maintained. It can therefore rarely happen that the waters of a lake without outlet are held at one level for the time necessary to produce a strongly marked, individual shoreline, and for this reason it was early surmised that Lake Bonneville found an escape for its surplus waters at the times of the formation of the Bonneville and Provo shorelines. Search was therefore made for a point of outlet, and eventually it was discovered at the northern extremity of Cache Valley. The sill over which the water at first discharged was of soft material which yielded easily to the wear of the running water and permitted the lake level to be rapidly lowered by the mere corrasion of the outflowing stream, but eventually a reef of limestone was reached by which the erosion was checked and the lake was held at a nearly constant level until its outflow was finally stopped by climatic changes which diminished the water supply. The level of the soft sill first crossed by the outflowing water is the level of the Bonneville shoreline at the nearest point where it is visible; the level of the limestone sill is coincident with that of the Provo shoreline; and the discovery of these facts correlated in a satisfactory manner the history of outflow with the history of the most conspicuous shorelines. As will presently appear, it was the work of the past summer to complement this knowledge by obtaining an interpretation of the Intermediate shorelines.

The detritus the waves bear away from one part of a coast is not all accumulated in the adjacent embankments; only the sand and gravel are there collected, and the finer matter, which is capable of being held in suspension by the water for a longer time, is borne to a greater distance from the shore and finally settles to the bottom in the form of mud. Moreover, the streams which flow from the land to a lake bring with them each its quota of mud too fine to subside quickly, and this, too, is deposited in the depths remote from the shore. Thus the whole surface of every lake bottom becomes coated with a fine mud derived from the demolition of the surrounding land by rains and rivers and by waves.

Nor is this all: the wear of the rains and even the wear of the waves is not limited to abrasion, but includes also solution. All rock material is to some extent soluble by water, and every river carries to the sea or lake into which it empties not merely gravel and sand and silt, which are visible to the eye as impurities, but various minerals so intimately combined that the eye cannot detect them, although they are readily discovered by chemical tests. A lake which receives the water of a river or rivers, and is itself drained by an outflowing river, catches in its sediments the mechanical detritus only, which settles to the bottom where the current is checked, and permits all or the greater part of the chemical contents of the water to escape; but a lake with no outlet accumulates the entire mineral contents of the tributary streams, storing the mechanical detritus as a sediment, and the dissolved minerals either as a precipitate or else, by the aid of animal life, in some form of organic débris. The record of a lake is therefore written, not only by its wave-wrought shorelines, but by its mechanical and chemical sediments, and the investigation of Lake Bonneville necessarily included a study of the beds deposited upon its bottom. The work of the first year of the Geological Survey demonstrated the divisibility of these deposits into two members, separated by a break or interval during which no deposit took place. In the work of the second year the distribution of the two members and of the break were widely traced, so that now it is possible to give a comprehensive description of them.

In the central and deeper portions of the basin the section of the deposits is as follows:

First and lowest, the *Yellow Clay*, a fine, argillaceous, laminated deposit, with a pale olive tint where unoxidized, but exhibiting on weathered surfaces a dull yellow color. In a few spots this has been found interbanded with sand, but these interruptions are not continuous and its typical exposures exhibit clay only. Its thickness is unknown, the base of the deposit not having been seen, but 90 feet have been measured in one locality.

Second and highest, the *White Marl*, a fine, white earth, exhibiting little change from exterior to interior, and in its hardest varieties resembling chalk. Its thickness varies from 10 to 20 feet.

At all points the line of demarcation between the two deposits is strongly drawn, and at many points there has been found evidence of a break in the continuity of the deposition at this horizon. This evidence consists in part of traces of erosion of the surface of the Clay before the deposition of the Marl, and in part of the local interpolation of various coarse deposits due to superficial streams.

These relations will be made clear by the diagram, which exhibits the lake strata in section at a point where they rest against a steep mountain slope of quartzite. The Clay and Marl (2 and 4) are fine in texture, and have their bedding marked by laminæ, which are nearly horizontal. In the direction to the left of the drawing they extend for many miles without interruption. The wedge of gravel which separates them, and the similar wedges above, are all restricted to the

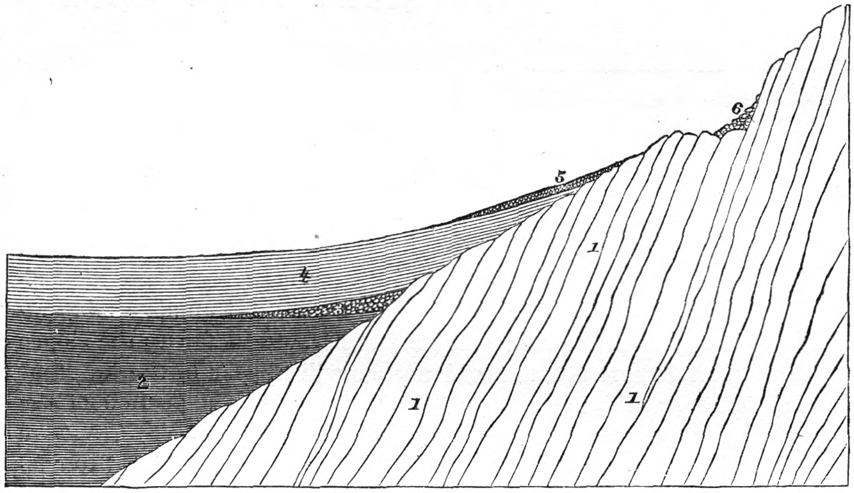


FIG. 17. Section showing the alternation of lacustrine and alluvial deposits at Lemington, Utah. 1. Paleozoic quartzite. 2. The Yellow Clay (lacustrine). 3. Wedge of alluvial gravel. 4. The White Marl (lacustrine). 5. Recent alluvial gravel. 6. Terrace and sea-cliff of the Bonneville shoreline, with recent talus at foot of cliff.

vicinity of the mountain; they are composed of fragments of the quartzite, cracked away by frost and washed down by rain. The process of their formation still continues, and those numbered 5 and 6 receive additions with every storm. When 2 and 4 were formed the lake bathed the foot of the mountain, and was the vehicle for the distribution of their fine material, but the intervening wedge of gravel, which was washed to its place by rain and rain-born rills, could not have been formed in the presence of the lake. It testifies, therefore, to a temporary subsidence of the water, and a drying of the bottom of the lake.

Neither the Clay nor the Marl passes beyond the limit marked by the Bonneville shoreline, but they rise upon the slopes on all sides until they merge with the shore deposits. As they approach the outer shorelines, however, they undergo changes of character and their distinctive features disappear. Their texture becomes coarser and they pass at many points into sands. In such case their separation can be made only where the evidence of the intervening break is present.

II. THE HISTORY OF THE OSCILLATIONS.

The general interpretation of these deposits and of their discontinuity is not difficult. The Yellow Clay was thrown down from deep and quiet waters, and therefore marks a period when the lake was large. It has been traced upwards along the slopes to within 200 feet of the highest water mark, and it is therefore known that the body of water to which it belonged attained at some time a depth of more than 800 feet, although there is no reason to suppose that that depth was continuously maintained through the whole period of deposition. The break between the two beds, with its local deposits of alluvium, records with equal clearness a period when the lake shrunk to small size, laying bare the surface of the Yellow Clay and exposing it to waste by running streams and to partial burial by subaerial agencies. This evidence has been traced continuously downward to a level only 200 feet higher than the surface of Great Salt Lake, and is there lost because modern erosion has exposed the section no farther. The shrunken lake could therefore have had no greater depth than 200 feet (plus the depth of Great Salt Lake), and its depth may have been much less. The White Marl, like the Yellow Clay, is a deposit from deep and quiet water, and unmistakably records a second rise of the lake. It has been traced as far up the slopes as the Clay, and there is some evidence, as will appear farther on, that it witnessed even a higher stage of the water during a portion of the period of its formation. Above the Marl the only deposits are shore embankments and recent alluvia, from which we are permitted to conclude that there has been no similar rise of the water since the retirement of the second flood.

There can be no question of this history so far as it goes, and any changes which may be made in it must be of the nature of additions. The climate of the region was moist and Lake Bonneville was large for a period represented by 90 feet and more of Yellow Clay; the climate was dry and the lake was small for an unknown period represented by the intervening alluvia; there was a second epoch of moist climate and expanded lake represented by 15 feet of White Marl; and that was followed by the present period of shrunken waters and dry climate.

But while this history is the necessary deduction from the facts in hand it does not include all of them, for it fails to account for the conspicuous difference in character between the Clay and the Marl. The character of the surrounding country affords no warrant for the belief that there was a large difference in the nature of the detritus brought to the lake during its two periods of maximum extent, and the explanation of the change in the character of the deposit must therefore be sought in the lake itself. The first hypothesis broached in regard to it was that it was dependent upon the establishment of an outlet, but this had to be abandoned. The establishment of an outlet would undoubtedly produce a change in the character of the water and a corresponding change in the character of the sediment, but it could only occur during a period when the lake was exceptionally full, whereas the change indicated by the difference between the Yellow Clay and the White Marl occurred at a time when the lake basin was exceptionally empty. Moreover, the effect of an outlet upon the character of the water would be to deprive it of a large share of its dissolved matter, and therefore to give to its sediments a relatively pure mechanical character, whereas the sediment which actually formed in the deeper places after the change is especially characterized by carbonate of lime, a mineral almost necessarily brought to the lake in solution.

For the purpose of determining, so far as practicable, the ratio of the chemical to the mechanical elements in the sediments of the lake a series of specimens, selected to represent the Clay and the Marl, were subjected to chemical analysis. Each bed was found to consist of the same constituents, but in different proportions, as will appear by the following generalized table:

	Yellow Clay. Per ct	White Marl. Per ct
Carbonate of lime and magnesia (the lime predominant)	30	45
Silicates of alumina, iron, and other bases (alumina predominant)	35	20
Silica	35	35

The carbonates possess so high a degree of solubility that they may be referred to the rank of chemical deposits without hesitation. The silicates have so low a degree of solubility that they may be referred with equal confidence to the rank of mechanical sediments. The silica holds an intermediate position and may be either mechanical or chemical, or may belong in considerable share to each division. However the silica is assigned, there is no reason to doubt that it has the same origin in both deposits, so that in any event the Marl contains a relatively large proportion of matter derived by chemical precipitation and the Clay a relatively large proportion of material conveyed by the water in suspension.

With these facts in view a second hypothesis was broached to account for the lithologic difference. It is shown by the stratigraphy that in the interval between the deposition of the clays and the marls the water fell below the 200 feet contour, but the stratigraphy fails to show how far below that line it fell. There is no violence in the supposition that the water dried completely away so that no lake whatever remained, and that all of the salt that may have been contained in the original lake was deposited by desiccation upon the lowest part of the lake bottom. Nor is there any violence in the further supposition that during the dry period the silt brought down by rivers in time of freshet was spread over the bottom of the lake valley, mingling with the salt at first and then covering it, until finally it was buried so deeply that the rising water, when the lake was again filled, did not redissolve it. By such a process the lake would be converted by desiccation from a salt body of water to a fresh body, and whatever influence loss of salinity might have upon the conditions of sedimentation would be indicated by an abrupt change in the character of the deposits.

For the verification of this hypothesis it is necessary to ascertain that the change which actually occurred in the nature of the sediment is such a change as would be produced by substituting fresh water for brine as the medium of sedimentation, and for its complete verification it would be necessary to probe the deposits in the lowest depression beneath Great Salt Lake and ascertain the existence of a heavy bed of rock salt. It was impracticable to undertake the latter investigation, but a series of experiments were conducted for me by Mr. Israel C. Russell, for the purpose of ascertaining what relation salinity of water bears to facility of sedimentation. No attempt was made to give a general character to the investigation, but it was made specifically applicable to the problem in hand by selecting for its materials the substances actually in question. The water of Great Salt Lake, which contains about 15 per cent of saline matter, was made to represent the supposed ancient brine of Lake Bonneville. The water of City Creek, a stream flowing through a calcareous district in the Wasatch Mountains and one of the tributaries of the Bonneville Basin, was taken to represent the water of Lake Bonneville in its supposed fresh condition, and specimens of the clay forming the lower bed of the lacustrine series were taken to represent the mechanical element of the Bonneville sediments. A chemist's beaker was filled with the brine, another with the creek water, and a series of others with various definite mixtures of brine and creek water. The clay was pulverized and divided into equal portions, which were severally added to the different beakers and mingled by stirring. Observation was then made of the time required by the different mixtures to become clear. The experiment was subsequently varied by preparing first those mixtures of which the clearing was found to be slowest, and then after an interval other mixtures observed to clear more rapidly, and then noting after what lapse of time they attained the same degree of approximation to clearness It is unnecessary to give here the detailed results, but it is sufficient to say that they all point in the same direction and show that the clay falls much more rapidly from City Creek water than it does from the Salt Lake brine, while its rate of falling from various intermixtures is proportioned to the percentage of brine. The degree of clearness attained with the City Creek water in twenty-four hours was reached with the Salt Lake brine only after a lapse of five days.

Evidently, then, if Lake Bonneville possessed the salinity of Great Salt Lake its mechanical sediment would be much longer retained by the water and would therefore be more evenly distributed than if it was characterized by the freshness of City Creek; and since the mechanical sediment necessarily entered the lake at its margin, being derived from the tribute of muddy streams and from the waste of the coast under the action of waves, it would in a fresh lake be largely deposited in the neighborhood of the shore, while in a salt lake it would be transported to greater distances before reaching a final resting place, and although possibly the upper slopes would still receive the lion's share a considerable portion would nevertheless find its way to the central region. The hypothesis of a loss of salinity during the interval between the deposition of the Yellow Clay and the White Marl accords therefore with the observed difference between those deposits. The upper and later-formed deposit, which hypothetically marks the prevalence of fresh water, is characterized by a smaller proportion of mechanical sediment, and its calcareous constituents, which thus acquire relative importance, are rendered conspicuous.

It is a necessary part of the hypothesis that the contrast of sediment exhibited by the Marl and Clay in the central area is reversed at the margins of the basin; for if it is true that the material furnished to the lake had always the same character, and that the contrast of the upper and lower deposits of the central area depends on conditions of distribution, then the small clay content of the White Marl at the center should be complemented by a large clay content of the shoreward prolongations of the same deposit; and in peripheral regions the lower bed should be more calcareous than the upper. As a matter of observation this has not been shown, but at the same time it has not been disproved. Both Marl and Clay become so variable and so coarse in the vicinity of the shores that a concise diagnosis of their constituents is impracticable. Whatever calcareous matter they contain is so masked by silicious and argillaceous material that it does not affect them in a manner appreciable to the eye, and chemical determination could not be brought to bear by reason of their variability, which made it impossible to select representative specimens.

It is possible that the contrasted conditions afforded by brine and fresh water may conduce to the observed disparity of sediments in yet another way. It is a familiar fact of the laboratory that the mingling of concentrated solutions of common salt and of carbonate of lime induces a precipitation of carbonate of lime, and although such a result is not observed when the waters of City Creek and Great Salt Lake are mingled, it may nevertheless be possible that a reaction of that nature took place about the margins of Lake Bonneville in its supposed briny phase. If it occurred, then the chief part of the chemical sediment would be accumulated near the shores, while a relatively small share would reach the central region. Afterward, when the water was freshened, the precipitate would in the absence of this reaction be equable in all parts, and a relatively greater proportion of carbonate of lime would be thrown down in the central region. It is noteworthy, however, that the off-shore equivalents of the Yellow Clay afford to superficial observation no indication of the presence of an exceptional share of precipitated carbonate of lime; so that while this consideration might help to sustain the general hypothesis it is not definitely sustained by facts of observation.

On the whole, the theory that the lake became fresh by desiccation finds too little positive support to entitle it to unreserved acceptance, but is controverted by no single known fact, and may therefore be considered to hold the position of a plausible working hypothesis. A series of investigations which have already been initiated by Mr. Russell in regard to the deposits of numerous natural evaporation pans of the Great Basin must eventually enable us to form a better judgment in regard to it than is possible at present. If it shall be established, a valuable addition will be made to the history of the ancient lake, for it will be shown that the climate in the inter-Bonneville epoch was so much drier than the climate of the present day that the water surface of the basin, which now has an extent equal to one tenth that of the broadest area of Lake Bonneville, completely disappeared. In our tentative history of the lake and the climate, subject always to revision with the addition of new facts, we cannot do better than to incorporate this element.

We now turn from the history written by the sediments to the contemporaneous history written by the shorelines.

Before the existence of Lake Bonneville its basin was dry, or nearly so. The water rose at the beginning of the epoch represented by the Yellow Clay, and receded to the base of the slope at the close of that epoch. It rose and fell again at the beginning and end of the epoch represented by the White Marl. Thus its margin was carried four times over the slopes of the basin, and every part of the profile was four times subjected to the action of the waves. In localities so circumstanced that the work of the waves was destructive, a portion of the land being eaten away, each successive attack cut deeper into the rock or earth and obliterated the traces of preceding attacks. In localities so circumstanced that the work performed by the waves was constructive, embankments of detritus being added to the pre-existent surface, each successive advance or recession built its embankments upon those which had previously been made and wholly or partially concealed them. The series of shorelines last formed are, therefore, generally speaking, the only ones visible, and the actual configuration of the surface is, in general, that wrought by the last passage across it of the water margin. Since the water is now at low stage, the last passage was a recession, and it was therefore assumed, both by the writer and by others, during the earlier progress of the study of the lake, that all of the visible shorelines represent lingerings of the water during its last recession. When, however, it became known that the portion of that recession included between the Bonneville and Provo shorelines was caused by the gradual cutting away of the barrier at the point of outlet, a difficulty arose, for the interval between the Bonneville and Provo shows in many places a number of well-characterized (Intermediate) shorelines, and it appeared strange that the rate of lowering should have been so irregular as to have permitted their formation. It was at first suspected that the lingerings of the water might have been determined by ledges of exceptional hardness in the material through which the outflowing channel had to wear its way, but an examination of the point of outlet gave no indication of the existence of such ledges. The idea then suggested itself that the phenomena were due to oscillations of climate, whereby the volume of discharge had been alternately increased and diminished, so that the rate of erosion had been alternately rapid and very slow; and with a view to testing this theory an elaborate study of the groups of embankments associated with the Intermediate shorelines was undertaken. The result of the investigation was entirely unexpected, but was none the less satisfactory, for it included a determination of the order of succession of nearly the entire series of shore marks.

When two embankments formed at successive water stages are so far separated upon a pre-existent slope that they are entirely distinct, they afford no means of determining their relative age, but if they are contiguous, one must always overlap the other in some way, and the determination of this overlapping serves to establish the order of priority. Thus, if the line *a b* of the diagram is the profile of a pre-existent slope upon which the series of shore embankments 1, 2, 3, and 4 have been built, then it is impracticable to determine the relative age of 2 and 3 or of 2 and 4, but it is evident that 1, which rests upon 2, must have been later formed, and that 3 was built before 4 which rests against it. This relation is not expressed by the external forms, for the profile of the group 1–2, is identical with that of the group 3–4, but purely by the manner in which they are superposed. To make the de-

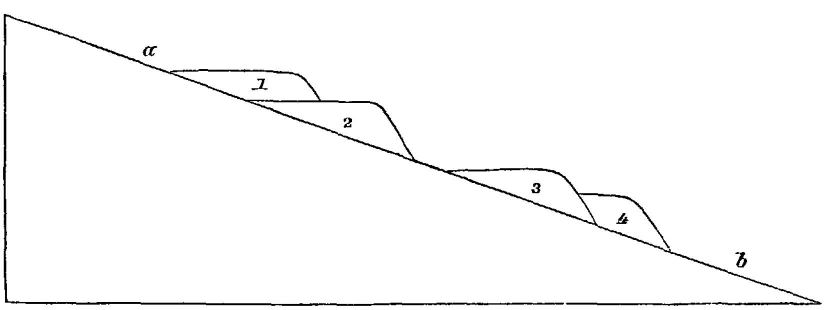


FIG 18—Diagram illustrating the superposition of shore embankments

termination it is necessary to have a cross-section, and in the embankments of the Bonneville Basin cross-sections are rarely exposed, for the reason that the recency of their formation has given subsequent erosive action little opportunity to perform its work. Nevertheless, a few localities were by patient search discovered, and although none of them sufficed to tell the entire story it was found possible so to combine their elements as to develop a tolerably complete history of the series of events by which the Intermediate shorelines were produced.

A graphic transcript of that history is given in Figure 19, where the chronologic order of the deposits is, first Y, then I, J, K, L, M, B, and P. The series of embankments YY was not discovered in section and the succession of its parts is unknown. I, J, K, L, and M, are the embankments of the Intermediate shorelines and their order of formation was from below upward; that is to say, they were built by the rising water and not by the falling. B is the Bonneville shoreline, formed after the completion of the Intermediate; and P, the Provo, last of all. The series YY records the first rise of the water and is the littoral equivalent of the Yellow Clay. It shows that the water at that time reached an extreme level about ninety feet lower than the Bonneville shore, and by so much failed to attain the height necessary to produce an overflow. The overlying banks from B to P record the second rise of the water and are the littoral equivalents of the White Marl. Their order of succession shows that the water rose by gradual stages until it reached its maximum at the Bonneville shore, and then, when an overflow had once been established, cut away the barrier and fell to the

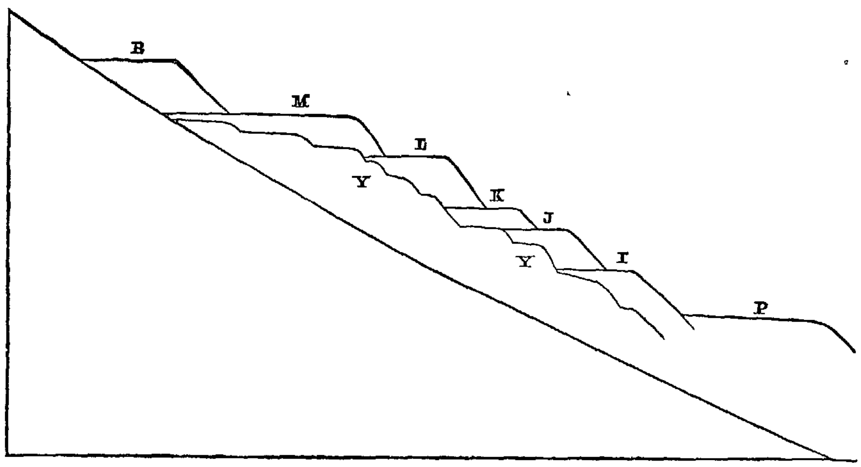


FIG. 19.—Diagram, showing the Overlap and Chronologic Order of the Shore Embankments of the Bonneville Basin

Provo level with a rapidity that afforded no opportunity for a record of the stages of its progress. At the Provo level the water was long retained by the resistance of the limestone sill at the point of outlet, and embankments of exceptional magnitude were formed on its shores.

It is especially interesting to learn that the second rise was higher than the first, for this fact carries with it the conclusion that the second great wave of climate was more strongly characterized by moisture than the first. Combining this information with that afforded by the sediments, we have the two climatic maxima distinctively marked: the first was long and relatively mild; the second was short and relatively intense.

It remains to consider the beginning of the Bonneville history. The history of the lake is written by wave sculptured topography and by lacustrine deposits. The history of the basin before the lake is written by rain-sculptured topography and alluvial deposits.

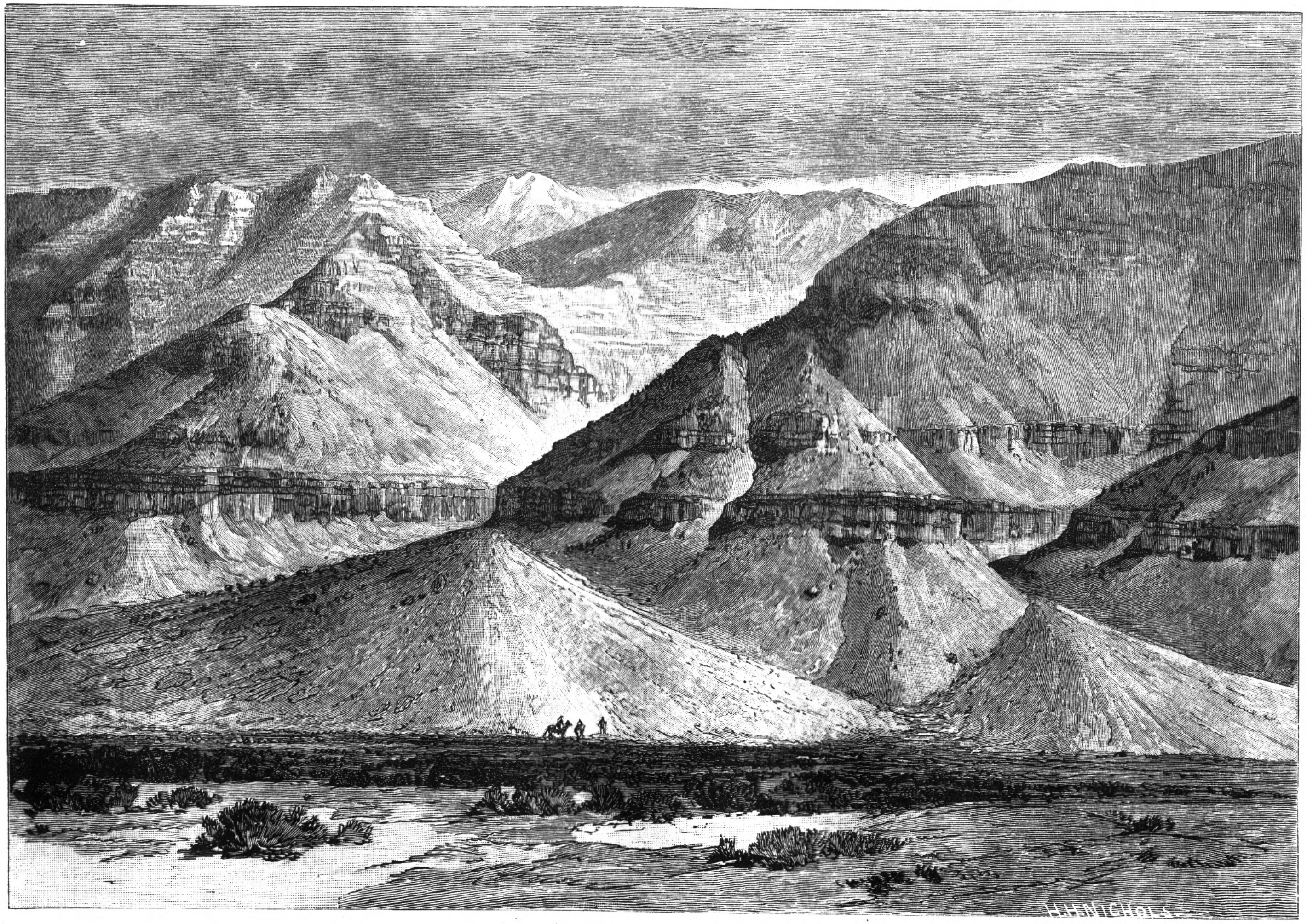
We are unaccustomed to think of the ordinary forms of land as a work of sculpture, but that is none the less their origin. If we except those restricted areas which have received their configuration from the recent occupation of lakes and oceans and those other restricted areas which owe their shapes to the passage of glaciers and the heaping of glacial débris, the whole surface of the land exemplifies the plastic art of the rain. The work of the wind is accessory to it; subterranean forces of upheaval and of volcanic energy give rise to mountain masses, and variations of hardness in the rocky strata of the earth assist in determining the positions of hills and crests and ridges; but rain is the agent which actually develops the forms we see. It penetrates rocks and dissolves them; swollen by frost it disintegrates them; it beats upon them and washes away the fragments, and gathering in rills, creeks and rivers it erodes channels and carries the débris to the valleys and the ocean. Its work is in the highest degree systematic, persistent and complete, and it either has molded or is molding every geographic form of nature to exemplify the laws of its action. Our eyes are so accustomed to these forms that we unconsciously anticipate them and readily detect the exceptional nature of all differing elements of sculpture. The sculpture wrought by the waves affords so marked a contrast that the eye distinguishes it at once, and it is thus that the tracing of the Quaternary lakes is made possible.

The sculpture of a mountain by rain is a twofold process; on the one hand destructive, on the other constructive. The upper parts are eaten away in gorges and amphitheaters until the intervening remnants are reduced to sharp-edged spurs and crests, and all the detritus thus produced is swept outward and downward by the flowing waters and deposited beyond the mouths of the mountain gorges. A large share of it remains at the foot of the mountain mass, being built into a smooth sloping pediment. If the outward flow of the water were equal in all directions this pediment would be uniform upon all sides, but there is a principle of concentration involved whereby rill joins with rill, creek with creek and gorge with gorge, so that when the water leaves the margin of the rocky mass it is always united into a comparatively small number of streams, and it is by these that the entire volume of detritus is discharged. About the mouth of each gorge a symmetric heap of alluvium is produced—a conical mass of low slope, descending equally in all directions from the point of issue; and the base of each mountain exhibits a series of such alluvial cones, each with its apex at the mouth of a gorge and with its broad base resting upon the adjacent plain or valley. Rarely these cones stand so far apart as to be completely individual and distinct, but usually the parent gorges are so thickly set along the mountain front that the cones are more or less united and give to the contours of the mountain base a scalloped outline.

The Bonneville Basin is surrounded by and interspersed with mountains, and from the summits of these down to the Bonneville shore the entire topography is of a rain-wrought type. From the shoreline downward to the valleys and plains its nature is composite, uniting the elements of wave sculpture with those of rain sculpture, but the manner of union is not indiscriminate and in it is written what we know of the pre-Bonneville history of the basin. All of the larger elements belong to the domain of rain, and upon these the elements derived from wave-work are lightly engraved and embossed. The alluvial cones of the mountains do not find their bases at the level of the upper shoreline, but extend downward uninterruptedly to the bottoms of the valleys, while the shorelines are wrapped about them, all of the greater capes and bays being determined by a pre-existent, rain-wrought configuration. Rain therefore dominated the basin before the lake, and the basin was empty for a long period before it was full.

The same story is told by the deposits. The alluvial cones are subaerial deposits, the lake beds subaqueous; and wherever a section of the latter is obtained upon the margins of the basin they are found to overlie unsorted accumulations of alluvium. The two are so distinct in character that they cannot be confused. The lake beds are fine earths, evenly laminated, and of great uniformity throughout the central district. Toward the margins they usually become coarser, passing into sands at first and being finally exchanged at the shore for thoroughly sorted gravel, smoothed and rounded by the rolling action of the waves. In the alluvial deposits no stratum is widely continuous and few are homogeneous, but coarse and fine fragments are mingled indiscriminately or with an obscure and lenticular bedding.

Form and substance thus conspire to prove that the lake had a beginning as well as an end, and that before its inception the basin was for a long time subjected to the ordinary laws of sculpture by the action of rain. It must not be supposed, however, that the period of exclusive rain sculpture was one of great aqueous precipitation, but rather the contrary. A large rainfall would fill the basin and subject its lower parts to lacustrine influence. Only a small precipitation, or a climate of relative aridity, could leave the lower valleys dry and give the entire slope to the unrestricted action of such rain as fell. The evidence of ancient rain sculpture in the lower slopes is therefore in this case the evidence of an arid climate instead of a humid one, and our data warrant the belief that the Bonneville epoch was an episode of moisture interpolated between the aridity of the present day and the aridity of the past.



ALLUVIAL CONES.

It is probable that with the diminished rainfall of the present day the wear of the mountains is slower than during the Bonneville epoch, and it is probable that it was similarly slow during the ante-Bonneville period of aridity. Detritus was therefore furnished less rapidly for the construction of the old alluvial cones than for the building of lake strata, and the magnitude of the cones as compared with the lake beds would lead us to ascribe an immensely greater duration to the ancient dry climate than to the epoch of moisture. It is to be borne in mind, however, that a moist period could make its record by shorelines and lake beds only on the condition of the existence of a closed basin, and it is a matter of geologic history that the Bonneville Basin came into being after the deposition of the latest Tertiary deposits known in the region. It is impossible to tell what fraction of the work of the construction of the alluvial cones was performed after the occurrence of the upheavals and subsidences to which the basin owes its origin, and it is therefore impossible to assign even a proximate limit to the duration of the dry epoch demonstrated to have preceded the Bonneville humidity; but it may be asserted with confidence, that the duration of the earlier period was not merely greater than that of the Bonneville but many times greater, for the condition of the various passes which constitute the lower parts of the rim of the basin suffices to show that the waters were not discharged for a very long period antecedent to the Bonneville outflow.

It follows from what we have said of the sculpture of mountains that an alluvial foot-slope is a necessary concomitant of an angular summit. It is impossible that the higher parts should be carved into peaks and scored into gorges without the accumulation of eroded material at the foot of the slope. But in the central parts of the Bonneville Basin, in the midst of the Great Salt Lake Desert, there are mountain peaks springing abruptly from the lake sediment without visible pediments of alluvium. They jut from the plain as abruptly as islands jut from the ocean, and the resemblance is so striking that it has caught the eye of the frontiersman and prospector, and the peaks have received such names as "Silver Islet," "Desert Island," and "Newfoundland." The resemblance involves something more than mere analogy, for they are really submerged, having their bases buried by the lacustrine deposits of Bonneville and earlier lakes. They serve to carry us back one step farther in the history of the basin, for they record a time when the visible lacustrine strata did not exist and when the relation of altitudes was such that the detritus from the peaks, instead of being arrested where it now is by the plain, was free to descend the slope for an additional distance of at least some hundreds of feet. At that time the basin may not have been a basin and may have permitted its drainage to escape to the ocean; but during the whole period required for the burial of the mountain bases its barriers must have been in existence so as to render the desert the repository of detritus. Before Bonneville Lake, therefore, there was a long history of smaller lakes in the Bonneville Basin. This history we cannot read in detail because the sediments which record it lie beneath the plain, completely buried by those of the later lake.

Putting together all these several elements we may construct the Bonneville history with some confidence:

1. A long period of dry climate and low water, during which the mountains of the desert were buried and the alluvial slopes of marginal mountains were formed.
2. A period of moist climate and high water, during which the Yellow Clay was deposited and the shore was carried within ninety feet of the summit of the lowest barrier of the basin.
3. A period of extreme dryness, during which the lake disappeared and its salt was buried.
4. A relatively short moist period, during which the White Marl was thrown down and within which the water overran the barrier, diminishing by erosion its height at the point of discharge.
5. The present period of relative dryness.

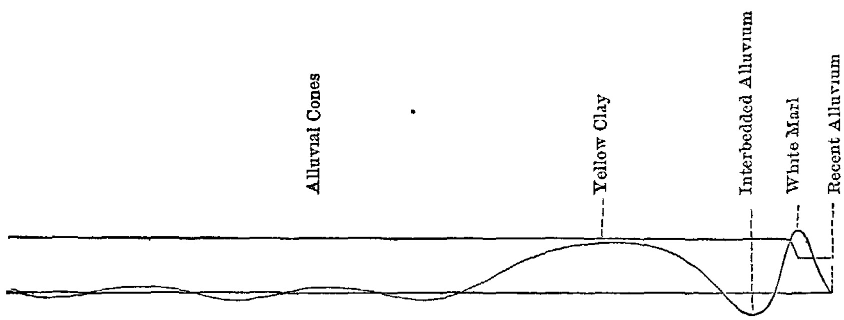
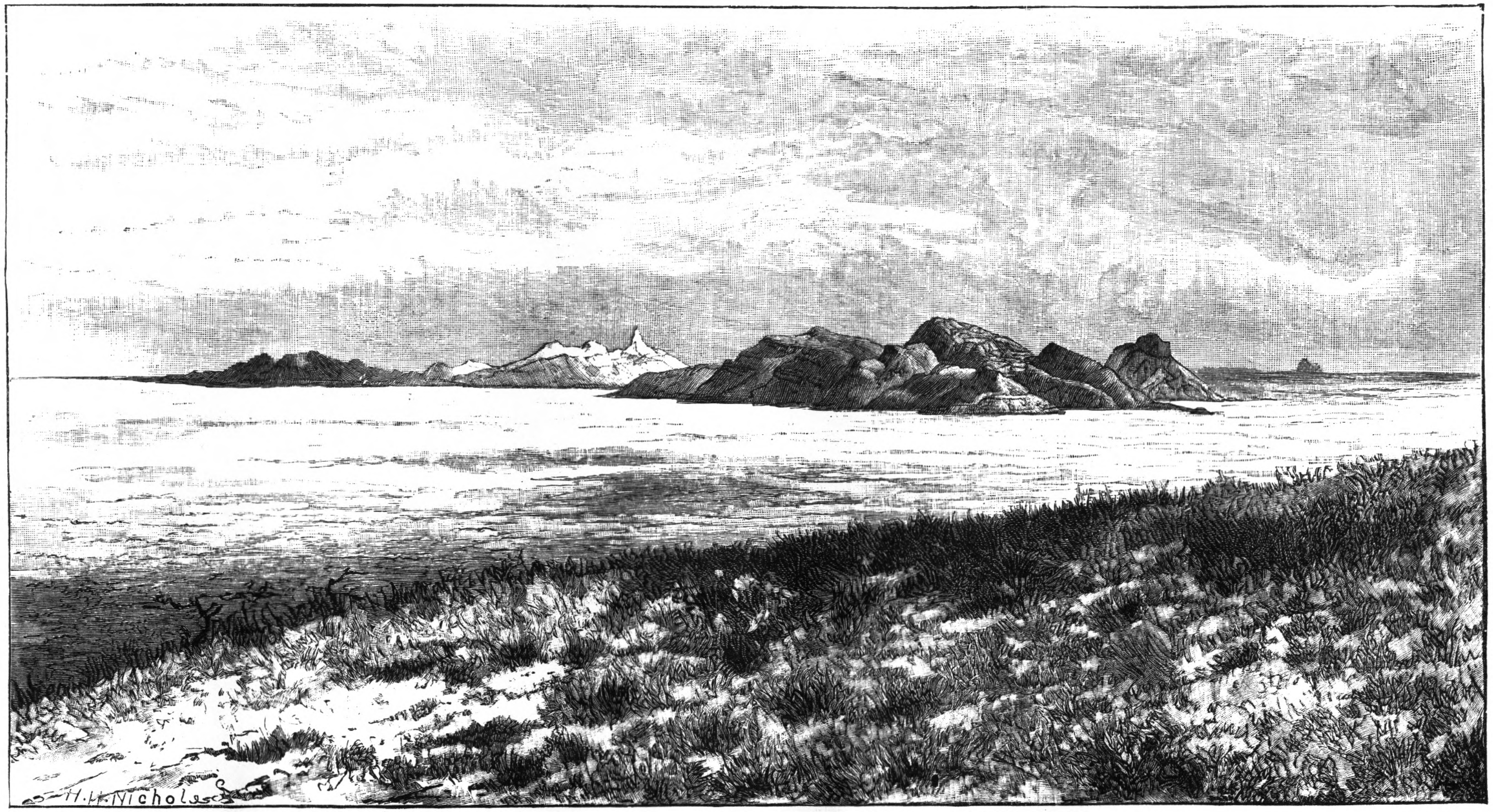


FIG 20 —Curve of the Quaternary Oscillations of Climate, as recorded by Lake Bonneville

In the diagram an attempt has been made to give a graphic representation of these oscillations of climate. The lower horizontal line represents the dry climate of the present day. The upper horizontal line represents a climate with such a degree of moisture as to permit the basin to overrun its rim. The relative proportions of the curve are, of course, tentative and crude, for the investigations have afforded no absolute time gauge and very little that can be interpreted in time ratios. We know that the moisture was greater at the time of the second rise than at the time of the first, but have no means of telling how much greater. We know that the earlier rise was of longer duration than the later, but do not know how much longer, because the Yellow Clay which represents it has never been seen in complete section. It is theoretically probable that the inter-Bonneville dry epoch was characterized by a climate more arid than the one we experience, but we cannot say how much its aridity exceeded the present, and of its duration we only know



VIEW ON GREAT SALT LAKE DESERT, SHOWING MOUNTAINS HALF BURIED BY LAKE SEDIMENTS.

that it was far briefer than that of the dry period preceding the first rise of the water.

If it were possible to replace this tentative curve by the actual curve of climatic oscillation for the same period, we should undoubtedly have a form less simple in its character. Indeed, there is abundant evidence that each great rise and fall recorded by the shorelines of Lake Bonneville was interrupted by intervals of reverse motion, the rising water occasionally hesitating and sinking for a time, and the falling water occasionally oscillating upward. It may be asserted with some confidence, however, that the history includes but two *great* waves. If the water had many times, instead of twice only, risen to the upper levels of its range, the tell-tale sediments could not have failed to record the intervening subsidences.

The student of the climate of the Glacial Epoch will be interested to compare this history with that deduced from the glacial beds of Europe and the United States, and if he correlates the second humid wave with the Reindeer Epoch of English geologists he will be surprised to find that in Utah the climate was more severe than during the first maximum, although maintained for a shorter period. It is yet too early, however, for final conclusions, for the Bonneville history is but one of a group, and when Lake Lahontan and the other lakes of the ancient family have received a similar treatment the conjoint verdict of the whole may be notably different from the single verdict of an individual lake. There is a partial blank in this history, regarded as a history of climate, embracing the period while the lake overflowed, for then its water level ceased for a time to be an index to the amount of precipitation. There is another partial blank during the inter-Bonneville desiccation. It is by no means improbable that these will be filled by the evidence to be gleaned in other valleys of the Great Basin.

Before leaving the subject of the chronology of the lake, I cannot forbear to add my testimony to that which other geologists have rendered of the extreme brevity of the Quaternary as compared with other divisions of geologic time. If it could be measured in years its extent might excite our wonder, but when gauged by those imperfect standards to which geologists are limited it appears of extreme insignificance because overshadowed by the greater magnitude of all other elements of geologic duration. The weight of the bowlder which we strive to lift may seem great because our strength is small, but it is a mere trifle as contrasted with the distant hill, and we have no terms by which to compare it with the mountain beyond. Such differences the geologist must confess his inability to measure, but he is none the less impressed with their magnitude.

If we attempt to compare the duration of the Bonneville epoch with that of earlier portions of geologic time, we find no criteria available except those afforded by the relative thickness of the accumulated deposits, and these are practically valueless because rates of deposition are entirely controlled by extraneous conditions of which we have no knowledge in the case of the older deposits. A better, but yet a very inadequate, idea may occasionally be gleaned of the relative antiquity of different events by comparing the subsequent erosion. Rain, the great sculptor of natural forms, attacks all exposed surfaces of land, and whatever may have been their original shapes, works them over until they accord to certain types embodying a certain system of laws. Its attacks are renewed with unwearied persistency until its ends are accomplished. The sediments of a dead lake are measurably protected from it because they occupy depressions and have few slopes steep enough to be worn by running water, but shorelines are fully exposed and are powerless to resist. Nevertheless, the Bonneville shores are almost unmodified. Intersecting streams it is true have scored them and interrupted their continuity for brief spaces, but the beating of the rain has hardly left a trace. The sea cliffs still stand as they first stood, except that frost has wrought upon their faces so as to crumble away a portion and make a low talus at the base. The embankments and beaches and bars are almost as perfect as though the lake had left them yesterday, and many of them rival in the symmetry and perfection of their contours the most elaborate work of the engineer. There are places where bowlders of quartzite or other enduring rock still retain the smooth, glistening surfaces which the waves scoured upon them by dashing against them the sands of the beach.

When this preservation is compared with that of the lowest Tertiary rocks of the region—the Pliocene beds to which King has given the name "Humboldt"—the difference is most impressive. The Pliocene shorelines have disappeared. The deposits are so indurated as to serve for building-stone. They have been upturned in many places by the uplifting of mountains; elsewhere they have been divided by faults, and fragments dissevered from their continuations in the valley have been carried high up on mountain flanks, where erosion has carved them in typical mountain forms.

If we look back to the lower Tertiary of the adjacent plateau region of Utah, Colorado, and Arizona, we find a still greater contrast, for the Eocene of the Colorado Basin has not merely lost its shorelines and been upturned and faulted; its whole great sheet, with the exception of a few marginal fragments, has been excavated and carried away, and with it have disappeared several thousands of feet of the strata that lay beneath it.

The date of the Bonneville flood is the geologic yesterday, and calling it yesterday we may without exaggeration refer the Pliocene of Utah to the last decade; the Eocene of the Colorado Basin to the last century—and relegate the laying of the Potsdam sandstone to prehistoric time.

III. THE LAKE AND THE GLACIERS.

All geologists who have studied the Quaternary lakes of the Great Basin and at least one student of a Quaternary lake of the Old World, have agreed in regarding them as the contemporaries of the Quaternary ice-fields, but their conclusions have been reached purely by analogy. The moraines and other traces left by the ancient ice-fields are so fresh in their appearance, so little impaired by the waste of time, that they are regarded as the record of an epoch immediately preceding the present time. The same is true of the shorelines and deposits of the ancient lakes. It is further known that the Epoch of Ice was preceded by a still longer epoch not so characterized, just as the Bonneville Epoch was preceded by a longer epoch of relative dryness. More than this, the changes of climate were analogous in character. It is a matter of dispute whether the Glacial climate differed from that which preceded and followed it by an excess of moisture, or by a lowering of temperature, or by both. But whatever was its character it must have been one in which the ratio of precipitation to evaporation was relatively great; and that is the sole condition necessary to the production of the Quaternary lakes. But while this analogy is cogent and the conclusion to which it leads finds no opponent, it would, nevertheless, be more satisfactory to establish the relation by direct observation, and it was therefore with great interest that attention was turned during the field work to a locality at the western base of the Wasatch Range where the moraines of three ancient glaciers stretch below the limit of the ancient lake. It was anticipated that if the glaciers attained their maximum development after the culmination of the lake their moraines would be found either to consist partly of plowed-up lake beds or else to rest upon lake beds; and if the history of the lake was subsequent to that of the glaciers, it was anticipated that the moraines would be found partially buried by the lake sediments or else scored by the shorelines. Neither of these anticipations was realized. Two of the terminal moraines were found to be entirely dissociated from the lake beds, so far as could be ascertained, and they bear no trace of wave sculpture. The remaining terminal, that of Little Cottonwood Cañon, is partially buried by a sandy deposit that bears some resemblance to a river delta, but which has been so deformed by a system of faults by which the region has recently been shattered that its true character cannot be asserted with confidence. The locality failed therefore to yield the crucial evidence for which search was made, and practically afforded no contribution to the subject. There is reason to hope, however, that a series of localities announced by Mr. Russell as recently discovered upon the eastern flank of the Sierra Nevada will prove more communicative. His reconnaissance has served to show that the glaciers there descended and retreated more than once, and that their history has a determinable relation to that of the Quaternary predecessor of Mono Lake.

IV. THE LAKE AND VOLCANIC ERUPTION.

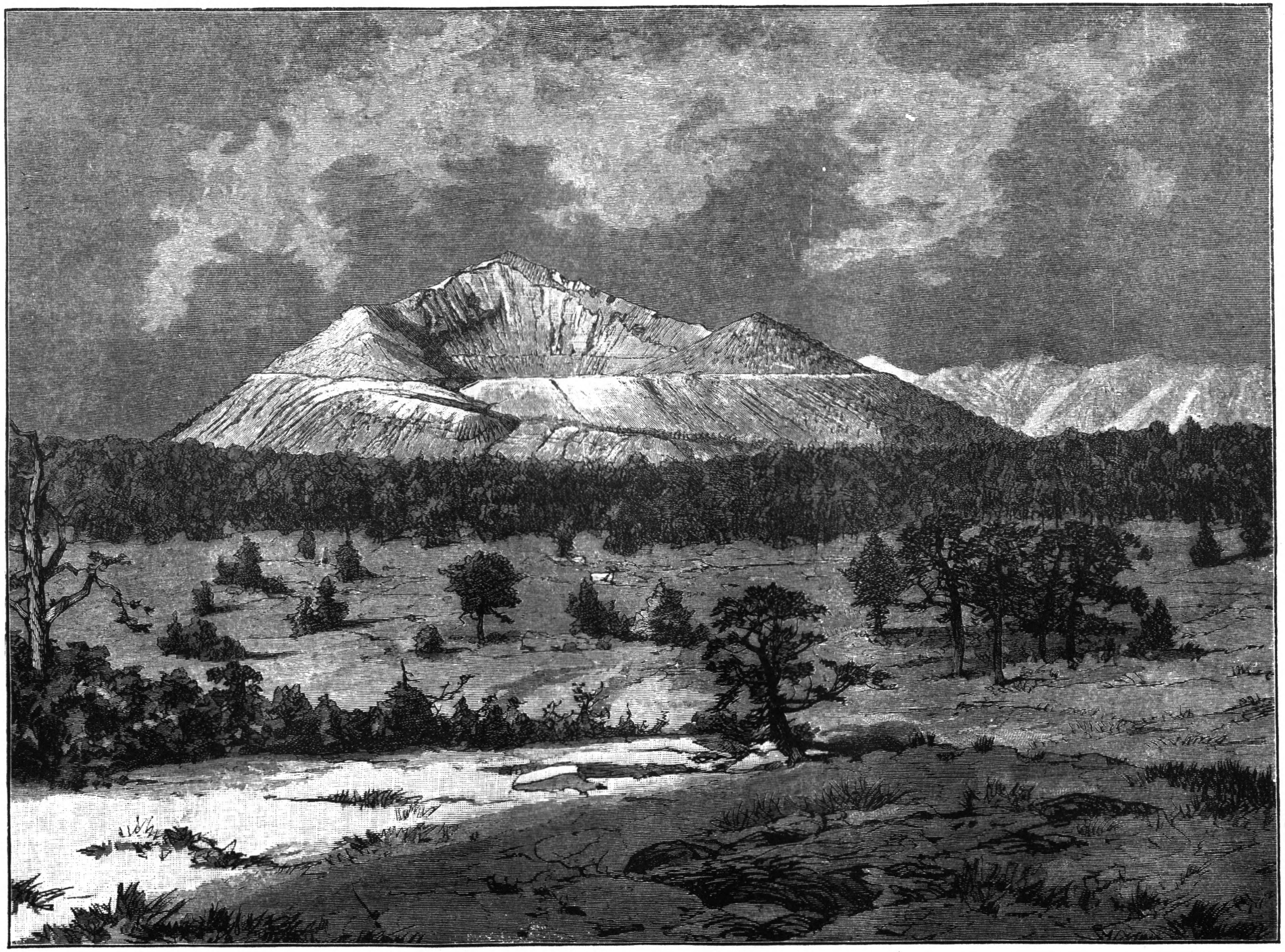
The discovery of Richthofen that the various lavas erupted in Western North America had a definite, uniform order of sequence has been abundantly verified by all later investigations. And not only do his successors in that field of inquiry find the order of sequence in every place the same, but some of them at least are disposed to assign a definite geologic date to the appearance of each variety of eruptive rock. The cycle of eruptions to which his conclusion applies belongs to the Tertiary and Quaternary history of the region, and the latest in order of the erupted rocks is basalt. Basalt is therefore the only volcanic rock the western geologist would expect to find associated with the phenomena of the Quaternary lakes, and so far as Lake Bonneville is concerned it certainly is the only rock thus associated. The only other eruptive rock known to appear within the circle of the shorelines is rhyolite, and all of its masses are so ancient that they have lost by erosion all traces of their original forms. The same may be said of some basaltic masses, but the greater number still preserve their original tabular shapes, and a few are still furnished with craters of cinder and slag. The majority evidently antedate the epoch of the lake, for they bear upon their sides the sculptured shore marks, and support on their flanks or backs the lake-spread sediments. To this rule, however, there are a few exceptions, and these serve to bring down the period of basaltic eruption to a date subsequent to the last rising of the water.

In the vicinity of the town of Fillmore the Sevier Desert is diversified by a group of hills composed of volcanic ejecta, recording the latest plutonic activity within the Bonneville Basin. The extravasated material appears in three forms, viz., *coulées* of lava, cratered cones of slag and cinder, and cratered cones of tuff.

The *coulées* are of the usual type, but by reason of the flatness of the surface upon which they flowed they are broadly spread, so as to constitute fields rather than streams of lava. In the interior they are of compact basalt, but superficially they are for the most part greatly inflated by bubbles.

The cratered cones mark in every case the points of issue of *coulées* and are themselves the product of explosive action. They are composed entirely of fragments which were hurled into the air from the vent and fell about the sides, piling up circular barriers, and they are of two distinct kinds, characterized by two kinds of fragments, slag and tuff.

In the case of the slag cones there is every evidence that a large share of the ejected material was either molten or pasty at the time it reached the earth, the successive pellets being flattened out by the force of the impact and fitted to the surfaces upon which they alighted. The in-



PAVANT BUTTE, A SUBMARINE VOLCANO.

teriors of the craters are stuccoed with clots of spongy lava, which adhered in so soft a condition as to flow and drip more or less after they became attached. Besides these pasty masses there is a great quantity of light, brittle, spongy material, such as has been called "cinders" and "lapilli," and it is possible that this constitutes the greater bulk, but the surfaces are largely composed of taffy-like slag.

In the tuff masses, on the other hand, there is nothing to show that any of the ejected material was soft at the time it reached its resting place. Lapilli or cinders, similar to those which enter into the composition of the slag cones, but finer grained, make up nearly the entire mass, and are cemented together in a coherent body which betrays an obscure bedding and has everywhere a brecciated appearance; in it are embedded at rare intervals both rounded and angular fragments of basalt, and these, although they have evidently reached their position by violent ejection, are not of a scoriaceous or frothy texture, but are compact. These cones appear to have been formed by subaqueous eruption, and are free from slag because the presence of water made it impossible for small fragments to escape from the vent in a hot condition.

The most conspicuous of the cones is Pavant Butte, otherwise known as the Sugar Loaf, which stands solitary on the plain, midway between the towns of Fillmore and Deseret. It is composed exclusively of tuff and does not form a complete ring, but has a semi-lunar base, and appears never to have been closed upon the south side. Midway between its base and its summit it is encircled by a terrace, carved by the waves at the highest stage of the lake, and there is evidence that the two processes of wave sculpture and volcanic construction were carried forward, in part, simultaneously, a first incision by the waves having been filled by new ejecta, and then partially reopened by later wave action. Pavant Butte, therefore, is the product of eruptions which occurred while the desert was covered by the lake, and the last addition to it was made during the highest stage of the lake.

At its base, and apparently constituting its foundation, there is a lava-bed half concealed by lacustrine sediments, but these sediments consist only of the White Marls, and nowhere exhibit the underlying Yellow Clay. It is probable, therefore, that the *coulée* outflowed during the inter-Bonneville epoch of low water.

A second crater, to which the name Tabernacle has been attached, is surrounded by two rims, the outer and older of which consists of tuff and the inner and newer of slag. No shorelines are carved on either tuff or slag, and no lake beds rest upon them. The eruption began, therefore, during a high stage of the lake and was continued or renewed after the water had fallen below the level of the vent. There is reason to believe, however, that the lake had not entirely disappeared, for a lava field which outflowed from the same vent during the formation of the slag cone, bears upon its outer margin the traces of the Provo shoreline. There is evidence also, in the exceptional thickening of the lava bed at its outer edge, that it encountered as it flowed the refrigerating influence of standing water, and it is therefore concluded that the date of the last eruption from this vent was during the Provo stage of the lake or just before the final subsidence of the water.

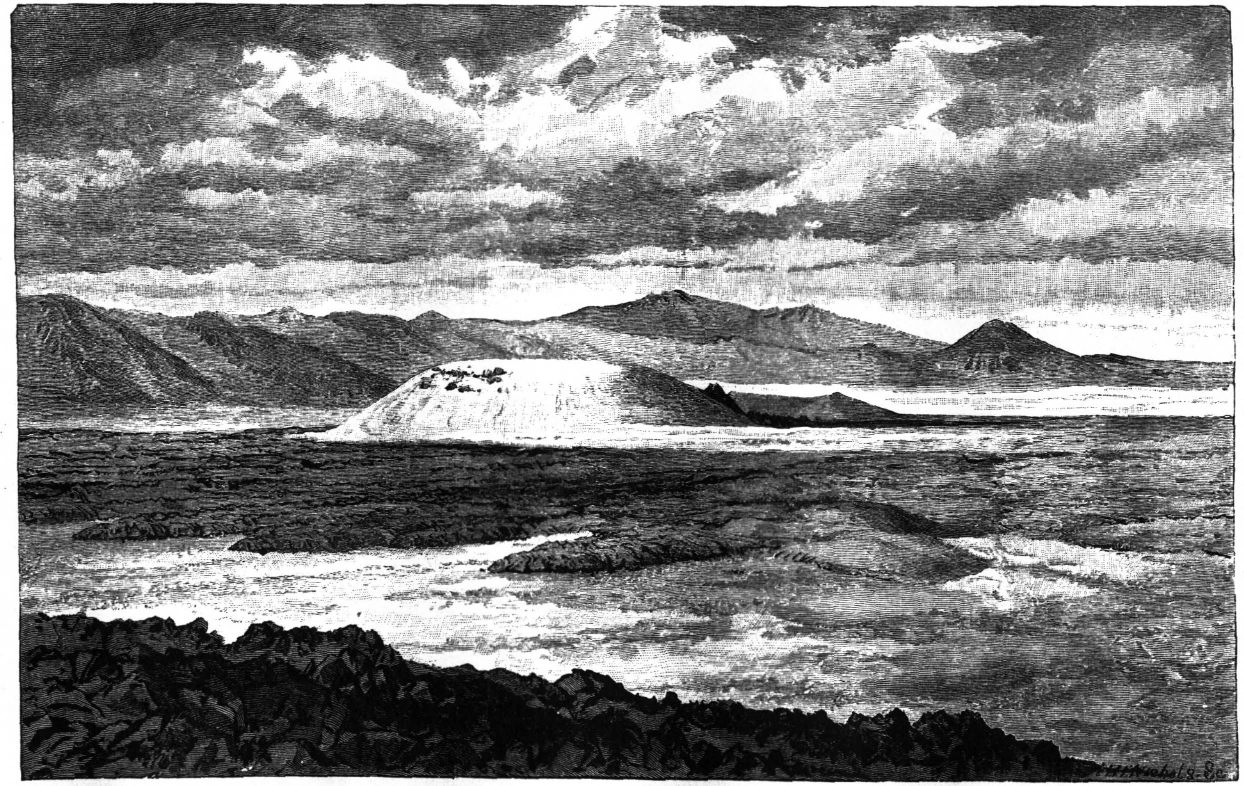
A third group of craters, known as the Ice Spring group, is still more recent, and with its associated *coulées* overlies the latest of the lake beds, while no shorelines whatever impinge upon it.

The period of volcanic activity therefore continued entirely through the epoch of the lake, and was brought down so nearly to the present time that there is no warrant for assuming that its end has yet been reached. No one who has seen the fresh, black, unworn surfaces of the most recent *coulées*, still absolutely barren of vegetation, could be affected by surprise if it should some day be announced that the now quiescent fires had again broken forth.

V. THE LAKE AND MOUNTAIN BUILDING.

It is not many centuries since the learned and ignorant alike regarded mountains as the embodiment of stability and permanence; but since the birth of geology it has been abundantly shown, first, that the sites of many individual mountains were in the remote past occupied by plains or oceans; second, that in the remote past there were mountains where now are only plains; and, third, that on account of the unceasing erosive work of the elements no mountain can be permanent. Each mountain therefore has a history,—involving its inception, its growth, its decay, and finally its extinction. With slight exception all mountain growth is by subterranean action, and if we exclude volcanic mountains from consideration we may refer mountain building almost wholly to upheaval. With slight exception the destruction of mountains is by erosion, and in most mountains the formative and destructive processes at some time coexist. So soon as the formation of a mountain is initiated, slopes are created which enable rain and streams to wear away its surface, and since this wear never ceases until its final and complete destruction, it is contemporary with every stage of growth except the initiative. The magnitude of each mountain at any time represents the excess of formation over destruction, of upheaval over erosion. Actual increase takes place only when the growth exceeds the decay, and actual decrease only when the decay by erosion is more rapid than the growth by upheaval.

Up to this point all geologists are agreed; but there is a difference of opinion in regard to the rate of formative action, and upon this difference investigators may be regarded as divided into two classes, each of which represents a tendency of thought. On the one hand are those who conceive that each mountain rose more or less abruptly, either by a sin-



TABERNACLE CRATER AND LAVA BEDS.

gle movement at a definite point of time, or else by a small number of such movements separated by long intervals of time. On the other hand are those who think the formative movement is continuous and slow, variable indeed in its rate, but never in any large way paroxysmal. Undoubtedly there are still others who hold to a middle ground of opinion, but in a general way geologists tend to catastrophism on the one hand or to uniformitarianism on the other.

Neither of these views is open to the charge of being purely speculative, but each can claim in its support a body of unquestioned facts of observation. The advocates of each include men of wide experience in the direct study of nature, and who must be supposed to have founded their ideas upon that study, and not to have been controlled by such preconceptions as closet philosophy is apt to engender.

The two theories in regard to the origin of mountains are correlated, however, with certain notions concerning the condition of the interior of the earth, which are necessarily to a great extent speculative. To the catastrophist it is natural to conceive the crust of the earth as a body of great rigidity and strength, resisting the force applied to it by subterranean action until by cumulation it had become very great, and then suddenly yielding. To the uniformitarian it is natural to conceive the crust of the earth as in a high degree mobile, responding promptly to all subterranean influences and reflecting them in the configuration of its surface. These differences of view are in the main independent of those other differences which are concerned with the thickness of the crust, and some physicists who are disposed to assign a great thickness to it or even to regard the entire mass of the earth as solid are at the same time of the number who ascribe an extreme mobility to its material.

To the catastrophist the growth of each existing mountain is a work of the past, the present day witnessing only its decay. He does not necessarily regard the work of mountain making as complete and look to the gradual extinction of mountain masses from the present time onward, but he at least views the present as a period of inactivity and conceives the mountains of the future as the products of paroxysms yet to occur. To the uniformitarian the present is, equally with the past, an epoch of mountain building, and whether the present rate be more rapid or less rapid than that of the past, the process is ever the same. He therefore expects to obtain from a study of that which is actually transpiring such criteria of judgment as will enable him to understand the revolutions of the past.

Erosion begins with the inception of a mountain, but is at first a slow process, because the gentle initiative slope gives to flowing water only a small velocity, and with a small velocity its erosive power is feeble. As the mountain rises the declivities of its sides increase and the eroding streams have greater power; so that the rate of waste of a mountain depends upon its height. There are other considerations which affect the matter, and the controlling conditions are somewhat complex, but it is true in a general way that as mountain masses grow the rate of waste increases much more rapidly than the altitude. It was hence argued most cogently by Powell that all large mountains are young mountains, and from the point of view of the uniformitarian, it is equally evident that all large mountains must be growing mountains; for if the process of growth is continuous and if a high mountain melts with exceptional rapidity before the play of the elements, it is illogical to suppose that the uprising of any mountain which to-day is lofty has to-day ceased. If, therefore, it were possible to ask of all great mountains the question whether they are now growing, and obtain an answer, a solution might be reached of the problem which has divided investigators; and for this reason great interest attaches to any answer which can be obtained in the case of any mountain. We shall presently see that the lake vestiges help us to an answer with regard to some of the mountains of Utah.

The origin of continents is closely allied to that of mountains. It is known by the same sort of geologic evidence that every part of every continent has been at some time submerged beneath the ocean, and that some parts have been many times submerged, and it has been established with equal certainty that at least some parts of the ocean have in the ages of the past been continental. The submergence of the land now continental has not been equable in all parts, but some districts were flooded while others were uncovered, and *vice versa.* Those districts which are at any time submerged are then subject to sedimentation, and those which stand as land surfaces are more or less degraded by erosion; but erosion and sedimentation both have their limits at sea level, and have no power either to build the sea bottom into land or to submerge the land. All the great changes have been produced by earth movements of uprising and depression, and must be referred to the action of subterranean forces either similar to or identical with those which have produced mountains.

With reference to the rate of continental movements, there is not the same conflict of opinion as concerning the growth of mountains, but they are generally regarded as slow and continuous. And there are none to question the fact that there have been notable local changes in the height of the land since the close of the Glacial Epoch and even some measurable changes within historic time. The evidence by which these movements are known has been derived almost exclusively from the vicinity of the ocean, but there are a few inland localities which afford facilities for their determination. The basin of Lake Bonneville is one of those localities.

Each shoreline of the old lake was originally the tracing of a level surface and was therefore horizontal. If it is not horizontal now, orographic movement must have intervened, and the difference of level between any two points of the same shore measures exactly the differential movements of the two points. It is, of course, conceivable, and it is indeed far from being improbable, that the entire basin has bodily moved upward or downward in the same interval of time, but of such changes the shorelines can give no proof; their evidence is limited to the relative vertical movements of different parts.

The value of the shorelines as an orographic record was early appreciated, and great pains were taken, not only during the past summer but at every opportunity in previous years, to ascertain by the aid of the spirit level the altitudes of the Bonneville and Provo shores at as many points as possible. The numerous railroad surveys which now intersect the region made it possible by running short accessory lines of leveling to compare together widely separated portions of the coast, and still other comparisons were made by running levels from the water surface of Great Salt Lake at various points of its margin to the ancient water margins upon contiguous mountain slopes. Where the use of the level was impracticable recourse was had to the barometer, and although its determinations are far less trustworthy they were made with such precautions and under such restrictions that the additional information they convey cannot be regarded as entirely valueless. The summer's work increased the number of determinations of the Bonneville shoreline by spirit level to seventeen, and of the Provo shoreline to nine. In localities where no means were available for the determination of the absolute height of the water marks, it was nevertheless frequently possible to ascertain the relative altitudes of the different shores, and this was repeatedly done; so that the difference of altitude of the Bonneville and Provo shorelines is somewhat more widely known than the absolute altitude of either.

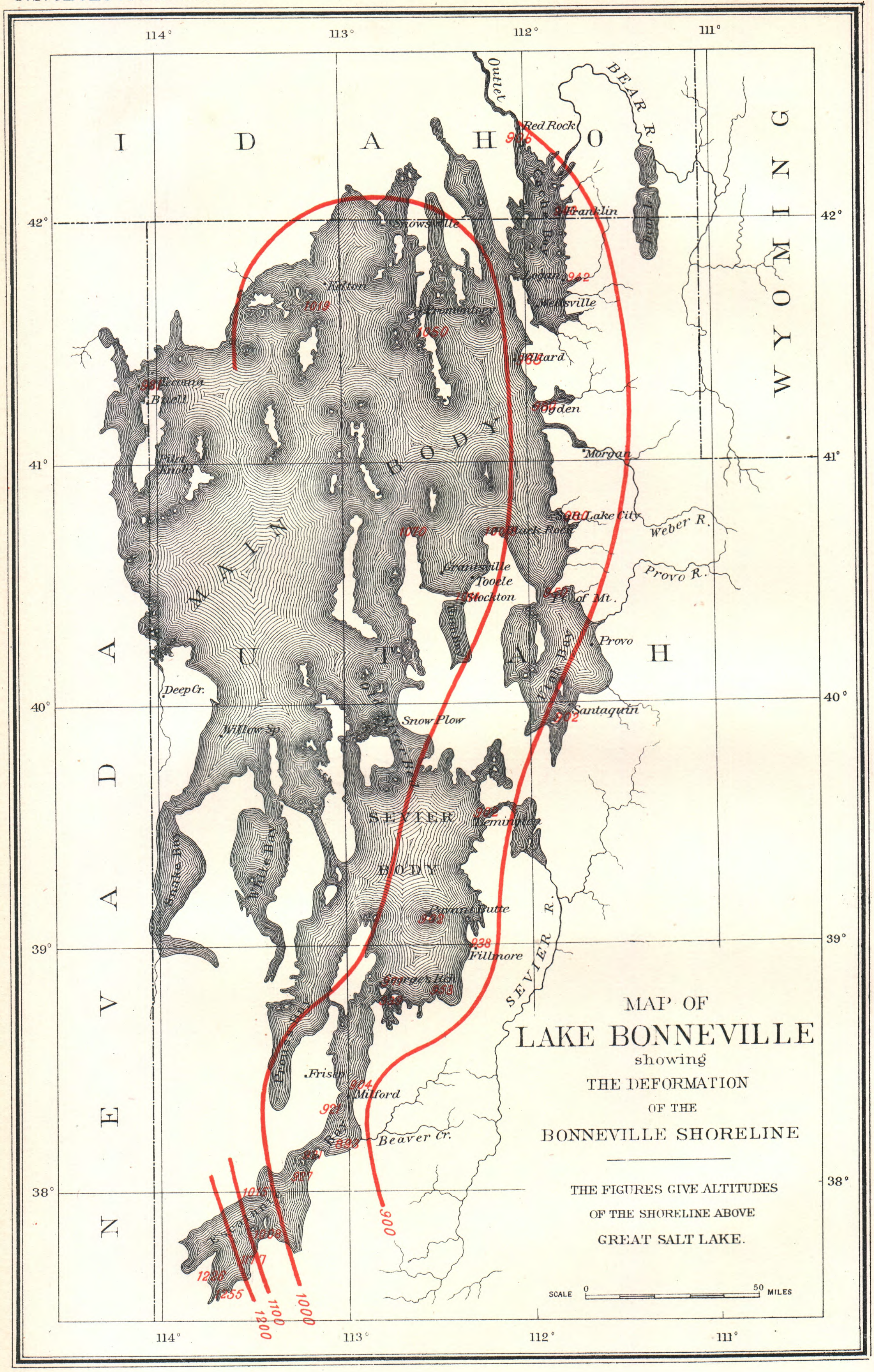
The general results of the investigation are, first, that neither of the two shorelines is now horizontal, and, second, that the two are not parallel; whence it is evident that the region has been the scene of orographic movements both during the existence of the last high stage of the water and since the final subsidence. The detailed results are not so simply stated, but they are too interesting and instructive to be passed in silence.

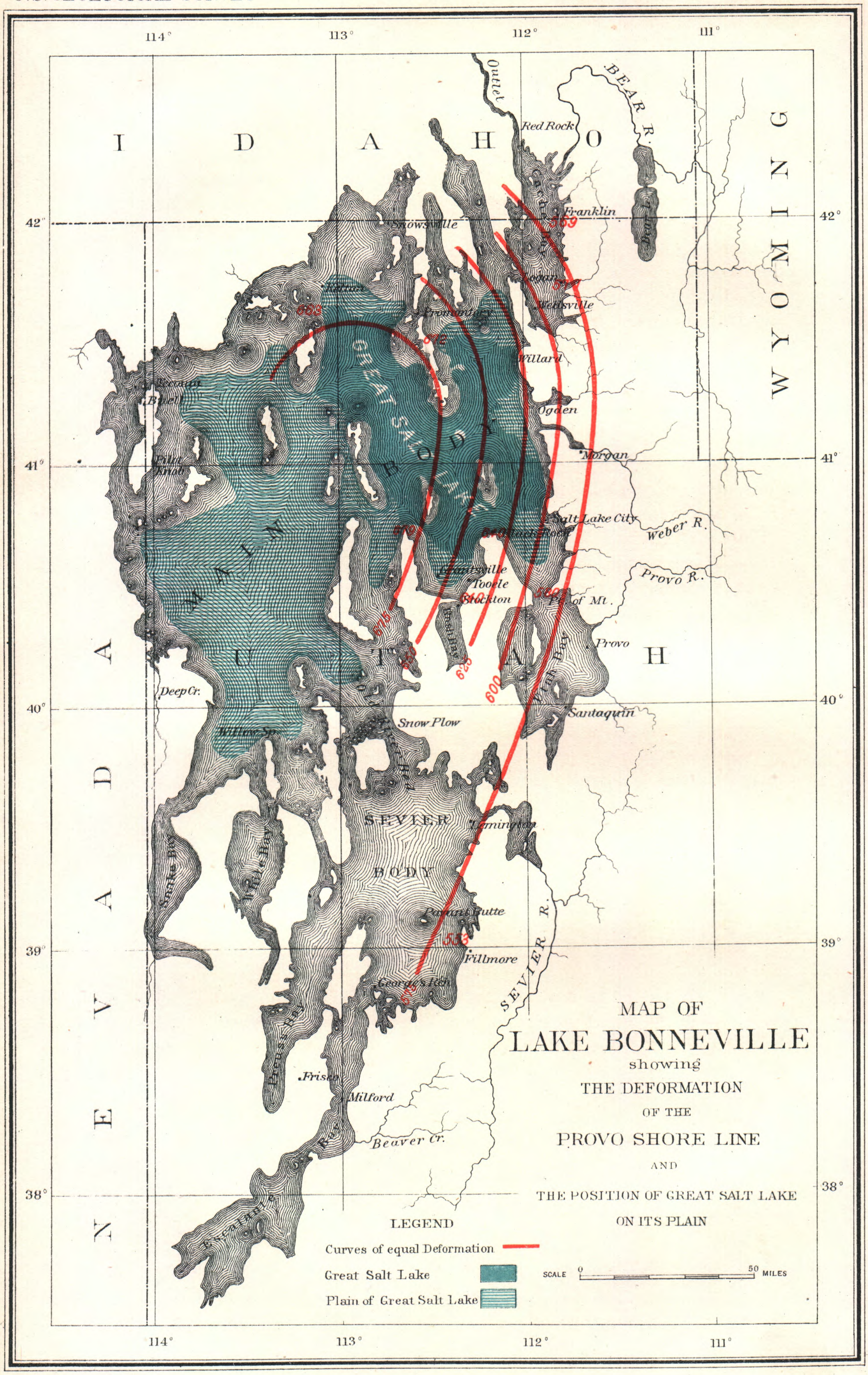
At the time of its formation every part of the Bonneville shoreline (for example) fell within the same horizontal plane, and we may conceive that plane as extending indefinitely not only through the mountains beyond the water margin but over the valleys filled by the water, and as having a fixed relation to the bottom at every point. Every orographic movement which took place subsequent to the formation of the shoreline would have the effect of deforming this imaginary plane; and if we were able to determine at all points the present position of the plane we could draw a perfect picture of the deformation effected by subterranean forces in the given interval of time. The only portion of the plane, however, which can now be determined is that marked by the shoreline, and our knowledge of the deformation cannot therefore be perfect. Nevertheless, the ancient lake had so sinuous a shore, and its surface was so frequently interrupted by islands, that a highly instructive restoration of the deformed plane could be made if only we knew the present height of every part of the shoreline; and even from the imperfect data which have been gathered it has been practicable to obtain a rude idea of the general character of the displacement.

If an outline of the lake be traced on a map, and if all points of the old shoreline which have now the same altitude be connected by a line, it is evident that this line will constitute a contour* of the surface of deformation. It is further evident that if a number of such lines be drawn, each at a different height, and if their several heights be chosen so as to form a uniform series, the lines will constitute a contour map of the deformed surface. An attempt was made to do this.

Three maps of the lake were prepared, and upon them the data were plotted. On the first every locality at which the height of the Bonneville shoreline had been determined was marked by writing the figures which express, in feet, the altitude of the shoreline at that point above the water surface of Great Salt Lake; on the second the determined heights of the Provo shoreline were similarly plotted; and on the third the determined differences of height between the two shorelines. The data on the first map illustrate changes which have occurred in the interval of time from the formation of the Bonneville shoreline to the present day; those on the second illustrate changes which have taken place between the formation of the Provo shoreline and the present day; and those on the third illustrate changes occurring after the formation of the Bonneville shoreline but before the completion of the Provo. When it was attempted to draw contour lines through and among the determined points of the third chart, it was found that the data were so irregular that they could be satisfied by no simple system of contours, and of the numerous complex systems which could be invented in conformity with them there was no single one entitled to preference. The result was therefore indeterminate. The chart of the post-Provo deformation proved more tractable, and all of its data were found to consist well with a simple system of contours drawn at vertical intervals of 25 feet. The post-Bonneville chart, which in the presence of full data should represent the combined result of the other two, was found to hold an intermediate position in facility of interpretation, admitting of a scheme of contours with vertical intervals of 100 feet. The post-Bonneville and post-Provo charts are reproduced in Plates XLII and XLIII.

*A contour is a device for the expression of topographic forms. Conceive a hill to be intersected by a horizontal plane; the line in which the plane meets the surface of the hill is a contour of the surface, and has everywhere the same height. If there are many intersecting planes parallel to each other and separated each from each by the same space, the corresponding contours constitute a system. It is evident that where the slope is steep, contours will fall near together, in a horizontal sense, and where it is gradual they will fall farther apart. When the contours of a hill are traced on paper they constitute a contour map. In practice the lines are not drawn on the ground, but on paper only, as a means of expressing the form of the ground.


MAP OF
LAKE BONNEVILLE
showing
THE DEFORMATION
OF THE
BONNEVILLE SHORELINE
THE FIGURES GIVE ALTITUDES
OF THE SHORELINE ABOVE
GREAT SALT LAKE.
SCALE 0 50 MILES
114° 113° 112° 111°
42° 41° 40° 39° 38°
IDAHO
WYOMING
NEVADA
UTAH
MAIN BODY
SEVIER BODY
Outlet
BEAR R.
Red Rock
Franklin
Snowsville
Logan
Wellsville
Kelton
Promontory
Willard
Ogden
Morgan
Salt Lake City
Weber R.
Provo R.
Black Rock
Grantsville
Tooele
Stockton
Pt. of Mt.
Provo
Utah Bay
Santaquin
Snow Plow
Deep Cr.
Willow Sp.
Snake Bay
White Bay
Leamington
Pavant Butte
Fillmore
George's Rch
Frisco
Milford
Beaver Cr.
SEVIER R.
900
1000
1100
1200


MAP OF
LAKE BONNEVILLE
showing
THE DEFORMATION
OF THE
PROVO SHORE LINE
AND
THE POSITION OF GREAT SALT LAKE
ON ITS PLAIN
LEGEND
Curves of equal Deformation
Great Salt Lake
Plain of Great Salt Lake
SCALE 0 50 MILES
114°
113°
112°
111°
42°
41°
40°
39°
38°
IDAHO
WYOMING
UTAH
NEVADA
GREAT SALT LAKE
MAIN BODY
SEVIER BODY
BEAR R.
Outlet
Red Rock
Franklin
Snowsville
Logan
Wellsville
Promontory
Willard
Ogden
Morgan
Salt Lake City
Weber R.
Provo R.
Tooele
Stockton
Provo
Utah Bay
Santaquin
Deep Cr.
Snow Plow
Lemington
Pavant Butte
Fillmore
SEVIER R.
Frisco
Milford
Beaver Cr.
Snake Bay
Preuss Bay
Escalante
Bay

Referring to Plate XLII it will be seen that the figure of deformation of the Bonneville shoreline exhibits at the north, in the district of the main body of the lake, an axis of uplift, coinciding approximately with the 113th meridian. The altitudes determined at Promontory and near Grantsville, points which lie slightly to the east of that meridian, are greater by about 100 feet than those along the eastern and western shores of the old lake. The westward slope of the anticline was demonstrated by a single station only, that near the town of Tecoma, and was not traced farther south, but the eastward slope was traced continuously southward along the eastern shore of the old lake quite to its southern end. At the extreme southern limit of the lake, the southwestern shore of Escalante Bay, there is a rapid rise of the surface of deformation toward the west, amounting to 200 feet in a distance of about twenty-five miles. In the northern part of the lake the range of altitudes, all of which were determined by spirit level, is 168 feet. At the south, where a portion of the altitudes were determined by the aid of the barometer, the range is 353 feet.

Plate XLIII exhibits in the same manner the curves of deformation of the Provo surface and the data from which they were drawn. At the Provo level the lake did not extend so far south as the Escalante Bay, and no verification is afforded of the indications there given by the Bonneville shoreline, but at the north the lines curve in a precisely similar manner about an axis in the vicinity of the 113th meridian. The greatest determined altitude of the Provo shoreline above Great Salt Lake is 680 feet, at the north end of the Aqui Mountains, near Grantsville, and the least determined height is 553 feet, at a point known as White Mountain, near the town of Fillmore; the difference between these two, or the range of all the determinations, is 127 feet.

The principal concurrent result of the two systems of measurement—that a region in the middle of the main body of the ancient lake has in recent times been upraised with reference to the adjacent region at the east—finds a curious and interesting support in an entirely independent fact. Great Salt Lake does not occupy a marked local depression but rests upon the surface of a broad plain. Its mean depth is scarcely fifteen feet, and only a slight oscillatory movement of the plain would be necessary to decant its water into another portion. By reverting to the map in Plate XLIII, the reader may obtain a clear idea of the form of this plain and of the position of the lake upon it. He will see also that the Bear River, the Weber, and the Provo, the only large streams which send their water to the plain, all rise to the eastward and enter it from the east side. That is the side of the Wasatch Mountains and associated uplands, which in the time of Lake Bonneville as well as now afforded the chief and almost exclusive water supply of the basin. The sediment which accumulates in the basin is brought to it by the tributary water, and the greater part of it is conveyed by these large streams flowing from the east. If there were no disturbing causes it is easy to see that the detritus would build up the eastern side of the plain and leave the greatest depression at the west. The normal position of Great Salt Lake is therefore in the extreme western part of the basin, between meridians 113 and 114, and its actual position between meridians 112 and 113 must be regarded as abnormal. To account for it there is no hypothesis so simple and satisfactory as that which assumes an orographic tilt of the surface of the plain—a tilt executed at a rate sufficient to overcome the opposing tendency of the silt-bearing streams from the east. The position of the lake therefore conspires with the indication of the deformed ancient lake margins to show that the region of the eastern margin of Lake Bonneville has recently undergone depression and presumably is still subsiding.

The gentle undulations of the earth's crust which are thus exhibited are of the order of those which have produced continents and have continuously modified their contours and limits. Indeed Great Salt Lake is in some sense an epitome of the ocean, and its position within its basin is as thoroughly controlled by orographic displacement as are the greater features of the distribution of land and water upon the surface of the globe.

When these movements are spoken of as "orographic" it must not be understood that they are here concerned in the construction of mountains. The greatest mountain of the district, and the one therefore to which the uniformitarian would look for evidence of recent growth, is the Wasatch, a massive range which forms the eastern wall of the desert. The deformation indicated by the shorelines actually diminished its altitude with reference to parallel and smaller ranges at the west, instead of increasing it, and therefore tended to make it a less conspicuous structure than before. There were, however, other changes in progress, and these, as we shall see, had the effect of really increasing the height of the Wasatch above its base.

It should be said in passing that the only growth of a mountain with which we are here concerned is growth as referred to the adjacent country. It is hardly conceivable that it should ever be known whether the summit of a mountain is at one time nearer the center of the earth than at another, and it is a matter of great difficulty to determine the relation in altitude which a mountain summit bears to our least variable datum plane, the level of the ocean. And even if these relations were known they would not determine the height of a mountain *as a mountain*, because no eminence, however great, would constitute a mountain unless surrounded by land of less altitude. In discussing the growth of a mountain, therefore, we are concerned only with the relation of its crest or its mass to the adjacent lowlands, and we must regard it as actually growing so long as its height increases relatively to the lowlands.

In order to understand the evidence of the recent growth of the Wasatch it is necessary to understand its general structure. In detail its structure, like that of most mountains, is highly complex, but its dominating feature admits of easy statement. Before the mountain rose its site was occupied by horizontal strata. The uplifting by which it was produced had the effect of bending these strata upon one side, but broke them off upon the other, so that at the east the superficial strata of the country are seen to turn up toward the flanks of the range, while no such phenomena appear at the west. The diagram will probably convey the idea more clearly than words. At A are represented the horizontal strata from which the rocks of the mountain were torn away. At B the dissevered prolongations of the same strata appear in an upturned position. If there had been no erosion during the uplifting of the mountain it would be much higher than it actually is, and the crest would have some such position as that indicated by the dotted line. But erosion has actually supervened, and a large share of the uplifted mass represented by C has been worn away and deposited upon the flanks of the range in the strata D and E. Approaching the mountain from the

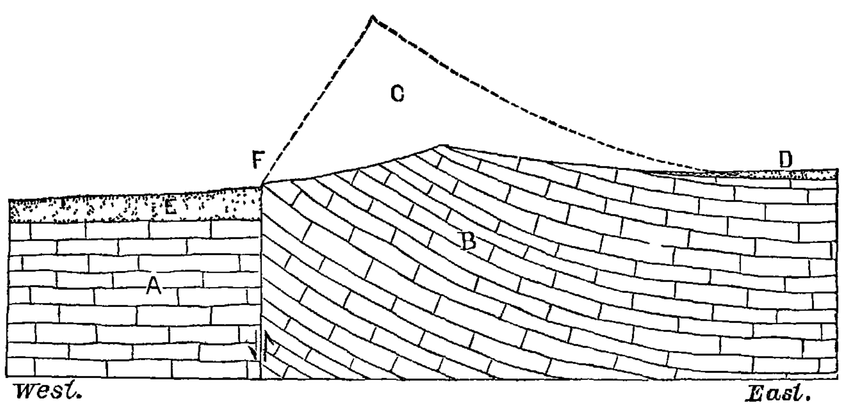


FIG 21—Generalized Cross-section of the Wasatch Range

west one traverses the surface of the deposit E, which is made up entirely of fragments from the range, and at the point F passes abruptly onto solid rock—the worn edges of the upturned strata. He crosses there the line produced by the intersection of the fault plane with the surface of the ground, and this line is everywhere marked at the present day by an escarpment or sudden ascent, produced by the last slipping of the rocks along the fault plane.

Mountain structures of this sort are not infrequent in the Great Basin, and it is by no means rare that a definite escarpment is found at the base of a range, recording a faulting at so recent a date that its evidence has not been obliterated by erosion, but there is usually no manner of fixing the date of the last movement with any high degree of precision. In the case of the Wasatch, however, our information is concise. The slopes interrupted by the escarpment are not simple alluvial slopes or rock slopes carved by subaerial agencies, but are slopes characterized by the peculiar sculpture of the waves; and the phenomena show not only that the last uplift of the Wasatch took place after the formation of the Bonneville and Provo shores, but that the water of Great Salt Lake has not since been even fifty feet higher than it is at present. It is therefore demonstrated that an actual uplift of the mountain occurred at so recent a date as to leave no reasonable suspicion that its growth has now ceased.

The amount of displacement along this fault plane is not great, but it is probably greater than the amount of coincident erosion of the mountain top; so that it is reasonable to believe that the Wasatch is a greater mountain now than it was during the existence of the Bonneville Lake. Where the range is highest the amount of recent faulting at its base is from fifty feet to seventy-five feet, and it diminishes irregularly in either direction—the fault being traceable from the town of Willard at the north to that of Levan at the south, a distance of one hundred and thirty-five miles.

SUMMARY.

In brief, the work of the year may be said to have completed the demonstration of the following conclusions:

1. The climatic episode of which Lake Bonneville was the expression consisted of two humid maxima, separated by an interval of extreme aridity. The second maximum was the more pronounced; the first the longer.

2. The time elapsed since the close of the Bonneville epoch has been briefer than the epoch, and the two together are incomparably briefer than such a geologic period as the Tertiary.

3. The period of volcanic activity in the Great Basin, which covered a large share of Tertiary time, continued through the Quaternary also, and presumably has not yet ended.

4. Such earth movements as are concerned in the molding of continents had not ceased in Western Utah at the close of the Bonneville Epoch, and presumably have not yet ceased.

5. The Wasatch Range, the greatest mountain mass of Utah, has recently increased in height, and presumably is still growing.

ABSTRACT OF REPORT

ON

GEOLOGY AND MINING INDUSTRY

OF

LEADVILLE, LAKE COUNTY, COLORADO.

BY S. F. EMMONS.

GEOLOGY AND MINING INDUSTRY

OF

LEADVILLE, LAKE COUNTY, COLORADO.

By S. F. Emmons.

INTRODUCTORY.

In the subjoined pages I shall endeavor to give a concise description of the general scope of the above memoir, and present a brief abstract of the more important practical conclusions arrived at, reserving to myself, however, the liberty of modifying the same between this and the time of publication, if further study renders it necessary.

The extremely complicated nature of the geology of the region examined, the wide area over which comparatively large underground workings have been carried on, and the fact that a large portion of the actual rock surface in the immediate vicinity of Leadville is covered to an average depth of nearly 100 feet by glacial drift or re-arranged moraine material, have rendered necessary the accumulation of an immense number of notes, which fill more or less completely twelve quarto and six smaller note-books. The general deductions which have been drawn from the facts therein contained could be compressed within a very small space, but the practical bearing of these deductions upon any particular spot might not be readily applied by the reader. Moreover, the truly scientific method demands that whoever presents generalizations should give in full the grounds upon which he has made them, in order not only that the critic may be enabled to determine if his reasoning is correct, but also that a later observer in the same field may see if he has correctly read his facts. A failure in either respect might modify or entirely invalidate his conclusions.

In this report, therefore, it has been judged advisable to err rather on the side of too great fullness than of too much conciseness, and its volume will probably necessitate its division into two parts, which will correspond approximately to the double title, Geology and Mining Industry.

The headings of the chapters as provisorily determined are as follows:

PART I.

I. INTRODUCTORY.

Leadville—Its topographical position—The history of its discovery and rapid development.

II. GENERAL GEOLOGY.

A brief outline of the geological history of the Mosquito Range, more particularly that portion represented on the general map.

III. ROCK FORMATIONS.

A somewhat detailed description of the characteristic features of the various groups of rocks found in the region examined.

a. Sedimentary formations, with lists of fossils.

b. Eruptive or igneous rocks, with their microscopical structure.

IV. DESCRIPTIVE GEOLOGY OF THE MOSQUITO RANGE.

a. The geology and rock occurrences of the region included in the General map, described in topographical order.

b. A discussion of the general distribution of rock formations, forming a résumé of the above.

c. Short sketch of mines and ore deposits outside of the Leadville map.

V. DESCRIPTIVE GEOLOGY OF LEADVILLE AND VICINITY.

a. The geology and rock occurrences of the region included in the map of Leadville and vicinity, described in topographical order.

b. Distribution of rock formations, being a résumé of the above.

VI. GENERAL DISCUSSION OF GEOLOGICAL PHENOMENA.

a. Structural.

b. Eruptive.

APPENDIX A.

Microscopical description of porphyrite and other rocks, by C. W. Cross.

PART II.

I. ORE DEPOSITS OF LEADVILLE.

a. Mineralogical description.

b. Chemical composition of ores, vein materials, and inclosing rocks.

c. Probable origin of ore deposits.

II. IRON HILL GROUP.

Description of the geology and ore deposits of Iron Hill, as shown by its underground workings.

III. Carbonate Hill Group.

Description of the geology and ore deposits of Carbonate Hill, as shown by its underground workings.

IV. Fryer Hill Group.

Description of the geology and ore deposits of Fryer Hill, as shown by its underground workings.

V. Other groups.

a. Description of geology and ore deposits of other important groups of mines.

b. Probable extent of ore bodies in as yet unprospected grounds.

VI. Kindred Deposits.

Brief description of similar occurrences of ore in Europe and South America.

VII. Economical.

Description of systems of working and of mining machinery employed at Leadville.

Appendix B.

Metallurgical report, by A. Guyard. A detailed description of the smelting works of Leadville, and discussion of the processes employed, including full analyses of all ores, fluxes, and furnace products.

Appendix C.

Analytical tables, by W. F. Hillebrand. Tables of analyses, partial and complete, of ore, vein materials, and country rocks, with outlines of processes employed.

Illustrations.

The text of the report will be accompanied by the following illustrations:

I. Three heliotype views of Leadville and vicinity.
II. Six heliotype illustrations of characteristic rock specimens and micro-sections.
III. Fourteen engraved book-plates illustrative of ore occurrences and geological structure.
IV. Twenty-three book-plates of smelting works and their appliances.
V. Eight wood-cuts, illustrative of special features of interest in the mines.

In addition to the above the report will be accompanied by an atlas containing the following maps and sections:

Atlas.

I. Topographical map of the Mosquito Range. Scale, ½ mile to 1 inch; contours 100 feet vertical interval; area, 16 by 20 miles.

II. The same map, colored geologically.
III. Eleven colored geological sections illustrative of the above. Natural scale.
IV. Topographical map of Leadville and vicinity. Scale 800 feet to 1 inch; contours 25 feet vertical interval; area, $4\frac{3}{4}$ by $5\frac{3}{4}$ miles.
V. The same, colored geologically.
VI. Sixteen colored geological sections illustrative of the above. Natural scale.
VII. Geological map of Iron Hill, southern part, showing the underground workings and ore bodies. Scale, 160 feet to 1 inch; contours 10 feet vertical interval.
VIII. Eight colored geological sections illustrative of the same.
IX. Geological map of Iron Hill, northern part, showing underground workings. Same scale as above.
X. Three colored sections illustrative of same.
XI. Geological map of Carbonate Hill, with mine workings. Same scale.
XII. Eight colored sections to accompany the same.
XIII. Geological map of Fryer Hill, with mine workings. Same scale.
XIV. Twelve colored sections to accompany the same.

The following gentlemen have taken part in the preparation of this report, either as regularly enrolled members of the corps or as tempory assistants, the names of the latter being marked by an asterisk (*):

A. D. Wilson, chief topographer.
Ernest Jacob, geological assistant.
C. Whitman Cross, geological and microscropical assistant.
W. F. Hillebrand, chemist.
* A. Guyard, chemist and metallurgist.
* W. H. Leffingwell, topographer and draughtsman.
* Morris Bien, topographer and draughtsman.
* W. B. v. Richthofen, draughtsman.

Valuable assistance in the preparation and compilation of the underground working of the various mines has been rendered by the following civil engineers of Leadville: H. Huber & Co., G. H. Robinson & Co., F. G. Bulkley & Co., Jaycox, Goad & Corning, and others; and acknowledgments are due to many gentlemen, mine superintendents and others, who have given valuable information and afforded us facilities for carrying on the work, among whom may be particularly mentioned Messrs. A. Eilers, W. S. Ward, W. S. Keyes, Charles M. Rolker, George Daly, T. S. Wood, W. Arens, A. B. Wood, J. L. Loomis, H. A. Ford, O. H. Harker, J. G. Watson, M. E. Smith, W. H. James, J. B. Grant, M. W. Iles, F. E. Canda, Th. F. Van Wagenen, J. R. Loker, F. Guiterman, C. C. Baldwin, J. T. Herrick, W. Huntington, D. S. Covert, C. W. Derry, J. T. Long, A. D. Foote, W. S. Duval.

CHAPTER I.

TOPOGRAPHICAL POSITION.

The present city of Leadville is situated in the county of Lake, State of Colorado, on the western flank of the Mosquito or Park Range, and on the eastern slopes of the valley of the Arkansas, near its head. Its exact position is in longitude 106° 17′ west from Greenwich and 39° 15′ north latitude, and its mean elevation above sea-level 10,150 feet, taken at the court-house, in the center of the city.

In this latitude the Rocky Mountain chain is made up of three main and more or less parallel uplifts; the Colorado or Front Range, the Mosquito or Park Range, and the Sawatch Range. The first rises immediately from the Great Plains, and to the traveler from the East, who has just passed over 500 weary miles of unincidented and practically level country, represents at first view the whole Rocky Mountain system. It is a broad, somewhat irregular chain, whose more prominent peaks rise to a height of over 14,000 feet above sea-level, and whose flanks are deeply scored by the tortuous ravines or cañons cut by streams flowing out to join the Platte and Arkansas Rivers.

Beyond this range lies the mountain valley known as the South Park, a broad, basin-like depression, sloping gently to the southward, having an elevation of 8,000 to 10,000 feet above sea-level.

The next mountain uplift, which forms the western border of the South Park, is the Mosquito Range, a narrow and abrupt ridge having a trend nearly north and south, and whose prominent peaks also rise above 14,000 feet, the average height of its crest being nearly 13,000 feet above sea-level. It is characterized in general by long, easy slopes on the east toward the Park, and broken, abrupt slopes, which are nearly perpendicular walls near its crest, on the west toward the Arkansas Valley, while either flank is deeply scored by amphitheaters and deep gorges or cañons of glacial origin.

The Arkansas Valley is a meridional depression, about 60 miles in length by 16 in width, bordered by the sharp peaks of the Mosquito Range on the east, and by the equally high but broader mountain mass of the Sawatch Range on the west. This valley is not only remarkable as presenting some of the grandest mountain scenery to be found in the Rocky Mountains, but also on account of the great mineral wealth found along its borders, and the scientific interest of its geological structure. To the upper 20 miles alone will attention be especially directed here.

At about this distance from its head the foot-hills of the bordering ranges close together, confining the present bed of the stream within a narrow rocky cañon, a few miles above the town of Granite. Above this cañon the valley widens out in broad grassy meadow-lands, on each side of which flat table-like terraces rise for several miles, with a gentle, almost imperceptible slope to the foot of the more rugged mountain spurs. Such topography suggests at once to the thoughtful observer that this portion of the valley was once a mountain lake, and, as will be seen later on, the present investigation proves this to have been the case.

On the upper edge of one of these gently sloping terraces, between Big Evans and California Gulches, and at the base of Carbonate Hill, the extremity of a western spur of the Mosquito Range, is situated the city of Leadville.

Discovery.—The history of the discovery and development of the mineral wealth of Leadville, which well illustrates the uncertainties and vicissitudes attendant upon a life of search for the precious metals in these wild regions, can be here but briefly touched upon. Among the hundreds of weary gold-seekers whom the so-called Pike's Peak rush brought to Colorado in the fall of 1859, only to find themselves the victims of exaggerated and chimerical stories, a few undaunted spirits pushed still further on into the recesses of the then unknown mountain regions. Gold was first discovered in the same year on Tarryall Creek, at the head of the South Park, and early in the spring of 1860 two parties of prospectors, pushing westward still, stumbled almost simultaneously upon rich diggings in California Gulch, near the present site of Leadville.

The news of the discovery spread with wonderful rapidity, considering the difficulties of travel and sparseness of population in those early days, and eager miners flocked rapidly in. Large amounts of gold-dust were obtained from this gulch, and the town which was built along its banks, known as Oro City, is somewhat freely estimated to have had within a year 10,000 inhabitants. A similar generosity of estimate, so readily accorded to bygone times of which accurate information is not attainable, places the aggregate production of the gulch in gold-dust at ten millions, while more conservative and better-grounded opinions would give it a maximum of $3,000,000. At all events the richer placers were soon exhausted, and the population of the ephemeral city of Oro gradually decreased, the thousands having dwindled within three or four years to hundreds.

At that day miners had gained most of their experience in the gold-fields of California, and to them silver ores were comparatively unknown and worthless. Some prospecting was done for the gold veins from the croppings of which the gold of the placer diggings was originally derived, and resulted in the discovery of several gold mines, such as the Printer Boy, Five-Twenty, and a few others, whose working gave a fitful gleam of renewed prosperity to the camp, but of whose actual yield no accurate data are attainable. Few, if any, however, suspected the value of the so-called "heavy rock," fragments of iron-stained carbonate of lead, which obstructed their sluices, being too dense to be carried down by the force of water alone, and which had to be thrown out by hand. Although many now claim to have known of the existence of the rich argentiferous lead ores of Leadville in earlier days, its practical discovery is apparently due to Mr. A. B. Wood, an educated and experienced miner and metallurgist, who first came to this region in 1874, and at once recognized the mineralogical character of the miners' worthless "heavy rock." In 1875 the titles acquired by the gulch-miners under local laws had lapsed by limitation, and Messrs. Wood and W. H. Stevens located, under United States laws, the claims which now belong to the Iron-Silver Mining Company, covering, with remarkable accuracy, when it is remembered that at that day little or nothing was known of the geological structure of the region, the croppings of the ore-bearing stratum over a distance of more than a mile. The first practical test of the value of the ore was made by Mr. A. R. Meyer, a graduate of the Freiberg Mining Academy, and agent for the Saint Louis Smelting and Refining Company, who shipped a small lot to Saint Louis in the fall of 1876.

Development.—Active prospecting over the whole region may be said to have commenced in the spring of 1877, and the development of rich and productive mines from that time on advanced with a rapidity that is truly marvelous. This can be more easily comprehended by a comparative statement of the economical conditions of Leadville in the spring of 1877, and at the same period in 1880, after a lapse of three years.

At the former time the nucleus of the present city, known as the town of Agassiz, consisted of a few log cabins, relics of the palmy days of gulch-mining, scattered along the edge of California Gulch, with an estimated population of less than 200 persons; its business houses consisted of a ten-by-twelve grocery and two small saloons. Three of the now productive mines had been discovered, but were still scarcely more than mere surface scratchings. A single lead furnace was planned, but not as yet erected. Communication was had with the outside world by stage or wagon, either across the crests of two high ranges to Denver, or by an almost equally difficult road to Colorado Springs.

The latter date finds a broad, populous, admirably situated city of 15,000 inhabitants, with 28 miles of streets, in part lit by gas, and furnished with hydrants and over five miles of water-pipes. It has thirteen schools, with an average attendance of 1,100 pupils; five churches, and three public hospitals, supported by charitable contributions; an opera house and numerous smaller theaters; six banks, and block after block of business stores, many substantially constructed of brick or stone.

Its assessable property is estimated at $30,000,000, and $1,400,000 were expended during the year 1880 in new buildings and improvements.

To support this population are over thirty producing mines, with innumerable smaller mines and prospects, which are either producing small amounts of ore or give promise of so doing in a comparatively short time. Ten large smelting works are in active operation reducing the ore of these mines, and the value of the aggregate annual production of the district in gold, silver, and lead amounts to $15,000,000.

Two lines of narrow-gauge railway connect it with the East, the one by way of Denver, across the Mosquito and Front Ranges, the other following down the valley of the Arkansas to Pueblo, and these find ample remuneration, even over the heavy grades which the mountainous nature of the region traversed necessitates, in the business its mines afford.

CHAPTER II.

GENERAL GEOLOGY OF MOSQUITO RANGE.

To the proper comprehension of geological description, graphic illustration in the form of maps, sections, and diagrams is absolutely essential. As, however, it was impracticable within the limits of this abstract to present more than a small section of the general map of Mosquito Range to cover the area in the immediate vicinity of Leadville, which will be illustrated in the final publication by a detailed map on a large scale, I shall confine my description to a bare outline of the more prominent features of its geological history.

The area now occupied by the Mosquito Range and the Upper Arkansas Valley was once the littoral region of an Archæan continent or island, whose area is approximately expressed by the Archæan exposures of the Sawatch Range. The Rocky Mountain chain, or eastern member of the Cordilleran system, in this latitude consists of a series of Archæan islands or continents which have never been entirely submerged. Some superficial geological observers have reasoned, from the fact that the later sedimentary beds are here generally found resting on the flanks of Archæan masses, and dipping away from them often at high angles, that these strata once arched entirely over the Archæan masses in anticlinal folds. Were this the case, however, wherever the edges of folded strata were exposed around the eroded crest of the anticlinal, beds of invariably the same geological horizon would be found resting directly on the Archæan, and their angle of dip should be sufficiently steep to carry the strata, in an ideal reconstruction of the original arch, entirely over the present mountain masses. In point of fact, however, along the flanks of the Archæan of the Colorado Range Carboniferous, Triassic, and even Cretaceous beds are found at different points directly abutting against the crystalline schists; and, with few exceptions, the angle of inclination of the sedimentary beds is far too low to carry them up to any considerable height, even on the present surface of the mountains, which must have been considerably planed down by long periods of erosion and abrasion.

The sedimentary deposits of the Mosquito Range were, as above stated, originally deposited, in the Paleozoic seas, along the shores of the Sawatch island, and have been lifted to their present position by dynamic forces, which have resulted in a series of sharp folds and longitudinal faults, in which the upward movement has been almost invariably on the east of the fault line. There is every reason to suppose that, like the Archæan masses of the Colorado Range, the Sawatch island was never entirely submerged. But the fact that in the limited region studied absolutely the same bed, with one single exception, is found resting upon the Archæan rocks, shows that the bottom of the ocean in which they were deposited had a comparatively smooth and regular surface, and that no steep cliffs existed along the immediate shore line, as in the Colorado Range, or that if they did exist within this area, they, together with their bordering sediments, have been entirely removed by subsequent erosion.

The dynamic movements which resulted in the elevation of Mosquito Range, and produced its present complicated structure, can be most readily explained on the generally received contraction theory, as the result of tangential pressure exerted upon the upper portion of the earth's crust in a direction approximately at right angles to the shore line, or radial to the center of the Sawatch island. The primal effect of such pressure exerted against a comparatively unyielding mass of crystalline rocks would be to compress the series of conformable sedimentary beds into longitudinal folds, whose principal axis would be at right angles to the direction of pressure. In the region under consideration the pressure would act from the east westward. The upper beds being relatively more plastic than those beneath, the pushing force would tend to produce anticlinal folds having a gentle slope to the eastward and a steep or approximately vertical inclination on the west. That sedimentary beds, even though formed of apparently rigid and unyielding material, may, under favorable conditions of pressure, be flexible and plastic, is abundantly proved by observation in nature. Such plasticity must, however, have a limit, and when such limit is reached the tension produced by pressure will result in a fracture of the beds and a vertical displacement, or faulting.

After the deposition of the sedimentary beds in the area under consideration, there occurred, during Secondary times, an intrusion of igneous or eruptive rocks, which spread themselves out in sheets between the strata, and became, as it were, an integral part of the sedimentary formation. It was after the eruption and consolidation of these masses of igneous rock that the dynamic movements in question occurred.

Sedimentary strata are comparatively thin sheets of homogeneous and coherent material, whose plasticity, other things being equal, would be proportionate to the average thinness of the beds. An augmentation of the aggregate number of stratification planes in a given thickness would increase the possible movement of each on the other along such planes, and, as in the familiar illustration of folding a number of sheets of paper, the sharpness and number of folds into which, under given conditions of pressure, they could be compressed without fracturing. The igneous rocks, however, which were spread out in irregular and comparatively thick masses, having no bedded structure, but fracturing with equal ease in any direction, would render the whole series more rigid, and favor the production of faults rather than folds. Such is the case in this region, where the action of faulting and displacement is predominant over that of folding, and particularly prominent in those portions where there is the greatest concentration of eruptive rocks, as in the district immediately adjoining Leadville.

The general geological map of Mosquito Range which will accompany the memoir on Leadville, and from which the accompanying map has been cut out, includes about twenty miles of the range, extending from Weston's Pass on the south to Frémont Pass on the north; with a width of sixteen miles, or from the Arkansas Valley to the South Park. In this area the prevailing or major direction of strike of the sedimentary beds is N. 60° W. or N. W. magnetic, and the prevailing dip about N. 30° E. This is the direction of the axis of the main anticlinals, while the principal faults have either the same course or are due north and south, with minor irregularities which may be considered a resultant of these two directions.

Mosquito fault.—The main crest of the range within this region runs north and south, parallel to which, and immediately adjoining it on the west, is this principal fault, which may be considered to extend continuously from the northern to the southern limits of the map. On the eastern flanks the sedimentary beds slope back with comparative regularity towards the South Park.

London fault.—This easterly sloping area is broken by one main fault line, stretching diagonally across it in the major direction of strike, which crosses the main ridge just north of Mosquito Peak, and extends southeastward from there through London Hill and Sheep Mountain, in the direction of the little volcanic butte known as Black Hill, on the Little Platte. This main line of fracture corresponds very closely to the steep western edge of an anticlinal fold.

North of the London fault the line of strike assumes a northerly direction, and in the region around Mount Lincoln the sedimentary beds have been removed from the main crest of the range and the deep beds or cañons of the larger streams, and are only left on the eastern flanks of the outlying masses of Mount Lincoln and the adjoining ridges, known as Loveland and Pennsylvania Hills. South of the fault they reach to the main crest of the range in a thin shell or cap over the underlying Archæan granites and schists, which constitute the steep western wall.

Weston fault.—The third main fault passes through Weston's Pass, in a direction parallel to the London fault, and nearly coincident with the steep western side of an anticlinal fold whose crest has been almost entirely removed by erosion; so that, except near the extreme southern end of the map, no westerly-dipping sedimentary beds are found. At the west of this fault line there still remains a portion of easterly-dipping beds, resting directly on the granite, extending from the ridge between the head of Empire and Union Gulches along the head of the latter to the ridge southwest of Weston's Pass, and beyond the limits of the map, to Buffalo Peaks. To the southwest of this line of outcrops, which extends in a northwesterly direction from the peak west of Weston's Pass, to Tennessee Park, no Paleozoic sedimentary beds are found. It may therefore be considered as approximately representing the shore line of the original Archæan continent. At the point where the Weston fault crosses Empire Gulch it is joined by the main Mosquito fault, which extends from there in a direction a little east of north to the foot of the steep grade leading up to Mosquito Pass, and then along the foot of the steep slope parallel to the crest of the range in a direction nearly due north, following beyond the limits of the map the general direction of Ten-Mile Creek.

Displacement.—In all these faults the upthrow has been to the east, and the movement of displacement reaches a maximum in the last mentioned, the Mosquito fault, of 5,000 feet near the northern edge of the map. That of the London fault has a maximum of about 2,500 feet near its northern end, as has the Weston fault, but gradually decreases towards the south, in both cases, until it becomes nothing, as either merges into an anticlinal fold.

The larger features of structure might be simply expressed by restored cross-sections of the range, in the northern and southern portions respectively, giving an ideal position of the sedimentary beds after folding and displacement had taken place and before they had been subjected to erosion. In the former case the section would show an arch and basin, or an anticlinal and synclinal fold, the former occupying the position of the crest of the range and the latter adjoining it on the west; through the adjoining sides of these folds would run the line of fault, along whose plane the anticlinal or eastern member had been lifted up nearly 5,000 feet. In the southern section a similar structure would be shown, only instead of one set of folds and faults there would be two; the main anticlinal, still occupying the crest of the range, the second, that of the Sheep Mountain ridge, being some miles to the east of it, and the movement of displacement, always upward east of the fault or in the crest of the anticlinal arch, being distributed between the two faults, with about the same aggregate movement of 5,000 feet. To obtain the conditions now to be observed one must conceive the planing action of erosion to have removed the crests of the anticlinal folds in either case, having cut more deeply into that which was lifted highest on the crest of the range.

In the central or intermediate region the structure is far too complicated to be described without actual maps and sections, although the eastern slope of the range shows clearly the gradual convergence of the two series of arches and faults into one.

The most intricate portion is that on the western flank of the range in the immediate vicinity of Leadville, which is shown on the accompanying map, with the different rock formations designated by appropriate colors. Before proceeding to a description of this structure in detail it will be necessary, therefore, to describe briefly the different varieties of rock found and their manner of occurrence.

CHAPTER III.

ROCK FORMATIONS.—COMPOSITION.

ARCHÆAN ROCKS.

All the sedimentary rocks found within this area belong, geologically, to the Archæan, Paleozoic, or Quaternary eras.

The Archæan rocks are, as well as the present limited data enable us to determine, the very oldest of the crystalline rocks, and may be considered as the Rocky Mountain equivalent of the Laurentian of Eastern geologists. They consist here of granites, gneisses, and amphibolites, whose exposures are indicated on the accompanying map by a uniform brown color.

Granites.—The granites are, in most cases, distinctly stratified and of undoubted sedimentary origin. In other cases the evidence is less clear and at times they even have characteristics of eruptive granites. In composition they belong to the normal type of granite, viz., those which consist of quartz, two feldspars, biotite, and muscovite. They are generally very coarse-grained and contain large twin crystals of orthoclase porphyritically distributed. In color they are gray or red, the latter tint being more prominent in the coarse-grained varieties; but in some instances fine-grained, deep-red granites, not unlike the famous Aberdeen granites, occur. There is sometimes a foliated structure approaching that of gneiss, especially where found immediately adjoining sedimentary rocks. Within the mass of normal granite occur large, irregular, vein-like white masses of secondary origin, corresponding to the German definition of pegmatite. They consist of large, inter-grown crystals of white orthoclase, microcline, and quartz, with irregular masses of muscovite.

Gneiss.—Among gneisses the mica-gneiss is the prevailing type; hornblende-gneiss, which is so frequent in other Archæan masses to the north, being comparatively rare. Their composition is similar to that of granites. In structure, however, they present a great variety of forms, from the normal gneiss structure, with fine, even grain and constant composition in the different layers, to a coarse-grained porphyritical structure, containing large twin crystals of orthoclase and approaching that of the coarse-grained granites.

Amphibolites.—The amphibolites are of less frequent occurrence than either of the previously-mentioned rocks, and occur interstratified with them in layers of varying thickness, and sometimes in large lenticular bodies. Under this name are included hornblende rocks of less marked schistose structure than is common in normal gneisses or schists. They consists mainly of quartz, two feldspars, and hornblende, with not infrequent biotite.

PALEOZOIC FORMATIONS.

Among Paleozoic formations beds of the Cambrian, Silurian, and Carboniferous groups have been recognized, although, owing to the difficulty of obtaining distinct fossils in such a highly metamorphosed region, the limits of the two first mentioned have not been definitely fixed. The question of the existence or absence of Devonian beds is one upon which too little evidence has been gathered for a definite decision. Such as it is, it is purely of a negative character, viz., that no undoubted Devonian forms have yet been found in the Rocky Mountains, and that in the area under survey a slight, though not unquestionable, evidence of non-conformity by erosion exists between the horizons of the Carboniferous and Silurian periods.

A comprehensive idea of the relative thickness and general character of these beds will be given by the subjoined table of the average section obtained in Mosquito Range, to which is added, for purposes of comparison, a typical section of corresponding beds in the Wahsatch Range,* and a section of the same in the region of the Lower Colorado, made by Mr. C. D. Walcott.†

Mosquito section, 4,050–5,600 feet, possible unconformity by erosion.

Carboniferous 3,700 ft to 4,200 ft	Upper Coal-measure limestones.	1,000 to 1,500	Blue and drab limestones and dolomites, with red sandstones and shales Mud shales at top
	Weber grits	2,500 (Weber grits and Weber shales)	Coarse white sandstones, passing into conglomerates and siliceous and highly micaceous shales, with occasional beds of black argillite and blue dolomitic limestone
	Weber shales		Calcareous and carbonaceous shales, with quartzite.
	Blue limestone	200	Compact, heavy-bedded, dark-blue dolomitic limestone Siliceous concretions at top, in form of black chert
Silurian 200 ft	Parting quartzite	40	White quartzite.
	White limestone	160	Light-gray siliceous dolomitic limestone, with white chert concretions
Cambrian 200 ft	Lower quartzite	150 to 200	White quartzite, passing into calcareous and argillaceous shales above.

* Geological Exploration of the 40th parallel.

†American Journal of Science, September, 1880, page 222.

Kanab (Colorado River) section, 5,000 feet, unconformities by erosion.

Permian 855 ft.	Upper Permian	710	Gypsiferous and arenaceous shales and marls, with impure shaly limestone at base.
	Lower Permian	145	Same as above, with more massive limestone.
Carboniferous 3,260 ft.	Upper Aubrey	835	Massive cherty limestone, with gypsiferous arenaceous bed, passing down into calciferous sandrock
	Lower Aubrey	1,455	Friable, reddish sandstone, passing down into more massive and compact sandstone below. A few fillets of impure limestone intercalated
	Red Wall limestone	970	Arenaceous and cherty limestone 235 feet, with massive limestone beneath. Cherty layers coincident with bedding near base
Devonian 100 ft.	Devonian	100	Sandstone and impure limestone.
Cambrian 785 ft.		235	Massive mottled limestone, with 50 feet sandstone at base
	Tonto Group	550+	Thin-bedded, mottled limestone in massive layers. Green arenaceous and micaceous shales 100 feet at the base

Wahsatch section, 30,000 feet; conformable

Permian 650 ft.	Permian	650	Clays, marls, and limestones, shallow
Carboniferous 15,000 ft.	Upper Coal-measure limestone	2,000	Blue and drab limestones, passing into sandstones
	Weber quartzite	6,000	Compact sandstone and quartzite, often reddish, intercalations of lime, argillites, and conglomerate
Waverly	Wahsatch limestone	7,000	Heavy-bedded blue and gray limestone, with siliceous admixture, especially near the top
Devonian 2,400 ft.	Ogden quartzite	1,000	Pure quartzite, with conglomerate
Silurian 1,000 ft.	Ute limestone	1,000	Compact, or shaly siliceous limestone
Cambrian 12,000 ft.	Cambrian	12,000	Siliceous schists and quartzite

NOTE.—Planes of unconformity by erosion denoted by double dividing lines.

CAMBRIAN.

Lower quartzites.—The beds assigned provisorily to this horizon, which are indicated on the map by a blue purple color, are prevailingly quartzites; to them, therefore, the local name of Lower quartzites has been given. Their average thickness is about 150 feet, of which the lower 100 feet are composed of evenly-bedded white saccharoidal quartzites, while the upper 50 feet are shaly in character and more or less calcareous, passing by almost imperceptible transition into the siliceous limestone above. At the base a thickness of a foot or more is conglomeritic and stained with oxide of iron. Above this is a heavy white quartzite of remarkably uniform and persistent character, from 40 to 100 feet in thickness, always very readily distinguished as a white line in the numerous sections afforded by the cañon walls of the range.

Primordial fossils belonging to the Potsdam epoch were found in the shaly beds above this quartzite. In its upper portion also occurs a remarkably persistent stratum, about a foot in thickness, of siliceous limestone, to which the local name Red Cast bed has been given, from the red concretions resembling casts of fossils which are constantly found in it. The siliceous dolomites near the dividing line between this and the overlying series contain local developments of serpentine, resulting from metamorphic action, which range in color from a dark, beautifully veined verd-antique green to a homogeneous mass of yellow tint resembling beeswax, not only in color but in texture.

SILURIAN.

White limestone.—The beds of this horizon, to which the above local name has been given from their prevailing light color as distinguished from the formation immediately succeeding, are designated on the map by a light reddish-purple tint. They consist in the main of light-drab dolomites, containing, besides the normal proportion of lime and magnesia, from 10 per cent. upwards of silica. They are thinly bedded, compact rather than crystalline, often with conchoidal fracture, and only rarely of absolutely white color. Their characteristic feature is the occurrence in certain beds of concretions of white, semi-transparent hornstone or chert. Their average thickness is about 150 to 160 feet.

Parting quartzite.—Above the White limestone occurs a remarkably persistent bed of rather variable thickness, to which the local name of Parting quartzite has been given, and which, in the absence of any direct geological evidence, has been included in the Silurian group. It has an average thickness of from 10 to 40 feet, and is not to be distinguished lithologically from the numerous white quartzites found at other horizons. It is, however, of geological importance as determining the dividing line between the Silurian and Carboniferous groups.

The fossil evidence obtained as to the age of the above formation is rather meager, being confined to a few Niagara forms found near its base, and to forms of the Trenton and Calciferous epochs contained in float fragments which probably came from this horizon.

CARBONIFEROUS.

Blue limestone.—The beds included under this local name, which are designated on the map by a deep blue color, and which, from the fact that they form the ore-bearing rocks *par excellence* of the region, it is most important to be able to trace accurately, are fortunately marked by persistent and characteristic features. They have an average thickness of 150 to 200 feet. Their composition, which is remarkably regular, is that of normal dolomite, containing a very small percentage of silica. In color they are of a deep grayish blue, often nearly black above, while some of the lower beds are lighter, approaching the drab, and, where locally bleached, difficult to distinguish lithologically from the underlying White limestone. The upper bed is well marked by characteristic concretions of black chert, frequently hollow in the center, and often containing within their mass distinct casts of fossils. The typical rock is generally granular or coarsely crystalline, and has a characteristic ribbed structure produced by irregular lines and spots of white crystalline dolomite, resulting from the dissolving out and redeposition of this material. The principal characteristics, therefore, which distinguish the ore-bearing limestone from the underlying White limestone are, first, its color; second, its composition, the latter being invariably more siliceous; third, its texture, which is generally crystalline, while the latter is more frequently compact; fourth, the chert secretions, which in the former are always black and in the latter light colored or white; to which may be added the fact that the Blue limestone is generally more heavily bedded than the White. The fossils obtained, which were comparatively abundant in the upper beds, contain, among prevailing Coal-measure forms, some which belong to the Lower or Sub-carboniferous of the East.

Weber grits.—The rocks included under this head form a series of relatively great thickness and of prevailing siliceous composition. They have been designated on the map by a lighter blue tint. At their base, immediately above the Blue limestone, occurs a series of shales and quartzites of very variable thickness and composition, which have not been designated by a distinct color on the accompanying map. The thickness may be roughly estimated at 150 feet. The quartzites are not to be distinguished from other quartzites of the region, while the shales are sometimes green, more frequently black, and highly carbonaceous argillites, which are generally impregnated with pyrites, and contain at times beds of impure anthracite coal. Locally there are developments of impure dolomite, which, as well as the shales, are often very rich in Coal-measure fossils.

The Weber grits proper, which have an average thickness of about 2,500 feet, consist of coarse white sandstones, passing into conglomerates, containing pebbles of Archæan rocks, most frequently white or pinkish quartz. They have a varying admixture of finely-disseminated carbonaceous material, which at times gives them an almost black color. Besides the sandstone there are abundant schists, generally siliceous, and always rich in brilliant white mica. At irregular intervals through the horizon are found beds of compact black argillite, sometimes calcareous, and about the middle of the series two persistent beds of blue-gray dolomite, from 10 to 50 feet in thickness.

Upper Coal-measure limestone.—Less favorable opportunities were offered for studying this group than either of the preceding, and its limits are therefore less definitely determined. It consists mainly of calcareous beds, alternating with coarse reddish sandstones and quartzites, more or less micaceous, and sometimes passing into mica-schists. Its lower limit is drawn at the base of the first important limestone bed above the siliceous series of the Weber grits. This limestone, locally called the Robinson limestone, from the fact that it forms the ore-bearing horizon of an important mine of that name in the Ten-Mile district, is noticeable from the fact that it is the only true limestone observed among the calcareous beds of the region; the others are all practically dolomites of varying purity. As developed in this mine it is of a drab color and of peculiarly compact texture, resembling a lithographic stone. These textural characteristics are apparently not persistent, however, not having been recognized in other portions of the region. Several beds of blue-gray limestone, and one of a very fossiliferous black limestone, were observed on the western flanks of Mount Silverheels, and in the upper horizons of the Ten-Mile district were found mud shales, recalling the Permo-Carboniferous beds of the Wahsatch. No fossils other than Coal-measure forms were found, however. The red sandstones of this group are distinguished from the overlying Triassic rocks by a deeper color, approaching a Venetian red, whereas in the latter it is rather a light brick-red.

QUATERNARY.

The Quaternary formations, which have been distinguished in the accompanying map by distinct colors, are the *Lake Beds* and the *Recent* formations, including drift and moraines. The former were deposited in the bed of a fresh-water lake at the head of the Arkansas during the intermediate flood period of the Glacial epoch. The material of which they are composed is therefore not essentially different from that of the moraine material, but it is distinguished from it by its bedded structure. These beds consist at times of fragments, more or less rounded, of the various rocks which make up the range, frequently with calcareous cement, and at other times of a mixture of clays resulting from the decomposition of porphyry, and of decomposed granite, and still again of earthy marls. In the Recent beds are included not only the later alluvial deposits, where these are accumulated in sufficient depth to obscure the underlying rocks, but also moraines and rearranged moraine material, for which the local name of "Wash" has been preserved. In the accompanying map the latter formation is shown only in the sections, having been eliminated from the surface map, since its color would have obscured too large a portion of the underlying rocks whose outcrops have been actually determined by the exploration of the numerous prospect shafts in the Leadville region.

The Paleozoic rocks described above have an aggregate thickness of between 4,000 and 5,000 feet. In the seas in which they were deposited, however, a continuous sedimentation went on through the successive Triassic, Jurassic, and Cretaceous periods, it being at the close of the latter that the dynamic movements took place which resulted in the folding and fracture which raised the Mosquito Range to its present position. The limited time at our disposal did not permit a study of these later formations, but from data available their thickness may be estimated at not less than 7,000 feet. Probably the greater part, if not the whole, of these sediments were already accumulated at the bottom of the ocean before the intrusion of the Secondary eruptive rocks now found in the region, and which will be next described. An explanation of their exceptionally crystalline structure may therefore be found in the fact that they solidified under the pressure of a thickness of at least 10,000 feet of superincumbent beds.

ERUPTIVE OR IGNEOUS ROCKS.

The eruptive rocks of the district are mostly of Mesozoic age, and belong to the general types of porphyries* and diorites, or those in

* In the absence of any universally accepted classification and definition of eruptive rocks of Secondary age, it seems important to state here the system adopted and the reasons therefor. To the use of the term porphyry, as applied to a type of rocks of definite age and composition, the very valid objection may be brought that in its original acceptation it simply defined a certain type of structure, viz., that of a fine-grained or amorphous groundmass containing larger crystals porphyritically imbedded. On the other hand, the custom of applying this term to orthoclastic porphyritic rocks of Secondary age has become so firmly established by long-continued usage that it would seem unwise to abandon the present use of the term until a satisfactory substitute were found which would be received by all lithologists. The normal quartz-porphyry is a porphyritic compound of quartz, prevailing orthoclase, and some plagioclase feldspar, with mica or hornblende, in which the groundmass contains more or less isotropic amorphous material. A granite-porphyry, on the other hand, is a porphyritic rock of similar composition in which the groundmass contains only crystalline and no amorphous material. It is distinquished from granite, structurally, by the fact that it has a porphyritic rather than an evenly crystalline texture, but, like granite, it contains microscopically only fluid and no glassy inclusions. The rocks described above are, however, essentially crystalline as viewed under the microscope, though certain specimens contain a limited amount of amorphous material, and glassy inclusions are found in them, but less frequently than fluid inclusions. Strictly defined, therefore, they cannot be considered as granite-porphyries, though frequently indistinguishable from them in the hand-specimen. Rosenbusch has proposed (*Rosenbusch, Mass. Gesteine*, pp. 85–87) to separate all such rocks from the quartz or felsite-porphyries, and call them micro-granites. To call the rocks in question micro-granites, however, would be to add a new and somewhat ambiguous term to the already sufficiently confused lithological nomenclature, without gaining thereby in clearness of definition, since although they approach granite in microscopical structure, they are widely divergent from it in geological habitus. It has been judged best, therefore, to preserve the term quartz-porphyry, which is sanctioned by local usage, and of which they form the extreme crystalline type.

which monoclinic or triclinic feldspars are relatively predominant. Of Tertiary eruptive rocks, which are closely allied to the products of modern volcanoes, the only representatives are andesites, which occur at Buffalo Peaks beyond the limits of the general map, and rhyolite of the crystalline variety classed by Richthofen as Nevadite, which occurs in two localities only, at the northern and southern limits of the map respectively. Of these rocks only the porphyries are found in the region represented on the small accompanying map.

Although of infinitely varied appearance in the field, their structure and ultimate composition as revealed by analysis, both chemical and microscopical, admit of two main divisions, and to these two divisions only have distinctive colors been given on the general map.

WHITE OR LEADVILLE PORPHYRY.

Under the lighter red color of the map has been designated this single type only, partly because of its intimate connection with the ore deposits of the region, and partly because it constitutes the most distinct and well-characterized variety of the porphyries. It is a white, homogeneous-looking rock, composed of quartz and feldspar, of even, granular texture, in which the porphyritical ingredients, which are accidental rather than essential, are small rectangular crystals of white feldspar, occasional double pyramids of quartz, and fresh, hexagonal plates of biotite, or black mica. More frequent than either of the above are aggregations of fine leaflets of muscovite, or white mica, which are a secondary product resulting from the decomposition of feldspar. The rock is always in a more or less advanced state of decomposition, which is first shown by the opaqueness of its feldspars and the development of spots of muscovite, and in its extreme stage in the neighborhood of the ore deposits results in a general softening of the mass, due to the kaolinization of the feldspar. Among the miners of Leadville it is known also as "Block Porphyry," on account of its tendency to split up into angular blocks; and also as "Forest Rock," from the deposition of dendritic oxide of manganese on the surfaces of such fragments. Its composition is that of normal quartz porphyry, containing about 70 per cent. of silica.

OTHER PORPHYRIES.

Under the deeper red has been included all the other forms of porphyry found, which, though presenting a number of varieties in the field, have essentially the same general composition, both mineralogical and chemical. They consist generally of quartz, two feldspars, and biotite; hornblende occurring as an essential ingredient in only one variety. The crystalline ingredients are easily distinguishable by the eye, and there is, therefore, no danger of confounding them in the field with White porphyry. This crystalline structure, on the other hand, is often so far developed that they are not readily distinguishable by the untechnical eye from granites; as such, indeed, they are generally classed by the miner. A careful examination, however, readily reveals their structural difference, which is that in them the larger crystals are enclosed in a finer-grained groundmass, whereas between the crystals of granite there is no such intervening and apparently structureless material.

Lincoln porphyry.—The principal subdivision of this group has been called the Lincoln porphyry, from the fact that it is typically developed in the mountain mass around Mount Lincoln. It consists of quartz, orthoclase and plagioclase feldspars, and biotite. Its most striking peculiarity is the frequent occurrence of large crystals of rather glassy-looking orthoclase feldspar about an inch in length. The quartz, which occurs in double pyramids, appears to have a rounded outline, and frequently a delicate rose tint. The mica is found in hexagonal plates, generally decomposed and of greenish color.

Although the type-rock does not occur in the immediate vicinity of Leadville, a variety known as *Gray porphyry*, which does not differ in its essential constituents, and occupies generally the same stratigraphical position, is a prominent feature in the geology of that region. It has a prevailing dark greenish-gray color, due to the alteration of the constituents of its groundmass; but when found in the mines, where it is more thoroughly decomposed, it is quite white, and only to be distinguished from the White porphyry by the traces left of outlines of former crystalline ingredients. The large feldspars are often finely developed, but the groundmass is relatively more prominent than in the Lincoln porphyry proper. The specimens analyzed yielded 66 per cent. of silica for the Lincoln porphyry and 68 for the Gray.

Sacramento porphyry.—The second important variety of quartz porphyry receives its name from the locality of its typical occurrence, which is at the head of the Sacramento Gulches. At first glance it does not differ from the Lincoln porphyry, except in the absence of the large feldspar crystals. It contains the same large rosy quartz-grains, two feldspars, and biotite, but is distinguished from it by carrying hornblende also. It is in general comparatively fresh, and perhaps more likely to be confounded with granite than even the Lincoln porphyry. This rock does not occur on the surface within the Leadville region, although the variety next to be described, which occupies a nearly equivalent stratigraphical position there, may be allied to it.

Pyritiferous porphyry.—This rock, which forms an extremely important mass in the Leadville region, is found in such a universally decomposed condition that its original constituents cannot be definitely determined. It is generally of a white color, with grayish-green or pinkish tints, comparatively fine-grained, and with no traces of large crystals. In it can be distinguished small grains of white feldspar, quartz, biotite which is generally altered to a chloritic substance, and pyrite. The latter ingredient, from which it derives its name, is found abundantly scattered through the rock in crystals, often so fine as to be indistinguishable by the naked eye. They occur at times within the crystals of quartz and biotite, and are hence supposed to be an original constituent of the rock. They are frequently concentrated along cleavage planes, sometimes associated with finely disseminated crystals of galena. Pyritiferous porphyry is readily distinguished from the White porphyry by its crystalline constituents. It differs from the Sacramento and Gray porphyries by a relatively small amount of plagioclase feldspar, and from the former by the absence of hornblende. Its most strikingly distinctive feature is the amount of pyrites which it contains, which is estimated to constitute, on the average, 4 per cent. of its mass.

Besides the above-mentioned varieties are the Silverheels, the Mosquito, and the Green porphyries, only the former of which is found in any considerable mass, and that mostly beyond the limits of the map. The others are generally fine-grained, of a greenish tinge, and present no important typical features, having approximately the same ultimate composition as those already mentioned.

DIORITIC ROCKS.

Diorite.—Of the rocks in which plagioclase feldspar is the characteristic ingredient the crystalline type or diorite, which is the structural equivalent of granite, is of comparatively rare occurrence.

Porphyrite.—Its porphyritic variety, known as porphyrite, is, however, extremely well developed in the region, so that an excellent opportunity was afforded for its study. Inasmuch as these rocks are relatively little known to lithological science, and the collections made present a complete series of all different varieties, both of structure and composition, a special microscopical study has been made of them by Mr. Cross, which will be presented in an appendix to the final publication. As this is essentially technical in its nature, and the rocks themselves do not occur in the Leadville region, nor have any economic bearing, no further mention of them need be made here.

CHAPTER IV.

ROCK FORMATIONS—DISTRIBUTION.

SEDIMENTARY.

The superficial distribution of the various sedimentary formations, or the relative area covered by their outcrops, being a function of, or dependent upon, erosion, are intimately connected with the existing topographical structure of the region. Were erosion the only factor to be considered, the Archæan rocks would be found exposed continuously on the west side of a line approximately representing the old shore line, and in the deeper drainage valleys and anticlinal axes of the eastern side. The displacements of the numerous faults which run through the region have, however, considerably modified this normal distribution. In point of fact the central portion in the latitude of Leadville is mainly covered by the outcrops of Paleozoic sedimentary beds and intruded masses of porphyry; the Archæan exposures being confined to deep glacial amphitheatres near the crest of the range, and to minor masses which represent the eroded crests of anticlinal folds. In the northern portion of the area, Archæan rocks are exposed along the main crest of the range, and in the deep cañon valleys and glacial amphitheatres of the streams which flow into the Platte; the Paleozoic beds being found only on the easterly sloping flanks of the included spurs. On the western side of the range, owing to the displacement of the great Mosquito Fault, the area adjoining the valley of the East Fork of the Arkansas is covered by beds of the Weber grits formation, while a bordering fringe of outcrops of Lower quartzite, and White and Blue limestone beds is found on the northern and eastern rim of Tennessee Park. In the southern half of the map, the western limit of the Paleozoic beds is a line running southeasterly from the forks of the Arkansas to the crest of the range at Weston's Pass, and southward beyond the limits of the map along the crest approximately in a north and south line. West of this line are found only the granites and schists of the Archæan, and irregular dikes and intruded masses of porphyry. In the area included between this line and the crest of the range are triangular zones of easterly-dipping sedimentary beds, in some cases forming a continuous series from the Cambrian to the Upper Coal-measures, cut off abruptly by fault lines, and succeeded again on the east by Archæan exposures.

On the west of the crest the Paleozoic beds slope regularly back beneath the floor of the South Park, the Archæan rocks being found only in the deeper hollows at the heads of the streams. Beyond the limits of the map the outcrops of the more resisting beds of Mesozoic age form parallel ridges running across South Park from north to south.

ERUPTIVE.

Distribution.—The most striking fact connected with the distribution of the Secondary eruptive rocks is that an east and west line drawn through Leadville represents very closely the limit of the two main varieties of porphryry recognized above. South of a line drawn through Empire and Horseshoe Gulches the White porphyry is absolutely the only one which has been found within the limits of our exploration, while it is practically wanting north of a line drawn through Evans and Mosquito Gulches, the only exceptions being dikes of comparatively insignificant size, and not absolutely identical in structure.

Mode of occurrence.—In their mode of occurrence the type feature is that of intrusive masses, which are developed on a scale of unprecedented magnitude, and follow certain horizons with remarkable regularity. These interbedded sheets are found to have a maximum thickness at certain points, or along certain lines, and to become thinner in proportion to their distance from such central point, which is probably near a vent or channel through which they were erupted. This form resembles the structure of the intrusive masses of the Henry Mountains, which have received from Mr. G. K. Gilbert the name of *Laccolites.* Nor is the resemblance confined to external structure, but extends also to internal texture and mineralogical composition. It is probable that this mode of occurrence of eruptive rocks, viz., as intrusive masses, which originally did not reach the surface, but were forced up to a certain horizon and then spread out between the beds, is far more common than has hitherto been suspected by geologists. It is difficult to conceive of the conditions under which a fused mass could pry open strata to a width of 1,000 feet or more, overcoming the weight of 10,000 feet of superincumbent rocks, and spread itself out in a continuous sheet between the beds to a distance of 10 miles from the point or line of eruption. That they did exist, however, can be clearly demonstrated in this region, thanks to the intense action of folding and faulting, and the enormous amount of erosion which has taken place since such eruption, and afforded exceptional opportunities for a study of their form and extent.

Instrusive masses.—The main sheet of White porphyry which lies upon the surface of the Blue limestone had its principal vent at the head of Four-Mile Creek, where it can be seen breaking through the underlying beds, and forming the main mass of a hill 2,000 feet high. The gradually thinning outcrops of this sheet can be traced southward continuously along the east slopes of the range nearly to Buffalo Peaks, and back again on the west side from Weston's Pass to Empire Gulch. The continuity of the outcrop on an east and west line is broken by faulting and erosion, but wherever the Blue limestone is found this sheet occurs, with some unimportant exceptions, directly above it, following all its undulations. Of less uniform extent are sheets of White porphyry at lower horizons, generally between the Blue and White limestone, whose principal development is in the vicinity of Leadville. One important mass can also be seen on the south wall of Horseshoe Creek, breaking up across Weber grits beds, and then spreading out between the strata.

Intrusive masses of the other porphyries are found developed on an even greater scale than those of the White porphyry. Although no single sheet has been traced over so great an area as in the case of the former, they have a much greater vertical distribution, extending up to the Jurassic and possibly even into Cretaceous beds. In one single section over fifteen sheets, many several hundred feet thick, were counted between the Blue limestone and the top of the Carboniferous. The great aggregate thickness of beds thus added to the conformable Paleozoic sediments must have given them in their original position an arched form, which is now seen in a very marked change in the strike of outcrops, where there has been the greatest accumulation of intrusive masses, as on the line of Mount Silverheels on the east, and of Sheep and Jack Mountains in Ten-Mile District on the west of the range. In many cases quite thin sheets show most remarkable uniformity of thickness and position over comparatively large areas; for instance, along the walls of Mosquito Cañon a twenty-foot bed of porphyrite, occurring between the Blue and White limestones, can be traced continuously several miles. While these intrusive sheets follow by preference one definite plane, they not infrequently change their horizon, crossing an intervening bed; in one case also a second sheet is seen to have forced itself horizontally through the mass of an already interbedded sheet.

Dikes.—While by far the greater mass of igneous rocks occurs in the form of intrusive beds, the dike form is by no means uncommon, although the normal dike with regular parallel walls, generally figured in text-books, is seldom seen; on the other hand, large masses, of no regular form and apparently quite independent of stratification lines, which are intermediate between the normal dike and the intrusive sheet, are quite common. Dikes are generally found in the crystalline or Archæan rocks, and may be best observed in the glacial amphitheaters. They are generally narrow sheets from 20 to 50 feet in thickness, and of no great longitudinal extent. A not uncommon form is the "interrupted dike," a succession of outcrops of porphyry or porphyrite on the same general line, separated by short intervals of the enclosing rock mass. These may be projecting points of one main sheet, or independent chimneys, the former seeming more probable from their close proximity and identical composition. Dikes within dikes are found as well as intrusive sheets within intrusive sheets. Dikes are also found extending up through the crystalline rocks into the overlying Paleozoic beds; wherever observed on cañon walls they were found to end abruptly at a definite, although not always the same, horizon. Opportunities for actually tracing the dike as the feeding-channel of an intrusive sheet were comparatively rare.

Relative age.—The evidence as to the relative age of the different varieties of porphyry, though generally satisfactory, offers some apparent contradictions; these may, however, be explained on the supposition that the eruption of any one variety was not strictly confined to a single definitely marked period, but was intermittent. In other words, after a main eruptive mass had consolidated and been succeeded by eruptions of other rocks or from different magmas, a renewed activity took place in the magma of the first rock, which resulted in later intrusions of less magnitude. Thus the White porphyry is definitely the oldest of the Secondary rocks. The great mass of the Sacramento porphyry, whose main vent apparently adjoined that of the former, between the head of Little Sacramento and Big Evans Gulches, contains caught-up portions of the White porphyry and of the Weber grits. The main sheet of Gray porphyry in the Leadville region occurs above, sometimes replacing, the White porphyry, while other intrusive masses of this rock are found cutting across both White porphyry and the sedimentary strata which enclose it. It is also significant that the White porphyry is the most thoroughly crystalline of all the Secondary eruptive rocks, and generally occupies a lower geological horizon. On the other hand, dikes of White porphyry have been found cutting across interbedded masses of Lincoln porphyry, which seems to be the equivalent in age and position of the Gray.

Contact phenomena.—There is a notable absence in the region of strongly marked contact phenomena in the sedimentary beds, that is, changes which have resulted from the contact of a fused mass, such as a baking or vitrification. The changes which are found in them near intrusive masses are evidently rather the result of the action of percolating waters.

Within the eruptive rocks themselves the usual phenomena observed near the outer surface of cooling masses are found here along their contact with the enclosing rock, viz., a finer grain and different relative distribution of mineral constituents as contrasted with the average character of the rock, and a tendency to the development of laminated structure at the actual contact. Angular fragments of the enclosing rock are, moreover, so abundant at times along the contact as to form a regular breccia.

Glacial phenomena.—Of the forces of erosion and abrasion which have removed an aggregate thickness of about 10,000 feet of sedimentary beds, together with an unknown amount of eruptive rocks, from a great portion of the area examined, only the later phases, viz., those which have acted during and since the Glacial period, come directly under observation.

As already stated, the present investigations afford evidence of the existence during the Glacial period of two epochs of maximum cold, separated by one of higher temperature. In its general bearing this fact presents no novelty, but is merely confirmatory of observations already made by American, as well as European geologists, who have arrived at the same conclusion by reasoning from different classes of phenomena, astronomical as well as terrestrial. The warmer intervening period here was, owing to the melting of enormous ice masses and great precipitation, one of great floods, which caused a rapid degradation, as well as the removal of existing detritus, and where, as at the head of the Arkansas Valley, conditions were favorable to the formation of a lake, by the damming up of the waters, the coarse detrital material was deposited in regular beds, of relatively great thickness at its bottom.

Actual outcrops of these Lake beds, as they are designated in this memoir, are only seen, within the area of the general map, along the lower valleys of Empire, Union, and Weston Creeks; the outlines shown on the accompanying map of Leadville are determined by shafts which have penetrated to them through the overlying Wash, or surface drift. While, therefore, the actual outlines, as here given, might be modified by more complete data, the information obtained is quite sufficient to establish the following important facts:

I. *That the present moraines have been deposited over the Lake beds;* consequently that the glaciers by which they were formed existed *after* the deposition of the latter and the draining of the lake in which they were deposited.

II. *That since the latter epoch there has been an elevation of the mountain mass, relatively to the adjoining valley, amounting in one place to over 1,000 feet.* This is proved by the existence of Lake beds at an elevation, on the spurs adjoining Iowa Gulch, of 11,000 feet; by the angle at which they now stand on the ridges adjoining the Arkansas Valley, and by the fact that where they are nearly horizontal, in the center of the basin, they have an average level of less than 10,000 feet.

Valleys.—In studying the configuration of the present surface the valleys may be separated into three classes as regards their age and manner of formation:

I. Glacial valleys.

II. Valleys of erosion

III. Surface valleys.

The first, which owe their main outline to the carving of glaciers, have in cross-section a characteristic U outline, head in a glacial amphitheater, and have a comparatively straight course. This original form is always more or less modified by the same action which has formed the other two kinds of valleys. To this class belong all the large cañons or valleys on the east side of the range, and the East Fork of Arkansas, Evans, Iowa, and Empire Gulches on the west.

The second class, formed exclusively by the action of running water, which has cut through surface accumulations into the hard rock mass, have a V shape; that is, the sides are proportionately less steep, and the bottom narrower than the former, while their course is generally tortuous, being affected by the unequal resistance offered by different positions or textures of rocks. They also want the amphitheater-shaped head.

The third class are also valleys of erosion, but cut out of surface accumulations, such as drift or Lake beds, which have not yet become solid rock. They are in consequence relatively wide and shallow, and have a straighter course than the second class. The most striking difference between these and ordinary valleys of erosion is seen on a geological map, where the outline of outcrops crossing the latter would have a re-entering angle in the direction of the dip, whereas the former would cause no divergence in the course of such outlines. This class would be anywhere of more recent origin than the other two, and in this region the second class is younger than the first. As instances of surface valleys may be mentioned, Little Evans, Georgia, and Thompson's Gulches. The former drains the amphitheater on the south face of Prospect Mountain, being separated from Big Evans Valley only by a moraine ridge formed by the glacier of the second epoch. It is thus proved that the amphitheaters were carved out by the earlier set of glaciers, since that from the Prospect Mountain amphitheater was originally a branch of the main glacier from the Evans amphitheater, and it was the moraine of the second Evans glacier which, being placed across the mouth of the Prospect Mountain amphitheater, necessitated its seeking a new outlet for its waters. That at one time ice must have filled the amphitheaters to their brim, and been in places over 2,000 feet thick, is proved by their configuration and the position of erratic blocks.

In the region shown on the accompanying maps, the two main glaciers of the second period were the Evans and the Iowa. The latter had three heads, but its lower portion, as shown by the lateral moraines which remain on the sides of the present gulch, was straight and narrow. The later Evans glacier, however, spread out as it descended, having left a prominent moraine ridge along the north bank of the present stream at the foot of Prospect Mountain, while on the south side a somewhat disconnected moraine ridge follows approximately the course of Stray Horse Gulch, the moraine material remaining being 250 feet or more thick in the Rothschild and Denver City shafts. The steep north face of Breece Hill below the present grade formed its southern wall, and below this it probably covered more or less completely all the region north of Stray Horse Gulch, so that to its action is probably due the exposure of the valuable ore deposits of Fryer Hill, and also the removal of a great portion of them.

CHAPTER V.

ORE DEPOSITS.

A brief outline having thus been given of the geological structure of the region, it will be next in order to show the general characteristics of its ore deposits, and give a brief résumé of the conclusions which have been arrived at with regard to their origin and mode of formation.

Classification.—To a scientific description of natural objects, the most valuable aid is a rational and universally accepted system of classification. The first obstacle one encounters in attempting a description of mineral deposits is the absence of such a classification. A rational system should take account, not only of the present outward form of the deposit, but also of its origin and manner of formation. Mining geology in the United States has hitherto found its principal discussion in the courts of law; and the authority there generally accepted is the classical though now somewhat antiquated work of B. von Cotta. This book, which is a most excellent compilation of what was known about the ore deposits of the world twenty-five or thirty years since, though containing many previously unrecorded observations, presents no claims as a work of original scientific investigation; and the classification adopted by Von Cotta takes account only of the external form of the deposits. It divides them into four classes of veins or lodes:

1. Ordinary. (*Gewöhnliche-gänge.*)
2. Bedded. (*Lager-gänge.*)
3. Contact. (*Contact-gänge.*)
4. Lenticular. (*Lenticular gänge.*)

The terms most current among mining men, which are probably derived in great measure from the above, seem to be:

True fissure veins.
Contact veins or deposits.
Blanket veins or deposits.
Pipe or rake veins.

The first are popularly supposed to be the most valuable, since they occupy, in general, a nearly vertical position, and may extend indefinitely in depth. The term blanket deposit, on the other hand, which is probably derived from the *mantas* of the Spanish miners, seems to be generally applied in rather a derogatory sense to any horizontal sheet of ore.

The last, whose proper definition has given rise to some discussion, is derived from local usage in a small district in the north of England, where valuable lead deposits are found in the Carboniferous or mountain limestone. According to Mr. Westgarth Foster this local usage classes as *Rake veins* fissures analogous to the faults in the Coal-measures, but which contain lead ore. When these are wide above and gradually contract below they become *Gash* veins. Pipe veins, on the other hand, are irregular deposits in the limestone, in shape like the caverns so often found there. When these occupy a nearly horizontal position between the strata they become *Flats*, or *flat* veins.

Since Von Cotta's time the most important general treatises on mineral deposits are those of Joh. Grimm, of Pribram, and of Dr. A. von Groddeck, of Clausthal, which include not only the ores of metals, but all minerals useful in the arts, such as coal and salt. Grimm's classification is very thorough, and takes account of the origin of the deposits, but is too complicated for general application. Von Groddeck divides all mineral deposits into four general classes:

1st. Bedded deposits (*geschichteten Lagerstätten*), including those which have been deposited at the bottoms of seas or oceans, whether mechanically, or as chemical precipitates—coal, gypsum, salt, etc.

2nd. Massive deposits (*massigen Lagerstätten*), a rather ill-defined division, including large masses of metallic minerals impregnating a particular rock.

3rd. Deposits filling pre-existing cavities (*Hohlraums-füllungen*), which include all veins or deposits, whatever their shape, whose vein-material is essentially different from the enclosing rock.

4th. Metamorphic deposits (*metamorphische Lagerstätten*), including those which result from a more or less complete metamorphism of the rock itself by metallic combinations.

In the last edition of Johnson's Encyclopœdia Prof. R. Pumpelly, in his article on ore deposits, proposes the following six divisions, in which the first two are based on the texture or mineralogical composition of the enclosing rock, and the three following considered as due chiefly to pre-existing open cavities or fissures:

I. *Disseminated concentrations.*
  1. Impregnations. Fallbands.

II. *Aggregated concentrations.*
  1. Lenticular aggregations.
  2. Irregular masses.
  3. Reticulated veins.
  4. Contact deposits.

III. *Cave deposits.*

IV. *Gash veins.*

V. *Fissure veins.*

VI. *Surface deposits.*
  1. Residuary deposits.
  2. Stream deposits.
  3. Lake and bog deposits.

Under gash veins Pumpelly would include those fissures which are limited to a certain bed or rock mass, while his fissure veins extend across different rock masses, without any definite limit.

A discussion of the above systems of classification, which have been quoted simply as aids in the subjoined description, would exceed the limits of the present abstract. That the difference of origin and manner of formation should be a more important factor in the classification of ore deposits than has been the case hitherto is generally admitted, but, owing to the fact that the definite determination of such origin requires more laborious and expensive investigations, especially from a chemical point of view, than geologists are in general able or willing to make, trustworthy data are as yet too meager to form a basis for a general classification from this standpoint. The utmost that can be claimed by this memoir is to contribute to the general store of knowledge reliable facts in regard to an important group of ore deposits, and to point out the bearing of those facts upon the generally received theories of ore deposition, and the modifications which they may suggest in present classifications.

The earlier geologists devoted much speculation to the subject of the origin of metallic minerals in ore deposits, and arrayed themselves on the side respectively of the Neptunists or Plutonists, according as they believed them to have been brought to their present position by descending or ascending currents, whether gaseous or liquid. As pure theory has been gradually modified by the results of actual investigation, the upholders of the two opposing schools have come to concede, in this, as in other questions of general bearing in geology, an element of truth even in the views of their opponents. Only extremists maintain that any series of geological phenomena admit of but one explanation, or are due to one universal immediate cause. It is generally agreed that subterranean waters, however deep-seated their apparent source, came originally from the surface. It is moreover proved that no rocks are absolutely impermeable to water, but as on the earth's surface, so within its solid crust, there is a constant circulation either through capillary pores, where it is not readibly visible, or through the larger and more apparent channels formed by joints, cleavage planes, faults, dikes, and stratification lines, the direction taken by such waters varying with different local conditions. In the case, therefore, of ore deposits which are derived from aqueous solutions circulating within the earth's crust, a class which is constantly augmented by scientific investigation, the question as to the immediate source of the metals in the solutions from which they were deposited, whether above or below the present position, is one which must be determined independently in each individual case, and to which no general answer can probably ever be given.

LEADVILLE DEPOSITS.

The present investigation has proved of the ore deposits of Leadville and vicinity as regards their origin—

I. *That they have been derived from aqueous solutions.*

II. *That these solutions came from above.*

III. *That they derived their metallic contents from the neighboring eruptive rocks.*

IV. *That in their original form they were deposited not later than the Cretaceous epoch.*

And as regards their mode of formation—

I. *That the metals were deposited from their solutions mainly as sulphides.*

II. *That the process of deposition of the vein-material was a chemical interchange, or actual replacement of the rock-mass in which they were deposited.*

III. *That the mineral solutions or ore-currents concentrated along natural water channels and followed by preference the bedding planes at a certain geological horizon; but that they also penetrated the mass of the adjoining rocks through cross-joints and cleavage planes.*

And with regard to distribution—

I. *That the main mass of argentiferous lead ores is found in calcareo-magnesian rocks;*

II. *That the siliceous rocks, porphyries, and crystalline rocks contain proportionately more gold and copper.*

As regards classification it is more difficult to make a definite statement. Von Groddeck's term "metamorphic deposits" would include all the deposits of the district, with the possible exception of certain veins in the Archæan which have not as yet been sufficiently developed for thorough investigation. These veins would, in any event, come under the popular definition of true fissure veins, even though they should prove to be metamorphic, or the result of the alteration of country rock in place. Those not in the crystalline rocks would, in the main, come under the popular definition of contact veins, but they not infrequently pass directly into pipe veins, as in England; while, on the other hand, the fissure veins, which some have considered true fissures, correspond to the English pipe or rake veins. They would, however, be excluded from Pumpelly's class of gash veins, inasmuch as they do not fill pre-existing fissures. There is no evidence that the deposits in limestone were made in pre-existing cavities; on the contrary, the caves, which are not infrequently found, are plainly due to the action of surface waters, and are sometimes hollowed out of ore bodies as well as of limestone. When ore is found in them it is through the accident that surface waters have followed or crossed a previous ore-channel. Moreover, the thickness of the original limestone bed, or the distance between the enclosing strata, is found to be proportionately reduced if the amount of replacement has been exceptionally great.

Secondary deposition.—As in the deposition of minerals from percolating waters the process is a practically continuous one, and by changes in the character of the waters, minerals already deposited may be redissolved and deposited again in another place or form, the statement that a mineral is in its original form or position may be only relatively true. The action of surface waters, that is, those which have penetrated the rock masses directly from the surface during recent geological time, is, however, one that can be readily traced by the preponderance of combinations of oxygen and chlorine with the metals of an ore deposit in those portions which are near the present surface. To such combinations, therefore, the term secondary may be safely restricted in speaking of ore deposits.

The deposits of the Leadville region are peculiarly exposed to the action of surface waters; first, because of the relatively great precipitation; and, second, because of the geological structure, the numerous faults and displacements bringing the ore-bearing horizon near the surface in a great number of points, and erosion having largely removed from above them the more impermeable sedimentary beds, and left a covering of relatively permeable porphyry. This is more especially the case in the immediate vicinity of Leadville, the value of whose ores is greatly enhanced by the predominance in them of oxides and chlorides. It may also be observed, in considering the distribution of minerals, as shown by present developments, that the proportion of secondary products is less in the higher altitudes, where the waters are imprisoned by frost during a comparatively larger portion of the year.

Composition.—The prevailing and by far the most important ore, from an economical point of view, is argentiferous galena, and its secondary products, cerussite or carbonate of lead, and kerargyrite or chloride of silver. Lead is also found as anglesite or sulphate, as pyromorphite or phosphate, and occasionally as oxide in the form of litharge or more rarely minium. Silver frequently occurs as chloro-bromide, less frequently as chloro-iodide, occasionally as sulphuret, and very rarely in the native state. Chemical investigation has failed to detect sufficient regularity in the proportions of chlorine, bromine, and iodine combined with the silver to justify the determination of distinct mineral species.

Gold occurs in the native state, generally in extremely small flakes or leaflets. It is also said to have been found in the filiform state in galena.

As accessory minerals, are:

Zinc blende, and silicate of zinc or calamine.

Arsenic, probably as sulphide and as arseniate of iron.

Antimony, probably as sulphide.

Molybdenum, in the form of wulfenite, and locally copper, as carbonate or silicate.

Bismuth as sulphide, and its secondary product, a double-carbonate.

Tin has been detected in furnace products.

Iron occurs as an ore, though in the Leadville deposits it may be considered as an essential part of the gangue or matrix in which the valuable ore is found. In the former case it occurs in considerable bodies, as pyrite or sulphide, and anhydrous oxide, or red hematite with a little magnetite.

Gangue.—The other components of the ore deposits, which may be considered as gangue, although this term is perhaps more strictly applicable to non-metallic minerals, are:

Silica, either as chert, or a granular cavernous quartz, and chemically or mechanically combined hydrous oxides of iron and manganese. A great variety of clays or hydrous silicates of alumina, generally very impure, and charged with oxide of iron and manganese, the extreme of purity being white normal kaolin, containing at times sulphuric acid in appreciable amount. Sulphate of baryta, or heavy spar. Carbonate of iron, pyrite, and sulphate of lime, are comparatively rare in the deposits of Leadville itself. The miner's term, "Chinese talc," has been preserved for a substance which is found with singular persistence along the main ore-channel, or at the dividing plane between the White porphyry and underlying limestone or vein material, and also at times within the body of the deposit. It is composed of silicate and a varying amount of sulphate of alumina, to which no definite composition can be assigned. It is compact, semi-translucent, generally white, and very soft and easily cut by the finger-nail. It is very hygroscopic; hardens, and becomes opaque on exposure to the air.

Paragenesis.—The metals were all brought in as sulphides. The evidence of this is found in the fact that they form the interior or unaltered kernels of masses of lead ore, that sulphurets already increase in proportion as the more unaltered portion of the deposits is reached, and in the fact that a basic sulphate of alumina is left as the result of the action of sulphurous waters on porphyry along the main ore-channel. The silver was without doubt originally contained in the galena, and where now found as chloride free from lead is a secondary deposition.

While the sulphide of lead was undoubtedly deposited as such, it seems more likely that an actual chemical interchange took place between the sulphide of iron and the carbonates of lime and magnesia, the latter being carried away as soluble sulphates, and the former deposited either as carbonate, or directly as oxide. As regards the relative age of lead and iron, it is difficult to determine definitely whether galena was originally deposited in the dolomite, and the process of replacement of the latter by oxide of iron went on around it later, or whether the two were deposited at practically the same time, as sulphides, the pyrites being in so much greater amount as practically to enclose the galena, so that, being thus first exposed to oxidizing action, and perhaps also more susceptible to it, they are now completely oxidized, while the galena is only partially so. That the replacement of dolomite by oxides of iron and manganese has been going on in comparatively recent times is quite evident. This, and other phenomena bearing upon these questions, will be explained in detail in the final report.

With regard to the immediate source from which the vein materials were derived, chemical examinations of the various rocks of the region made on specimens taken from portions at a distance from ore deposits, and in a comparatively unaltered condition, show that while the sedimentary and crystalline rocks contain no precious metals, appreciable amounts of gold, silver, lead, and baryta may generally be found in the eruptive rocks. The details of these examinations must be reserved for the final publication, but an idea of the amount of material available in these rocks may be obtained from the following estimate of the possible contents of a single variety of porphyry of the Leadville district, the Pyritiferous porphyry. The figures are deduced from the superficial area of its outcrop, as shown on the map, its probable thickness, and the average percentage of metals contained in it, deduced from chemical examination of eleven specimens taken from different parts. They are, in round numbers, 250,000,000 ounces of silver, 9,000,000 tons of galena, and 100,000,000 tons of limonite, which represents fairly the average proportions of each in Leadville ores as a whole.

As regards the agents of secondary deposition, chlorine was found in the surface waters, and also in all the dolomites and limestones; traces of bromine were also detected in the latter. Phosphoric acid is found in the White porphyry, and in comparatively large amount in the Lingula shales which overlie the Blue limestone. Carbonic acid, as is well known, exists everywhere in the air and water; it is chemically combined in lime and magnesian rocks, and mechanically in siliceous rocks.

Distribution.—The principal ore-deposits of the region are found at or near the contact of the Blue limestone with the overlying porphyry.

The contact of the main sheet of White porphyry has, wherever it has been examined, shown evidence of the passage of ore-currents, and in the region of Leadville, although not every inch, or every foot even, yields an appreciable quantity of silver, no considerable area has yet been examined without finding bodies of valuable ore. The ore is, however, by no means confined to the surface of the limestone, but often extends into its mass, pinching out however in depth; sometimes the bodies thus developed show no visible connection with the surface, but it is evident that they originally came from it.

While for some as yet unexplained reason the horizon of the Blue limestone was exceptionally favorable to the deposition and concentration of ore, valuable deposits are occasionally found elsewhere, generally along bedding planes or contact surfaces, less frequently on jointing planes. The deposits in crystalline rocks, which are popularly supposed to be true fissure veins, have, as before stated, been but little studied.

A brief mention of a few of the best known mines will, perhaps, give a better idea of the geological distribution of ores than any general statement.

On the east side of the range the Monte Cristo deposits, which occur on the east flank of Quandary Peak, consist of galena impregnating one of the upper quartzite beds of the Cambrian horizon. The Phillips mine, in Buckskin Gulch, is a concentration of gold-bearing pyrites along a bedding plane of the Cambrian quartzite, in the neighborhood of a dike or intrusive mass of quartz porphyry. The Criterion mine, now deserted, had large lenticular bodies of ore replacing this quartzite, adjoining which are natural caverns hollowed out of such bodies by surface waters, while the ore channels extend up into the White limestone above. The Orphan Boy, in Musquito Gulch, is also apparently an impregnation or replacement of quartzite beds of this horizon.

In the massive of Mounts Lincoln and Bross the Blue limestone has been the scene of the most extensive ore deposition. Here it is overlaid by a sheet of Lincoln porphyry, while innumerable dikes and cross-bodies of other porphyries exist, which could not be accurately traced out in the limited time that could be given to this region. The ore bodies of the Russia, Moose, and other mines extend irregularly from the surface into the mass of the limestone, while in the Dolly Varden mine, on Mount Bross, the ore is found in that portion of the limestone which immediately adjoins a vertical dike of White porphyry. In the Sacramento mine, on the spur between Sacramento and Four-Mile Gulches, rich galena and carbonates are found in irregular bodies in the Blue limestone; the Sacramento porphyry, which originally overlaid it, has been largely removed by erosion, and the connection with the contact surface, if it existed, is not to be seen. On the main crest of the range the Peerless, Badger, New York, and other mines find their ore at or near the contact of the Blue limestone and White porphyry. West of the crest, the Dyer mine, near the head of Iowa Gulch, has long been worked on rich bodies of galena, associated with some copper, which occur in the White limestone.

In the region shown in the accompanying map, the discoveries of ore have been more strictly confined to the Blue limestone horizon, which really offers the best promise to prospectors. Some of the prominent exceptions are the Printer Boy and Five-Twenty deposits which are mainly free gold, with a little pyrites and galena, occurring along a vertical joint or line of fracture in the porphyry. The Colorado Prince and Miner Boy have likewise a gash vein carrying gold in the Lower quartzite. The Black Prince has veins of sulphurets extending up into the White limestone. The Dania, J. B. Grant, and other shafts on Yankee Hill have found small bodies of iron on the White limestone contact.

The Great Hope found the Parting quartzite impregnated with gold to such an extent that it could be profitably worked. The Ocean is said to have obtained gold from the Lower quartzite and the Nevada tunnel has found ore bodies, possibly belonging to a similar horizon, though, as it is on a fault line, it is difficult to say what was their original position. The Ready Cash gets gold ore from a vein in the granite, while above the horizon of the Blue limestone the Green Mountain, Ontario, Tiger, and others have found ore in gash veins in the Pyritiferous porphyry and at its contact with the Weber grits.

The most valuable ore bodies, however, are those which occur as a replacement of the Blue limestone. At times the original dolomite has been so largely removed that its geological position can only be recognized by the bounding beds. In the subjoined description, however, the horizon is spoken of by its geological name, whether it be represented by dolomite or a mass of iron-stained clay, granular quartz, or chert. The reader must also bear in mind that when outcrops are spoken of not the actual surface of the ground is referred to, but the surface of rock in place under the Wash or other superficial detritus. In a great portion of the shafts mentioned this rock is only reached after passing through a hundred feet or more of detrital material.

CHAPTER VI.

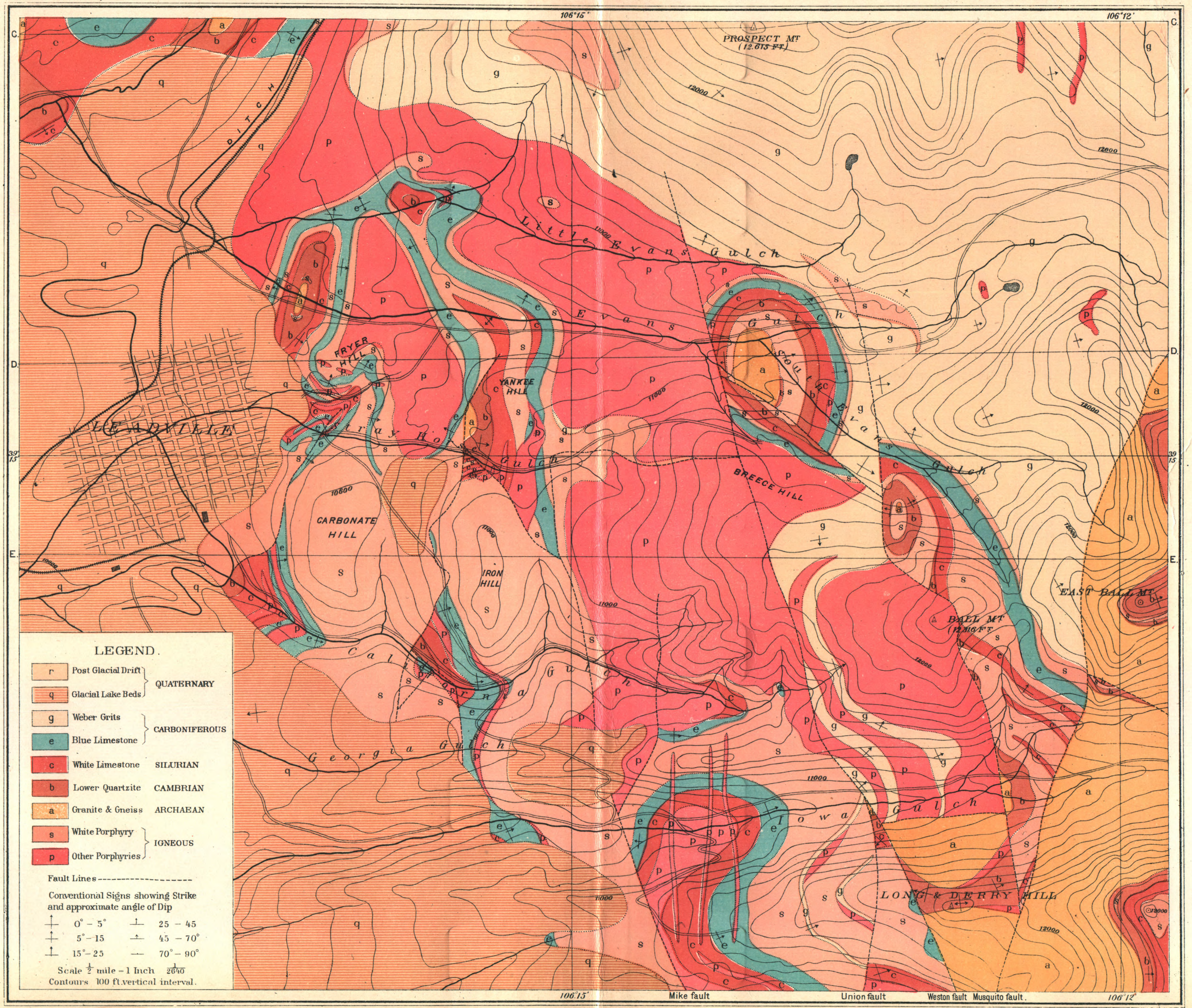
DESCRIPTIVE GEOLOGY OF THE LEADVILLE REGION.

GENERAL STRUCTURE.

The central region of the general map is, as has already been seen, the region of greatest dynamic, as well as eruptive, action. A section across the range at Leadville would show, as the result of dynamic action, five anticlinal folds and six principal faults. On the east side of the range, as already seen, the structure is relatively simple. The beds sloping back to the eastward are broken by one main anticlinal fold and its accompanying fault, the London fault. On the west of the crest, however, instead of one main fault as in the regions north and south, the continuity of the beds is broken by six principal and several minor faults.

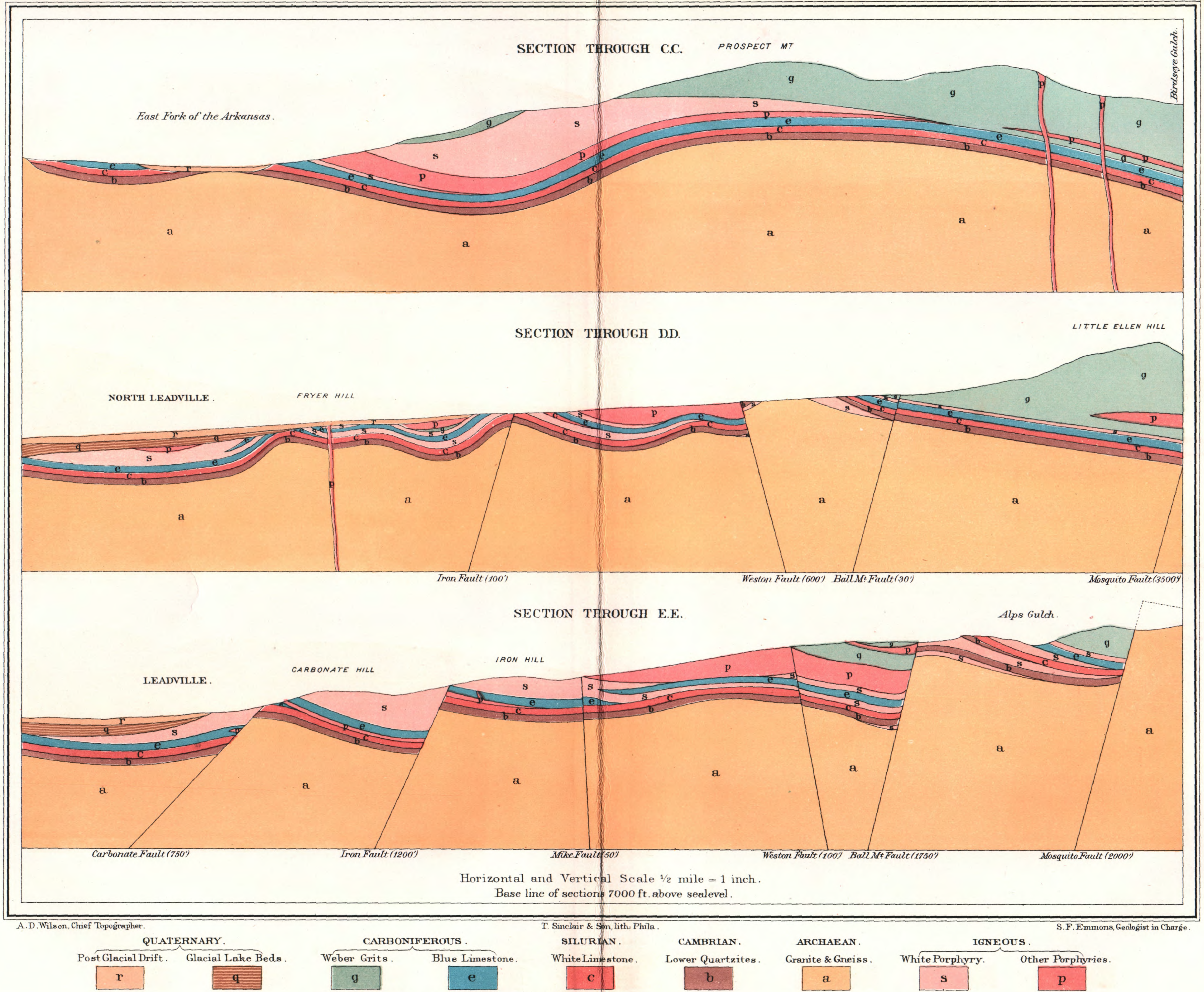
The accompanying map shows the most important features of the geology of that region. Its eastern border extends to within two to three miles of the main crest, which consists of Archæan rocks, capped by easterly-dipping Paleozoic beds and intrusive porphyries which rest upon them. For a better comprehension of the description which follows, the reader is requested to refer constantly to the map and its accompanying sections. He will there see that its area is divided into a series of irregular zones, or blocks, by the lines of six principal faults, having a general north and south direction. For the purposes of description these have received the following names, commencing on the east: 1st, Mosquito fault; 2nd, Ball Mountain fault; 3rd, Weston fault; 4th, Mike fault, with a branch called Pilot fault; 5th, Iron fault; 6th, Carbonate fault, with a branch called Pendery fault.

Besides these are the following minor and cross-faults: 1st, on the southern edge of the map, the Iowa Gulch cross-fault, which connects the Weston and Ball Mountain faults; 2nd, the Union cross-fault, which extends from the head of Union Gulch across Upper Long & Derry Hill, and joins the Weston fault in the bed of Iowa Gulch; 3rd, the Colorado Prince fault, north of Breece Hill, a diagonal cross-fault approximately parallel to South Evans Gulch, which joins the Ball Mountain and Weston faults; 4th, on the west slope of Breece Hill another cross-fault, the Breece fault, running nearly east and west, joins the northern end of the Mike fault with Weston fault; 5th, a little further west the Adelaide cross-fault which connects the Iron and Mike faults, while at California Gulch the southern continua-



A.D. Wilson, Chief Topographer. T. Sinclair & Son, Lith. Phila. S.F. Emmons, Geologist in Charge.

GEOLOGICAL MAP OF LEADVILLE AND VICINITY LAKE CO. COL



GEOLOGICAL MAP OF LEADVILLE AND VICINITY, _ SECTIONS.

tion of the Iron fault is formed by three different faults: the Dome fault, connected with the Iron fault by the California cross-fault following the line of the gulch, and the Emmet fault, which connects the California fault with the Iron fault. The Pilot fault, already mentioned, is a short north and south fault, crossing California Gulch above the Mike fault, running across the west end of Printer Boy Hill, and joining the Mike fault in Iowa Gulch. The Pendery fault, already mentioned, and the South Dyer fault, a cross-fault running eastward from the Musquito fault along the south slopes of Dyer Mountain, raise to seventeen the total number of faults represented on the map.

In ground broken by such a complicated net-work of fractures, and subjected since to the enormous erosion which is shown to have taken place in this region, it is extremely difficult, even for a trained geologist, to reconstruct ideally the original folds into which the sedimentary beds and their included sheets of porphyry were once compressed. As, however, the action of faulting was so intimately connected with that of folding, and the displacements in many cases pass into simple folds, it is essential, in order to obtain a clear idea of the relative position of the different beds below the surface, and the depths at which they may be found, that one should be able to reconstruct in his mind the original folds, and then figure to himself the faulting action which has brought the beds into the discordant juxtaposition in which they are now found on the surface, as shown on the map.

For this purpose the general structure along certain east and west lines will be first described, and after that the present condition of the surface, and the underground structure, as revealed by shafts, of each zone or block of ground included between the principal fault lines will be described in detail. The three cross-sections accompanying the map, which have been carefully drawn to scale, and in which the thickness of the beds is an average deduced from numerous observations, will be valuable aids; but it must be borne in mind that, owing to the great number of minor irregularities in faulting and folding, a section drawn a comparatively short distance to the north or south of either of these might differ very greatly from it.

In Section E, which is drawn approximately through the middle of the map, and which may therefore be considered as a type section, the effect of displacement is more prominent than that of folding. This line runs through the southern edge of the town of Leadville itself, across Carbonate, Iron, and Breece Hills, passing just north of the crest of Ball Mountain, and of East Ball Mountain, to the summit of West Dyer Mountain.

Along this line, going from west eastward, the following are the main features of folding: in the region under Leadville, or from the western edge of the map to the Carbonate fault, a shallow synclinal; under Carbonate Hill, or from the Carbonate to the Iron fault, a second shallow synclinal; and from Iron Hill eastward, a third; in all of which the prevailing dip is eastward, only a small portion of the eastern edge of the basin having a westerly dip. In the region between Iron Hill and Ball Mountain, or, in other words, on the western slope of Ball Mountain, the surface is so uniformly covered with Pyritiferous porphyry that there is no direct evidence of any folding; although a slight anticlinal fold might be expected near the line of the Pilot fault, from the fact that one exists on its strike both north and south. At Ball Mountain is a sharp anticlinal fold; and east of that the beds slope back in a monoclinal to the eastward. The effect of displacement produced by the faults has been to lift each successive block of ground up to the east of the fault, except in the case of a wedge-shaped portion included between the Mike and Pilot faults, in which there has been a slight downward movement.

On an east and west line south of this, say one following the ridge south of Iowa Gulch, the beds of the Blue limestone would be first met about due south of the summit of Carbonate Hill, sloping east in a shallow synclinal basin, and rising again in an anticlinal whose axis corresponds to the southern continuation of the Dome fault. The crest of this fold having been planed off by erosion, the contact would be wanting for something over half a mile and be found at the head of Thompson Gulch, dipping to the eastward, but rising gently as it approached the continuation of the Mike fault. The ground east of this fault having been lifted up, the Blue limestone has been in part removed by erosion, and would next be found at the Long & Derry mine, sloping again eastward as far as the Union fault. Beyond this fault it has again been removed by erosion, a little remnant only being found above the White porphyry, in the uplifted portion adjoining the Weston fault. Between this and the Mosquito fault is the arch of an anticlinal fold, on which only Lower quartzite is left. Beyond the Mosquito fault erosion has cut down to the Archæan rocks, the Blue limestone being next found on the western face of Mount Sheridan, along either of whose sides it may be traced, sloping back to the crest of the main ridge.

On the line of the section north of the first described, namely, Section B, which passes through Fryer and Yankee Hills, the faulting action is less prominent, owing to the fact that many of the faults have in their northern continuation merged into folds. On the north of Leadville, extending from the western limit of the map to the eastern edge of the town, is the same broad synclinal noticed in the first section. From here to the western edge of Fryer Hill is a short anticlinal, from whose crest the Blue limestone has been planed off. It is succeeded by a shallow synclinal fold under the western half of Fryer Hill, followed by a short anticlinal at its crest, while in the gulch back or east of the hill is found the rim of a deep synclinal basin, which passes under Little Stray Horse Park. At the west foot of Yankee Hill the ore-bearing horizon rises to the surface, and descends to the eastward again just beyond the summit of this hill; the crest of the intervening anticlinal fold, into which the northern continuation of the Iron fault merges, having been eroded off. From this point the strata descend to the westward, rising in a gentle wave near the Great Hope mine, but not reaching the surface, and then sloping again eastward until they rise on the South Evans anticlinal or are cut off by Weston fault. East of Weston fault, in the region around the mouth of South Evans Gulch, is another anticlinal, or quaquaversal, whose summit has been worn away, leaving the outcrops of succeeding beds in a series of concentric rings. On the east of this fold the beds slope continuously to the eastward at an angle of from 15° to 20°, a conformable series, extending high up into the Weber grits, being still left uneroded on the summit of Little Ellen Hill.

In Section C, which follows nearly the northern boundary of the map, the faults have apparently all been eliminated, and the outlines of formations shown on the map owe their form entirely to folding and erosion. One broad anticlinal under the west slope of Prospect Mountain, and a shallow synclinal in the Arkansas Valley, express the broader general features of folding. Near this line, at the mouth of the East Fork of the Arkansas, are found the westernmost actual exposures of Paleozoic rocks within the area surveyed. These consist of beds belonging to the Lower quartzite formation, exposed in the bed of the stream, and in the cliffs south of it, dipping to the southeast. They constitute the most definite evidence of the synclinal basin supposed to underlie the town of Leadville.

Distribution of porphyry.—Before proceeding to the detailed description of this region, it may be well to give the general outlines and distribution of the principal bodies of porphyry. The most important is the body of White porphyry which, within the limits of this map, is almost invariably found directly above the Blue limestone. As it forms, over a great part of the area, the surface rock, and has therefore been subjected to considerable erosion, but few opportunities were offered to determine its actual thickness. In general it thins out to the north and east. On Iron and Carbonate hills it has a possible thickness of over 1,000 feet. Along Evans Gulch it will scarcely average 100, and even thins out entirely. Along a line from Fryer Hill to West Sheridan the White porphyry seems to cut down across the Blue limestone; and northeast of that line is found a second sheet, between the Blue and the White limestone, which also apparently dies out to the northeastward. Locally, small sheets of White porphyry are found at a still lower horizon, in the body of the White limestone and even in the Lower quartzite.

Gray porphyry.—One main sheet of Gray porphyry is found above the main White porphyry body, separating it from the overlying Weber formation. This also is found in its principal development northeast of the line mentioned, running from Fryer Hill to West Sheridan. Besides this main sheet other bodies of porphyry, either identical or closely allied to it in composition, are found in different parts of the region, either as sheets irregularly interstratified, or more rarely in the form of dikes. The only prominent instances of the dike form are that on Fryer Hill, and the three prominent dikes which cross Long & Derry and Printer Boy Hills, in a north and south direction.

The *Pyritiferous porphyry* is principally concentrated on Breece Hill and Ball Mountain. Here it seems to form four principal sheets, the lower of which either replaces or occupies a horizon immediately above the main sheet of Gray porphyry, above which are three interstratified bodies in the Weber grits. In addition to these, a fifth body of Pyritiferous porphyry is found above Oro City in California Gulch, cutting up through the White limestone. Practically, its present exposure may be said to be bounded by the line of Breece fault on the north, Ball Mountain fault on the east, Iowa Gulch on the south, and Mike fault on the west.

AREA EAST OF MOSQUITO FAULT.

In the area between the Mosquito fault and the crest of the range, only a small portion of which is represented in the southeast corner of the map, glacial erosion has carved the amphitheater-shaped basins at the head of the various streams out of the Archæan rocks. The very summits of the intervening ridges are capped by remnants of Paleozoic beds and intrusive sheets of porphyry which have escaped erosion. In the Iowa amphitheater, at the head of Iowa Gulch, two minor faults, at right angles to each other, the one running a little south of east, the other a little east of north, have let down an included area to the southwest relatively to the portions north and east of these faults respectively. The end of one of these, the South Dyer fault, is shown on the map on the south slope of East Ball Mountain, where it joins the Mosquito fault. As is shown there, a portion of the Lower quartzite, with an included sheet of the White porphyry, is left on a shoulder of the steep slope to the south of the fault. Three tongue-like masses of the lower beds of the Paleozoic series are seen on the extreme eastern edge of the map, which represent the western end of the Paleozoic beds forming the crest of Dyer, East Ball, and West Sheridan Mountains, respectively.

BETWEEN MOSQUITO AND BALL MOUNTAIN FAULTS.

To the west of the Mosquito fault, the region adjoining the upper portion of Big Evans Gulch, namely the ridge extending eastward from Prospect Mountain to the foot of Mosquito Pass on the north, and the upper portion of Little Ellen Hill on the south, is formed of easterly dipping beds of coarse conglomerates and micaceous quartzites of the Weber grits formation. In these rocks are several bodies of porphyry, the approximate outlines of the most important of which are indicated on the map. Two on the Prospect Mountain ridge are apparently dikes. The western one is a fine-grained, the other a coarse-grained porphyry, containing large feldspars, neither of which belong definitely to either of the principal types mentioned above. A porphyry similar to the coarser-grained is found on the north slope of Little Ellen Hill; while in the Big Evans Gulch below the saw-mill, and extending up on to the north bank of the gulch, is an apparently interbedded mass of Mount Zion porphyry. The lower portion of the Weber grits in this region contains an unusual number of beds of carbonaceous shales, in which there is often a considerable local development of coal. This is shown by various shafts, notably the Ellesmere and Little Providence, near the head of the South Evans Gulch; in the former of which a bed of impure anthracite, nearly eighteen feet in thickness, is found. The coal has, however, thus far proved of little economic value. Similar beds of anthracite have been found and extensively prospected at approximately the same geological horizon in different parts of the West, especially in Nevada, near White Pine, south of Argenta and north of Elko. The result of these explorations offers little encouragement to a search for beds of workable coal at this horizon, especially where the Cretaceous rocks, which are known to contain valuable coal-beds, are so widely spread and easy of access as in Colorado.

The lower horizons of the Paleozoic series are brought to the surface by an anticlinal, or quaquaversal fold, at the foot of the steep northern slope of Ball Mountain. The western slope of this anticlinal is cut off by the Ball Mountain fault, whose line is shown in the Nevada tunnel, which has been run in on it near its junction with the Colorado Prince cross-fault.

The distribution of the White porphyry bodies is here rather exceptional, as they are principally developed in the lower horizons, forming several sheets within the Lower quartzite and White limestone; while the bed above the Blue limestone is comparatively thin, and at one point entirely wanting. It might be inferred from this that near here is one of its vents, or points where it has been intruded through the Archæan into the overlying Paleozoic beds.

The Blue limestone outcrop runs from the Ball Mountain fault eastward a short distance along the north bank of South Evans, and then bends southward, following up its south fork, or Alps Gulch, across the Alps saddle, and then sweeps around the hill to the eastward, until it is cut off near the Hawkeye shaft by the Mosquito fault. The contact between it and the overlying White porphyry has been actually proved in the Little Rische, Little Ellen, Lulu, Gnome, Wall Street, Dauntless, and Alps shafts, in the second of which only have any valuable ore bodies been developed. On the saddle east of Ball Mountain actual outcrops of the Blue limestone and the underlying Parting quartzite are found dipping steeply to the eastward; west of this the croppings of a sheet of

White porphyry separate the Parting quartzite from the White limestone, and cover the surface of Ball Mountain to its summit, while beyond the fault its slopes are covered by Pyritiferous porphyry.

Southward, towards Iowa Gulch, the surface is mainly covered by the lower White porphyry body, the White limestone being apparently divided into several distinct sheets or beds; one of these and the underlying Lower quartzite are found to outcrop on the steep southern slope of Ball Mountain, rising up against the fault with a dip of 50° to the eastward. The Lower quartzite is also exposed by erosion in the bed of Iowa Gulch, just above the fault-line. North of Ball Mountain the Lower quartzite is cut on the south side of the anticlinal already mentioned in the John Mitchell and St. Jo shafts; and on its north side in the Ocean shaft.

Ball Mountain fault.—From its junction with the Mosquito fault on Long & Derry Ridge, Ball Mountain fault extends nearly north across Mosquito Gulch to the crest of Ball Mountain, then curving sharply around to the westward to the End Squeeze, or Cleopatra shaft, it bends northward through the Nevada tunnel and Ocean shaft, across the foot of the steeper slope of Little Ellen Hill, and disappears beyond Big Evans Gulch. Its movement of displacement is an upthrow on the east which has a maximum at the southern end, or in Iowa Gulch, of about 2,250 feet, and gradually decreases to the northward.

BETWEEN BALL MOUNTAIN AND WESTON FAULTS.

This area represents a still more complicated structure than the one just described, owing to the existence of Iowa Gulch and Colorado Prince cross-faults; and further to the fact that the movement of displacement of the Weston fault is reversed at either end.

The *Weston fault*, which joins the Mosquito fault in Empire Gulch, crosses the intervening ridge to Iowa Gulch, in a northwesterly direction, at the foot of the steeper slope of Upper Long & Derry Hill. In Iowa Gulch it passes just west of the Ella Beeler shaft; then extends in the same general direction across the south slope of Green Mountain, and the head of California Gulch, below the Tiger tunnel and a little east of the Ella tunnel. On Breece Hill its exact location is difficult to fix, as Pyritiferous porphyry occurs on either side of it. It passes, however, close to the Highland Chief No. 2 shaft and a little west of the Ontario; then down the northern slope between the Fenian Queen on the west and the Chemung tunnel on the east, and crosses Big Evans just east of the mouth of Lincoln Gulch. North of Big Evans it disappears under the moraine ridge between it and Little Evans Gulch, and on Prospect Mountain apparently passes into an anticlinal fold.

The movement of displacement of this fault is quite remarkable. In Iowa Gulch it has an upthrow to the west of about 500 feet, which decreases to the northward, becoming null near the Yates shaft on Breece Hill. The movement of displacement is then reversed, the upthrow, which is on the east side, reaching a maximum of about 700 feet near the mouth of Lincoln Gulch, opposite the South Evans anticlinal, and then decreasing again to the north.

By the displacement of the *Iowa Gulch cross-fault*, which has an upthrow of about 2,700 feet on its south side, that of the Weston fault is again reversed, the upthrow being to the eastward, south of Iowa Gulch fault. In this uplifted block of ground, south of the Iowa Gulch fault, the only exposure, besides the Archæan rocks, is a strip of Lower quartzite left on the crest of Upper Long & Derry Hill, with a small body of underlying porphyry, which has an anticlinal structure, or a dip towards either fault on the east and west. In Iowa Gulch and up the southwestern slopes of Ball Mountain the surface is mostly covered by Pyritiferous porphyry, of which four principal sheets are found separated by intervening beds of the Weber grits dipping to the eastward. Included in the main, or upper body of Pyritiferous porphyry, are several detached fragments of these beds. Descending the western spur of Ball Mountain towards South Evans Gulch, the influence of the South Evans anticlinal is seen in the southerly dip of the beds, and one passes down geologically across the outcrops of the upper sheets of Pyritiferous porphyry, the underlying Weber grits, and the Weber shales which form its base, across the lower Pyritiferous porphyry and the underlying Gray porphyry to the Blue limestone, and the succeeding Silurian and Cambrian beds.

Colorado Prince fault.—The Colorado Prince cross-fault, which follows approximately the foot of the steep slope of Breece Hill, overlooking South Evans Gulch and the East Fork of Lincoln Gulch, has in general an upthrow to the southwest, its displacement being a maximum at the eastern end and decreasing westward; near Weston fault the movement is apparently reversed. The effect of its movement has been to cut off the southern end of the South Evans anticlinal, as the Weston fault has cut off a portion of its western slope.

South Evans anticlinal.—The data obtained from the numerous shafts around the mouth of South Evans Gulch show that there is here a sheet of White porphyry between the Archæan and the Lower quartzite. The main sheet of White porphyry above the Blue limestone is relatively thin, and on the south side of the anticlinal apparently wanting altogether; but in its place occurs a sheet of White porphyry between the Blue and the White limestone. East of the anticlinal the Weber grits rest directly on the White porphyry; but to the west were separated from it by the main sheet of Gray porphyry, which is now entirely removed by erosion, with the exception of small detached masses included in the porphyry. On the south point of the anticlinal, or under Idaho Park, the Gray porphyry comes directly in contact with the Blue limestone. On the crest of the anticlinal granite is exposed between the mouth of South Evans and Lincoln Gulches, being cut in the Caledonian and other shafts, while the Silver Tooth bore-hole has penetrated it to a depth of 340 feet. On the eastern edge of this outcrop in Lincoln Gulch the Boulder incline has been sunk on the Colorado Prince fault, which has here a reversed dip, granite being on the hanging wall, White porphyry and quartzite on the foot wall. The Cumberland shaft, close to this, south of the Colorado Prince fault, is in the White porphyry immediately above the granite. The Fitchburg incline, opposite the Boulder, on the south side of Lincoln Gulch, went down on the contact of the White limestone and Lower quartzite at an angle of 20° to the southwest. The Colorado Prince tunnel, also south of the Colorado Prince fault, cut successively southerly-dipping bodies of the lower White porphyry, and the Lower quartzite. On the hill above this, the workings of the Black Prince and Miner Boy, starting at a higher horizon, reach the vein material in the Blue limestone; the Miner Boy, or Kentucky tunnel, being run successively through the Lower quartzite, the White limestone, and an intercalated sheet of White porphyry, into the Blue limestone; while another shaft of the Miner Boy, further south, has struck Weber shales above the Blue limestone.

At the Highland Chief mine, still higher up the hill, both tunnel and shaft have been run through the overlying Gray porphyry to the crest of a secondary wave, or slight anticlinal, in the Blue limestone. The limestone is here almost entirely replaced by granular, porous quartz, which is impregnated with pay ore, consisting largely of carbonate of lead and chloride of silver, with a little carbonate of copper. It is interesting to observe, in connection with the concentration of ore at this point, that a dike of Gray porphyry is here found penetrating the ore-horizon. West of the Highland Chief, the Highland Mary, Curran, and other claims have struck the Blue limestone; while the Chemung tunnel beyond them has been run to the southeast, on the contact between Gray and White porphyry, and, cutting across the latter, passed into the Blue limestone which has at first a dip of 25° north, and then slopes southwest, showing that the wave or anticlinal ridge mentioned in the Highland Chief extends in this direction. Several shafts on the Eliza and Little Alice claims strike the limestone under the Wash; but the main shafts of these claims were sunk through the lower sheet of White porphyry to the White limestone.

North of the Colorado Prince fault the eroded edges of the beds which form the eastern side of the anticlinal cross the lower point of Little Ellen Hill, from South Evans to Big Evans Gulches, and north of the latter bend around to the west. The Virginius, Tenderfoot, and Cleveland shafts have cut the contact of the Blue limestone and overlying White porphyry, the former of which is largely replaced by vein material. This outcrop has not been prospected to any great extent, either in South Evans or Big Evans Gulch, although many shafts have been sunk to the eastward in the overlying Weber shales, and to the westward in the underlying Silurian and Cambrian beds. In Big Evans Gulch the U. S. Mint shaft is sunk in the shaly beds at the top of the Lower quartzite, on the northeast slope of the anticlinal. At the foot of Prospect Mountain, in the bed of the upper portion of Little Evans Gulch, the La Harpe, Stillwell, Little Louise, Golden Eagle, and other shafts are sunk near the contact of the main Gray porphyry sheet and the overlying Weber shales, which dip here 25° to the north.

BETWEEN WESTON AND MIKE FAULTS.

The southern portion of this area, which includes the main mass of Long & Derry and Printer Boy Hills, has been lifted up relatively to the succeeding zone on the west.

The Union fault runs across the upper portion of Long & Derry Hill in a direction due north, and joins the Weston fault in the bed of Iowa Gulch, just below the Ella Beeler tunnel. The displacement accompanying this fault has lifted up still further a triangular block of ground, in which two little remnants only of the Blue limestone are left adjoining the Weston fault above the lower White porphyry; while by the erosion of Iowa and Empire Gulches on either side of the ridge the White limestone, Lower quartzite, and a little Archæan are exposed under it.

The top of Printer Boy Hill and the upper portion of Long & Derry Hill are covered by the upper sheet of White porphyry, included in which on the latter are found thin beds of shales and quartzite, belonging to the Weber grits. On the steep cliffs of Long & Derry Hill, overlooking Iowa Gulch, actual outcrops of White limestone and overlying Blue limestone can be seen in the cliffs above the Long & Derry grade. The contact of the latter with the overlying White porphyry is well marked by a line of prospect shafts and mine workings, the most important of which are those of the Long & Derry mine, where the ore is found mostly in the body of the limestone, and of the Florence mine, on the north face of Printer Boy Hill, which have developed a considerable ore body extending from the contact into the body of the limestone. On the surface immediately below the Long & Derry mine is a prominent dark outcrop of siliceous oxides of iron and manganese impregnating a portion of the Blue limestone. The outcrops of this horizon, as shown on the map, curve back on either side of Long & Derry Hill, owing to the erosion of the adjoining gulches. From the Florence mine the contact slopes back to the eastward, through the Minor tunnel, to the First National; it also slopes to the westward through the Brian Boru and adjoining tunnels to the G. M. Favorite, thus evidencing an anticlinal structure. Under the White limestone, in the crest of this anticlinal, is a body of fine-grained quartz-porphyry, of a light green color, which is exposed in the bed of Iowa Gulch, on the Long & Derry grade, and in various shafts south of the Florence mine. Across the crest of Printer Boy Hill and the ridge below Long & Derry Hill run three apparently vertical dikes, about 50 feet in width, of typical Gray porphyry, which cut across the strata and no doubt influence the exceptional concentration of ore in this region.

On the north side of Printer Boy Hill, by the erosion of Upper California Gulch, portions of the Blue and White limestones and Parting quartzite are exposed. The former is cut in the Lovejoy shaft, which passes through it into an underlying bed of porphyry. The Stars and Stripes tunnel has disclosed a bed of porphyry, which somewhat resembles that found in Iowa Gulch under the White limestone. Opposite these, in the bed of California Gulch, is a body of Pyritiferous porphyry, already mentioned, which seems to be cutting up through the White limestone, the latter cropping to the east and above it. On the other hand, the overlying White porphyry is found on the north side of the gulch in contact with the Parting quartzite, showing that it must have cut down through the Blue limestone, a portion of which is found at the very head of California Gulch, at the Ohio Bonanza tunnel.

Pilot fault.—The Pilot tunnel, a little below the Ben Franklin, is run in on the line of a fault which has been named after it. This fault, which crosses the lower end of Printer Boy Hill and joins the Mike fault in Iowa Gulch, disappears to the north in the body of Pyritiferous porphyry on Breece Hill. By its movement the piece of ground included between it and the Mike fault has been let down relatively to the adjoining masses on either side. In this triangular piece of ground are the Printer Boy and Five-Twenty mines, which are in a body of porphyry resembling, though not identical with, the Gray porphyry. Their ore, which is mainly free gold, though in depth associated with some galena and pyrites, is deposited in the porphyry along a vertical plane which is probably either a natural cleavage plane in the porphyry or that of a minor fault.

The surface of Breece Hill in this zone, between California and Stray Horse Gulches, is entirely covered with Pyritiferous porphyry, along the western edges of which, at Oro City and from there to the Park mine in Adelaide Park, can be seen the underlying White porphyry. On the north the Breece fault cuts off the Pyritiferous porphyry, so that its exact relations to the Gray porphyry which forms the surface of Breece Hill beyond, cannot be definitely determined. The Mike shaft, from which the Mike fault receives its name, is sunk in the White porphyry on the fault line. The fault seems to end at the Breece fault, the most northerly evidence of its displacement being the east and west shafts of the Park mine, which have each struck the contact.

The Breece fault, passing through the Eureka and Silver Cloud shafts at the head of Adelaide Park, then bending around a little south of the

Breece Iron mine, takes a course due east, joining the Weston fault on the crest of the ridge of North Breece Hill. Its upthrow, which is to the north, has apparently a maximum at its eastern end, where it reaches about 500 feet; whereas at its western end it has White prophyry at either side, and its exact position and amount of displacement are not determined. So far as known, no shaft has yet reached the Blue limestone under the Pyritiferous porphyry; and the only ones which have penetrated to the underlying Gray porphyry are the Lady Jane and the Cumberland, a short distance south of the fault line, in the latter of which the Pyritiferous porphyry is 450 feet thick.

The Breece Iron mine, which is situated on the western slope of Breece Hill overlooking Adelaide Park, has a remarkable deposit of red hematite mixed with magnetite, which occurs at the contact of the main sheets of White and Gray porphyries. Its ore is found at the surface in two bodies, having a maximum thickness of nearly thirty feet each, the lower of which is underlaid by White porphyry; while between it and the upper body, which is apparently an offshoot from the main body, is a sheet of decomposed porphyry, which has certain resemblances both to the Pyritiferous and the Gray porphyry. This deposit is apparently due to the oxidation of a mass of iron pyrites, which were brought to their present position in solution in a similar manner to the other ore deposits of the region. Indications of iron are found along the contact line between the White and Gray porphyries to the eastward, but as yet no considerable bodies of iron have been developed. West of the Breece mine the Superior and Mountain Boy, on the ridge connecting Breece and Yankee Hills, have also struck a considerable body of iron between the Gray and White porphyries. This may be a continuation of the Breece iron body, the intermediate portion having been removed by the erosion of the head of Stray Horse Gulch, which has brought to the surface the White porphyry underlying the Gray. On the other hand, while the Breece iron is an anhydrous red hematite, the material developed in these shafts consists of brown hematite and bluish-gray chert, the usual replacement material of sedimentary beds. Moreover in the neighboring shaft of the Theresa mine, shales, belonging to the Weber series, have been found in the same relative position, for which reason the outcrop is indicated on the map by the color of that formation.

WEST OF MIKE AND WESTON FAULTS.

The line of Mike fault, if continued northward, would pass through an anticlinal fold whose crest reaches from the north slope of Yankee Hill to the southwest foot of Canterbury Hill, just below the forks of Little Evans Gulch. To this line converges also the northern end of the Iron fault, whose throw becomes null at the crest of the fold. The simplest expression of the structure of the region between Fryer Hill and the Weston fault, north of Stray Horse Gulch, is that of a synclinal basin in Little Stray Horse Park, the eroded crest of an anticlinal at Yankee Hill, and a synclinal further eastward, whose rim is partially cut off by Weston fault. The intrusive masses of porphyry here associated with the regular sedimentary series are, a lower sheet of White porphyry between the White limestone and Parting quartzite, an upper sheet of White porphyry above the Blue limestone, and the main sheet of Gray porphyry over it. This comparatively simple structure, resulting from folding alone, which obtains along the line of Big Evans Gulch on the north slope of Yankee Hill, is complicated on the south, first by the displacement of the Iron fault, which cuts diagonally into the crest of the fold crossing Stray Horse Gulch west of the Argentine tunnel, between the Double Decker and Highland Mary shafts, the east and west shafts of the Hard Cash mine, and through the eastern end of the Chieftain tunnel; second, by the movement of the Adelaide cross-fault, which extends from the Iron fault opposite the mouth of the Argentine tunnel, just west of the Laura Lynn shaft, to the saddle between Adelaide Park and the head of Nugget Gulch; and third, by the intrusion of several irregular masses of Gray porphyry.

The synclinal east of Yankee Hill.—The outcrop of the Blue limestone on the western rim of this basin occurs just east of the crest of Yankee Hill, where, in the Clara Dell, Greenwood, and Little Champion shafts, it is found to be replaced by iron vein material; it crosses Big Evans Gulch at the mouth of Johnson Gulch, and then bends to the westward, having been proved on the north side, in the moraine ridge between Big Evans and Little Evans, by a shaft about 900 feet west of the Abe Lincoln. East of this line the formations basin down, being successively covered by the White and Gray porphyries, which have been penetrated by the Onota, Andy Johnson, and other shafts in Johnson Gulch. The lowest point of the basin is probably somewhere near the Independence shaft, where the overlying Gray porphyry was found to be 420 feet thick. They then rise in a minor fold which brings the contact to within 80 or 90 feet of the surface at the Great Hope, Bosco, and Across-the-Ocean shafts, opposite Evansville. The former of these has penetrated the Parting quartzite beneath the Blue limestone, which is here found impregnated with gold to such an extent that considerable valuable gold ore is said to have been shipped from the mine. Beyond this ridge, as shown by the depth of the contact at the Nora shaft, the beds probably sink to the eastward for a short distance before they rise under the influence of the South Evans anticlinal, from which they have been cut off by the Weston fault. The evidence afforded by the few shafts which have penetrated the Blue limestone horizon in this region shows a considerable action of replacement, not only in those already mentioned, but in others south of them, on the slope of Breece Hill. The Little Prince, after passing through the overlying Gray and White porphyry bodies, cuts the entire thickness of the Blue limestone to the underlying quartzite and White limestone. Here the entire body of Blue limestone was found to be replaced by porous granular quartz, in which occur several irregular bodies of galena and carbonate of lead. In the Andy Johnson, which also passed through the Gray and White porphyries, was found a considerable body of iron vein material, whose development was temporarily stopped by the great in-rush of water.

The thickness of the White porphyry sheet evidently varies greatly within this region, being only 15 or 20 feet in the Great Hope and Across-the-Ocean, and wanting entirely in the Bosco and Nora; whereas to the westward it is found to be over 100 feet in thickness.

Yankee Hill anticlinal.—The beds below the Blue limestone, exposed on the eroded crest of the anticlinal, are shown on the north slope of Yankee Hill, in the William-and-Mary tunnel and the Sappho shaft east of the axis, and in the J. B. Grant, Dania, and others west. At the William-and-Mary tunnel the Parting quartzite is exposed, resting on a portion of the White limestone which here lies above the lower sheet of White porphyry, while the Sappho shaft has been sunk nearly 300 feet in the lower sheet of White porphyry. The Dania, J. B. Grant, and other shafts penetrate the White porphyry and strike the underlying White limestone. On the western and southern slopes of Yankee Hill, east of the Iron fault, are only easterly-dipping beds, owing to the displacement of this fault, which has lifted up the beds to the east of it so that the Lower quartzite and a portion of the Archæan are exposed. On the slopes of Yankee Hill towards Stray Horse Gulch, the Red-headed Mary and Woodruff shafts have been sunk through the lower White porphyry into White limestone; the Holden shaft through White limestone into Lower quartzite, the Silver Basin and Double Decker in the Lower quartzite and the former into the Archæan. Directly south of the crest of Iron Hill extends a body of Gray porphyry, which, at its northern end, seems to be more like a dike cutting across the Blue limestone, and at its southern end an intrusive sheet between Blue limestone and Gray porphyry. It is exposed in the Clara Dell, Rothschild, and Louisville shafts; in the Day bore-hole in Adelaide Park, and the Laura Lynn shaft on the northeast side of Iron Hill. The occurrence of this body and of numerous irregular bodies of the same rock, seen in the Adelaide and Argentine mines at different horizons, suggests a probable vent or point of eruption from beneath in this vicinity.

Little Stray Horse Park synclinal.—The body of Gray porphyry shown on the map between Yankee and Fryer Hills outlines a synclinal basin, being the uppermost bed which has escaped erosion by its position above the lowest portion of the basin. The Blue limestone, on the eastern rim of this basin, is found in the Cordelia Edmondson, Kennebec, Aztec, Cullen, Chieftain, Scooper, and other mines; and on the west in the R. E. Lee, Little Sliver, Bangkok, Tip-Top, Denver City, and others. In all these it is more or less replaced by iron vein material. In the middle of the basin, between these sets of shafts, the bottom of the Gray porphyry has not yet been reached, it being evidently very deep, and the in-rush of water consequent upon the basin structure, so great as to retard developments. The beds rise more steeply on the eastern rim, and in the Scooper shaft are almost perpendicular, so that the line between the Gray porphyry and the vein material underneath has been taken for a fault line. This mistake is not unnatural, since slickensides surfaces are largely developed, which indicate a movement of the beds on each other on this side of the basin, due to their intense compression against the adjoining Iron fault. The effects of this compression are well seen in the Chieftain tunnel, which has been driven directly to the fault plane, passing through a number of irregular folds in the limestone and vein material which has replaced it.

At the southern portion of the synclinal the White porphyry has cut down into the Blue limestone, splitting off a portion of the latter from the main body. The Highland Mary, in Stray Horse Gulch, and the Devlin, on the northwest slope of Iron Hill, have reached the main body of Blue limestone below the White porphyry at a comparatively shallow depth, showing that it basins up toward the Iron fault. The Greenback, Agassiz, Cyclops, Robert Emmet, and adjoining shafts have penetrated a body of iron which is the replacement of the portion of Blue limestone split off from the main body by the lower sheet of White porphyry, and which reaches the surface in a circular outcrop, partly concealed on the map by the Lake beds color. To the north the synclinal also basins up in the direction of Little Evans Gulch; the Buffalo shaft, which is between it and Big Evans, having been sunk about the middle of the basin in the Gray porphyry to a depth of 450 feet. The line of the western rim of the basin is irregular, owing to a minor anticlinal, which forms the continuation of the Carbonate fault on the upper portion of Fryer Hill, and will be described more in detail in the chapter devoted to that region.

NORTH OF EVANS GULCH.

On the western slopes of Prospect Mountain, to the north of Big Evans, are two anticlinal folds, which, for convenience of description, will be designated by their culminating points: the Little Evans anticlinal and the Big Evans anticlinal.

The apex of the *Little Evans anticlinal* is just below the forks of Little Evans Gulch, at the south foot of Canterbury Hill. It is formed by the junction of two anticlinal axes, the one running south in the direction of a small outcrop of White porphyry, where the Powhattan and Pocahontas shafts have passed directly through this rock to the Blue limestone, the overlying Gray porphyry having been eroded off; the other being the northwestern extension of the Yankee Hill anticlinal. The lowest horizons on the crest of the anticlinal have been proved in the Lucknow shaft, which was sunk in the Lower quartzite, the Little Clara, which passed through the White limestone into the Lower quartzite, and the Norcom, which is in the White limestone. On the north the Little Blonde and the Princeton disclosed two bodies of black chert replacing the Blue limestone and dipping steeply to the north. Directly west of these is a narrow synclinal basin, succeeded by another anticlinal, which is indicated on the map by a tongue of White porphyry extending into the Gray; and near the summit of Canterbury Hill is a second synclinal. East of the Little Evans anticlinal a body of Gray porphyry is intruded into the Blue limestone. Along the anticlinal ridge, extending in this direction, the following shafts have entered the Blue limestone: The Copenhagen, Carbonate King, Providence, Hancock, Little Cash, and Carbonate No. 2, the latter having passed through the intrusive mass of Gray porphyry. The Lac La Belle was sunk in the Blue limestone on the northwest slope of the anticlinal.

The Big Evans anticlinal.—In the region near the mouth of Big Evans Gulch the accumulation of moraine material is so great that but few shafts have as yet penetrated to any depth in the underlying rock. The location of the anticlinal ridge indicated on the map is therefore determined by comparatively meager data. Its axis runs, probably, in a north and south direction under the Cumming & Finn smelter. The Lower quartzite has been proved on its south side by the Lida shaft, and on the north by the Third Term bore-hole, each of which has disclosed a body of White porphyry within the quartzite. On the western side of this anticlinal the Oolite shaft has passed through the overlying White and Gray porphyries to the Blue limestone, obtaining characteristic fossils. The Mystic and Sequa were, at last accounts, still in the Gray porphyry, and, so far as known, no other shafts in this region have reached a lower geological horizon. The existence of a synclinal is, however, amply proved by the western dip disclosed by the above shafts, and the fact that the western rim of the basin has been found, as already shown, in the croppings of Lower quartzite at the mouth of the East Fork of the Arkansas.

The most important developments of ore bodies have been made in the mines of Iron, Carbonate, and Fryer Hills; these in the final publication will be illustrated by special maps drawn on a large scale, and showing not only surface geology but underground workings and the distribution of the ore bodies. The substance of the chapters to be devoted to these groups of mines will be next given in as much detail as can be hoped to be intelligible without the aid of maps.

QUATERNARY FORMATIONS.

Wash.—As already stated, the moraines, and their rearranged material the "Wash," have not been designated by a special color on the surface maps, as it would hide too large a proportion of the outlines of the underlying rocks, which the numerous shafts have furnished data to lay down with exceptional accuracy. In the detailed map of Leadville, of the final publication, the Lake beds will also be omitted, in order to show the probable outlines of the rock formations under them, which, though determined with a much less degree of accuracy than on the other portions of the map, may yet be of use to the miner in directing his explorations. The position of the principal actual moraine ridges already mentioned, on the north bank of Big Evans, and on either side of Iowa Creek, can be easily recognized by a trained eye in the shape given them by the contours. On the ground itself they are much more readily traced by one at all familiar with glacial topography, both by their position relative to the former course of the glacier, and by the little depressions without outlet, often filled by small ponds, which constitute a characteristic feature of moraine topography.

Lake beds.—The superficial evidence of the existence of Lake beds, where not shown by actual outcrops, is found only in the shape of the flat-topped, gently-sloping ridges which form the lower ends of the spurs adjoining the Arkansas Valley. Their existence high up on the spurs, reaching, as shown on the map, the 11,000 feet contour, is only proved by underground explorations, and in these they are often not easily recognizable, especially when, as is frequently the case, they closely resemble decomposed granite. In such cases the only infallible test is the existence of well-defined bedding planes. In general, however, they consist of an earthy marl, or a coarse conglomerate cemented by carbonate of lime, the "cement" of the miners. The marls are found in Graham Park in the City of Paris, Greenback, R. A. M., and other shafts. On the ridge between California and Iowa Gulches the Coon Valley shaft, opposite Graham Park, found the contact after going through over 500 feet of Wash and Lake beds, and in the Upper Printer Boy the earlier workings, following the vein southward or into the hill, are said to have reached a line of gravel deposits, which from description would appear to be a shore line of Lake bed deposits. Lake beds were found south of Iowa Gulch, in the Continental shaft on the moraine ridge just below the western angle of the Long & Derry grade, and also in shafts on the south side of the ridge overlooking Empire Gulch. In Leadville itself the Bob Ingersoll shaft and drill-hole on the moraine ridge in Ninth street found Lake beds between Wash and White porphyry. Other shafts lower down, or further west than this, have been sunk in the Wash and Lake beds, but at time of writing none had yet reached solid rock.

CHAPTER VII.

IRON HILL MINES.

General structure.—Of the three principal groups of mines those of Iron Hill present the simplest type, both in geological structure and in the character of their ore deposits. It is that of a block of easterly-dipping beds, capped by porphyry, with a fault on its western side, by whose displacement these beds have been lifted over a thousand feet above their western continuation, and in which the ore deposition has taken place on the surface of the upper limestone bed, at its contact with the overlying porphyry. This simple type obtains only on the southern end of Iron Hill, and even then only in a somewhat modified form, the northern presenting, as will be seen later, the extreme of complication.

The southern face of the hill has, by the erosion of the deep V-shaped valley of California Gulch, been left so steep that its surface is but thinly covered by detrital material, and east of the Iron fault, which is marked by slight depression, the outcrops of the succeeding beds can be readily traced up its slopes from the Lower quartzite, immediately overlying the granite, to the main sheet of White porphyry, which forms its summit. Besides this normal series of beds are two intruded masses of porphyry of later age, and allied to, though not absolutely identical with, the Gray porphyry. One occurs near the base of the Blue limestone, and has its greatest thickness at the fault line, thinning out to the eastward, and disappearing midway between it and the point where the Blue limestone reaches the bed of the gulch. The other has its greatest thickness at this point, where it cuts across the upper portion of the Blue limestone at so small an angle with its stratification planes that it forms the contact between it and the White porphyry for some distance up the slope on either side, and then passes up into the White porphyry, also gradually thinning out and disappearing.

The average strike of the formation in this vicinity is a little west of north, and the beds dip to the eastward at an angle of about 12° at the outcrop, which shallows to 7° and even less under the summit of the hill.

Iron fault.—The average direction of the line of the Iron fault is, as shown on the map, a little east of north, but its course is very crooked, as proved by actual development in shafts and winzes in the Garden City, L. M., Lingula, Iron, and Codfish-Ball claims. It has an average inclination to the west of 65°, and its movement of displacement, though no shaft has yet reached the Blue limestone to the west of it, is probably more than one thousand feet. Were the Carbonate Hill beds carried back at the angle of dip thus far determined it would give a still greater thickness of White porphyry above the limestone immediately adjoining the fault, but such thickness cannot be calculated on, since there are good grounds for assuming that the dip shallows, and even that the beds basin up before reaching the fault, as shown in Section E.

Dome Hill.—South of California Gulch the structure is more complicated, and the opportunities for accurate study of the rock surface diminished by great depth of Wash and underlying Lake beds, on the ridge which separates it from Iowa Gulch. Its expression will be made clearer if the displacement is considered as a downward movement of the beds on the west of the fault, instead of an upward movement of those on the east, as is actually the case.

The downward movement of the western block has, then, south of California Gulch, been distributed between the Iron fault proper, and a second fault further east, just below the Rock and Dome mines, which is connected with the former by a cross-fault following the bed of California Gulch from the Garden City shaft up to within 600 feet of the Montgomery quarry. Moreover, between these two faults is a third, running from just below the Robert Emmet tunnel, in the gulch, to connect with the Iron fault, and enclosing thus a wedge-shaped piece of ground, which has been lifted up and compressed into an anticlinal fold. As a result of the upward movement of this wedge-shaped piece of ground, Blue limestone is found outcropping on the south side of the gulch directly opposite the Lower quartzite on the Globe ground, and the Columbia, Ben Burb, and others, have been enabled to strike the contact comparatively near the surface; on its west side the beds dip steeply towards the Iron fault.

It is probable that before reaching Iowa Gulch the Iron fault merges into the axis of a synclinal fold, in which case the normal continuation of the Iron fault might be considered to be formed by the California Gulch and Dome fault, since the latter becomes beyond Iowa Gulch the axis of an anticlinal fold, as does the northern extremity of the Iron fault. Moreover, evidence of a westerly dip in beds between the Dome and Iron faults is found in the relatively greater depth at which the Blue limestone was reached in the Coon Valley shaft near the latter than in those further east. This region is worthy of being systematically prospected, being within the principal ore-bearing area of the district.

Mineral deposits.—As shown by present developments the principal deposition of ore has taken place along the contact plane between the Blue limestone and overlying White porphyry, and extended to greater or less depth into the mass of the limestone; in several instances large deposits have been formed within the body of the limestone, being probably on the line of some natural cleavage plane or fissure, which caused a deviation of the ore-currents from their normal course.

Gangue.—The vein material or gangue consists of hydrated oxides of iron or manganese, silica, and clay. The iron varies from a hard, compact, more or less siliceous, brown hematite to a simple coloring matter of the clay. Manganese is found sometimes in fine needle-like crystals of pyrolusite, but mainly occurs in a black clayey mass, known to the miners as "black-iron." Silica occurs either as a blue-black chert, or as a granular, somewhat porous mass, hardly distinguishable from quartzite. Clay is found in greatly varying degrees of impurity, from a white kaolin down, and is a product of the decomposition of porphyry. It occurs either in place or as an infiltrated mass. Besides this should be mentioned the "Chinese talc" of the miners, found mainly at the actual contact.

Ore.—The ore is principally argentiferous galena and its secondary products, viz., carbonate of lead or cerussite, and chloride of silver; as accessory minerals, or those of less frequent occurrence, are sulphate of lead or anglesite, pyromorphite, minium, zinc blende, and calamine. Native sulphur is found in one instance as a result of the decomposition of galena, and native silver, from the reduction of the chloride.

Mine workings.—The principal mine workings may be divided into the following groups, commencing at the north: 1st, the main Iron mine workings, including the north Bull's-Eye; 2nd, the Silver Wave and Silver Cord workings, including south Bull's-Eye; 3rd, Lime and Smuggler workings. Beyond California Gulch: 1st, the La Plata workings; 2nd, the Rock and Dome workings.

Iron mine.—This group has an area of about 25 acres of underground workings, being the most considerable of any single mine in the district. They have been driven a distance of over 1,500 feet along the contact from the outcrop of the Blue limestone. Here the contact has been found productive over an unusually large area, the main ore body extending diagonally through the claims in a northeast direction from the croppings, with an average width of 200 feet. In this area the ore currents have penetrated irregularly into the body of the limestone, and ore bodies of 30 and 40 feet in thickness have been developed. It is found that the limestone, while keeping its general inclination to the eastward, is compressed into lateral folds which have produced a series of troughs and ridges within the mass. The relation of the distribution of rich ore bodies to these minor folds is not, however, as clear as in the deposits of Carbonate Hill.

In the lower part of the mine, between the sixth and seventh levels, is a body of Gray porphyry, cutting up across the strata into the White porphyry, which would appear to have influenced a concentration of ore on its flanks. The developments here have been pushed already to a sufficient depth to show an increase in the proportion of sulphurets in the ore and a decrease in the tenor of silver, which would be naturally expected from diminished action of surface waters.

Silver Wave group.—In the Silver Wave group the contact surface has been found relatively unproductive, but large amounts of rich ore have been found in irregular lenticular bodies, standing nearly vertical, and extending downwards 60 to 100 feet from the surface of the limestone. That these are along water-channels is proved by the discovery of recent caves washed out of the ore bodies themselves, or immediately adjoining them, which have evidently been formed by the percolation of surface waters at a comparatively recent date. The general direction of these bodies is also northeast, but on a line convegent with that of the main Iron body.

Smuggler and Lime.—On the south end of Iron Hill, adjoining California Gulch, there is evidence of another zone where the limestone has been largely replaced by vein material, in which, however, present limited developments have disclosed no large bodies of very rich ore.

La Plata.—The La Plata mine has been developed by a tunnel run in near the contact, but with a direction a little west of that of the strike. As in the Silver Wave, but little rich ore has been found on the contact, but large lenticular bodies standing in a nearly vertical position have been found within the limestone extending to a depth of 100 feet below the tunnel level.

The Rock and Dome.—Near the mouth of the Rock tunnel once stood a huge outcrop of "hard carbonate" from which came the first silver ore that was discovered in the region. The main workings of these two mines are in a bonanza which is near the croppings, and which, like those on Iron Hill, has a general northeast direction. The ore in this body occurs mostly near the contact, extending at places to a considerable depth into the limestone. It is much more siliceous than that of the Iron mine. A second more or less parallel body, on a line with that of the La Plata body, may be looked for in the lower working of either mine.

Future explorations.—It is difficult to offer suggestions as to manner of exploration to those who so well understand the character of their deposits as do the managers of mines in this region.

Practical experience has already proved to them that not only should the contact be thoroughly explored, but indications of ore bodies extending into the mass of the limestone should be carefully followed. They should also look for bodies of porphyry which may cross the formation, either as dikes or irregular sheets, since they are likely to be accompanied by a concentration of ore at no great distance; the Gray porphyry forms such bodies more commonly than the White.

It is probably a fruitless task to search for valuable ore deposits below the horizon of the Blue limestone, although there is always a remote possibility of finding veins in the underlying granite. Ore indications on fault planes are also likely to prove deceptive; the evidence afforded by present developments goes to show that, while small fragments of ore are found which have probably fallen into the fissure, and a certain amount of secondary deposition from waters which have passed over the original deposits has taken place there, the ore to be obtained from them will at the best no more than pay the expenses of exploration.

To the west of the fault line, however, the contact undoubtedly exists below the porphyry and probably contains valuable bodies of ore, which, however, as present experience abundantly shows, are not continuous over the whole surface. In locating a shaft for such exploration the probable continuation of already existing bodies should be carefully calculated, taking into consideration the apparent lateral movement that would be caused by the fault-displacement. Directly opposite the Iron mine it may be calculated that at least a thousand feet of unproductive rock will have to be passed through; this thickness is probably less as one goes south, and the least depth will probably be found on Dome Hill, or beyond in Iowa Gulch, with the disadvantage in going south that the center of ore developments as at present known is further removed.

North Iron Hill.—Explorations in the Adelaide-Argentine group of mines on the northern end of Iron Hill overlooking Stray Horse Gulch, have developed a geological structure of such intricate and complicated nature, that the aid of the map and sections to be included in the atlas of the memoir is essential for its elucidation. Only a brief sketch of its main outlines, therefore, will here be presented. Along a line running southeast from Fryer Hill toward Mount Sheridan, as shown in the general description, the sheet of White porphyry cuts across the Blue limestone, or splits into two bodies, there being on the northeast of this line one body of White porphyry above the Blue limestone, and one below, between it and the White limestone. On Iron Hill this cutting across occurs in the region under description, in which, moreover, two minor sheets of White porphyry were forced in, the one in the middle of the Parting quartzite, the other in the body of the White limestone near its base; furthermore, two bodies of Gray porphyry were afterwards introduced, the main one into the mass of the White limestone above the lower sheet of White porphyry, and a smaller one above the Parting quartzite, between it and the offshoot from the main general sheet of White porphyry. In the movements of folding and displacement these beds were lifted by a fold and cut off by the Adelaide cross-fault, which runs diagonally from the Iron to the Mike fault. The whole upper part of the fold was then planed off by erosion, which entirely removed the portion of Blue limestone above the cross-cutting mass of White porphyry. During the period of ore deposition the currents followed the under surface of the porphyry body, and in these mines the main deposit of pay-ore has consequently been found at its contact with the Parting quartzite, although some replacement probably took place also along the basset edges of the Blue limestone. In the Argentine tunnel, which is driven in a direction nearly at right angles to the strike, the beds are found with a dip at first of 25° southeast, which shallows as one proceeds. One crosses in succession from the mouth inwards, or ascending in the geological scale;

1. Lower White porphyry.
2. White limestone.
3. Offshoot from Gray porphyry body.
4. White limestone.
5. Main Gray porphyry body.
6. White limestone.
7. Offshoot from Gray porphyry body.
8. White limestone.
9. Parting quartzite.
10. White porphyry.
11. Parting quartzite.
12. Ore horizon.
13. Blue limestone.
14. White porphyry (overlying).

The supposed contact of White porphyry over the basset edges of the Blue limestone is not seen, being above the tunnel level. The actual contact between the upper surface of the Blue limestone and White porphyry is barren in the tunnel, but has produced ore in the Hynes shaft on the Camp Bird claim to the south. The main ore body extends above the tunnel level, on the surface of the Parting quartzite, westward into the Camp Bird claim, and east and south on the dip into the Adelaide claim. Small bodies of carbonate of lead were also found in the Adelaide ground, at the contact of a small body of Gray porphyry which does not cross the tunnel, and the main White porphyry. Moreover, besides the surface of the Parting quartzite, replacement is found to have gone on to a considerable extent in the White limestone also, without, however, developing much rich ore. In the Discovery tunnel of the Adelaide, on Stray Horse Gulch, a small body of Blue dolomite was found immediately over the Parting quartzite, which is apparently a portion of the Blue limestone which had not been separated from the overlying rocks by the cross-cutting White porphyry. In such a complication of intrusive bodies the only maxim for the miner is, to follow all productive contacts so long as there are signs of ore or vein material.

CHAPTER VIII.

CARBONATE HILL MINES.

General structure.—The geological structure of Carbonate Hill is very similar to that of Iron Hill, in that it is formed by a series of easterly-dipping beds, broken on the west by a line of fault or displacement. Outcrops are also exposed on its southern face by the erosion of California Gulch, but in a less complete series owing to its being shallower and proportionately wider, in consequence of which its bounding slopes, being less steep, are more thickly covered by surface *débris*. The fault is nearly parallel to that of Iron Hill, and, like it, merges into the axis of an anticlinal fold on the north. In the southern half of the hill, however, the movement of displacement is distributed in part to a second nearly parallel fault, a short distance to the west. Of the southern continuation of these faults less satisfactory data are available, but they are supposed to merge together before crossing California Gulch, and probably pass into an anticlinal fold under the Lake beds to the southwest like the Dome fault, the normal continuation of the Iron fault. As on Iron Hill, also, there is evidence of a basining up, as they approach the fault, of the beds of the relatively downthrown mass on the west; in other words, of a synclinal structure. Upon this evidence, which will be given later in full, depends the solution of the important question whether ore bodies exist under the present site of Leadville or not.

Formations.—The series of beds of which it is composed is essentially the same as that given in the Iron Hill section, but the distribution of the later intrusions of Gray or Mottled porphyry differs somewhat in detail. Where these cross the beds, either as dikes or sheets, there is a noticeable enrichment of the ore bodies. One main sheet of Gray porphyry is found at or near the base of the Blue limestone, which apparently cuts up to a higher horizon in different portions of the hill. A second sheet is found in the White limestone in California Gulch, as shown on the map; but, as none of the underground workings have penetrated as yet to this depth, there is no evidence to show whether this is a distinct sheet or merely an offshoot from the main body.

Vein material.—The materials composing the ore deposits of Carbonate Hill are essentially the same as those of Iron Hill; they may perhaps be said to be less rich in bases of iron and manganese, and proportionately more in silica, therefore less favorable for the smelter, but this characteristic is rather one to be confined to individual mines, or parts of a mine, than applied in such a general way. Silica occurs less frequently as chert and more commonly as a very finely granular and somewhat porous quartz rock, than on either Iron or Fryer Hills. The ore is either galena or its secondary products, carbonate of lead and chloride of silver. In one instance native silver has been found. Exceptionally good opportunities are offered for observing the action of replacement, and the gradual passage from dolomite into earthy oxides of iron and manganese. The workings not yet having reached the great distance from the surface that they have on Iron Hill, no such definite evidence is found of decrease in the action of surface waters, producing oxidation and chlorination of the original deposits. The limit of the zone of oxidation would moreover be expected to be further from the surface, on account of its lower altitude.

Mine workings.—The underground workings of Carbonate Hill may, for convenience of description, be divided into three groups. 1st. A southern, including the Carbonate, Little Giant, and Yankee Doodle claims to the east of the main fault, and the Ætna and Glass-Pendery claims below or to the west of it. 2nd. A central group, including the Crescent, Catalpa, and Evening Star claims east of the fault, and the minor workings of the Lower Crescent, Catalpa No. 2, Lower Evening Star, Niles & Augusta, and Wild Cat west of it. 3rd. A northern group, consisting of the Morning Star, Waterloo, Henriette, Maid of Erin, and other claims above the fault line, and the Forsaken, Halfway House, and Lower Henriette below it.

Carbonate group.—In this group of claims, the principal developments have been made on what is practically one main body, running in a northeasterly direction from the outcrop in the Carbonate claim. A noticeable feature of the structure is a prominent fold in the limestone, which bends down sharply to the east, and rising again forms a narrow trough. This is best seen in the main Carbonate incline at about 350 feet from its mouth, and can be traced through the adjoining Little Giant and Yankee Doodle claims, running parallel to the ore body, of which its crest forms the southeastern limit. Approximately parallel to this, several minor folds or plications can be seen in the Carbonate workings. The ore body is narrower in the Yankee Doodle and Little Giant claims, but widens out as it approaches the surface in the Carbonate ground, having barren streaks corresponding to the minor folds mentioned. From the actual cropping of the southeastern portion of this body was taken the first ore discovered on Carbonate Hill. The region to the southeast of the fold has thus far proved barren of rich ore, but the explorations are hardly sufficient to warrant the conclusion that another bonanza does not exist in that direction. The influence of the fold as determining the deposition of ore may be ascribed to the compression of the beds produced by it, and the consequent partial arresting of ore currents, giving them time to deposit their metallic contents.

Carbonate fault.—The Carbonate fault runs nearly on the dividing line of the Carbonate and Ætna claims, cutting across the extreme southwest edge of the former and the northeast corner of the latter. It is well shown by a shaft sunk on this claim which has followed its plane; as thus developed, it stands with an inclination of about 60° west, shallowing somewhat in depth, and having a movement of displacement of only about 250 feet. Within the opening were found some fragments of ore, and the fault material was slightly impregnated with chloride of silver. The slickensides surfaces are smooth and clearly defined, and the beds on either side have the same angle and direction of dip.

In the Ætna and Glass-Pendery claims the contact has thus far proved practically barren, the principal ore extracted having been obtained from lenticular bodies within the limestone, lying mostly within the former claim. Judging from the few points at which its level has been determined, the general surface of the limestone would appear to slope westward, although, as before stated, at the actual fault line it dips east.

Pendery fault.—A short distance west of the Glass shaft a second fault, apparently nearly parallel and having the same angle of inclination with the Carbonate fault, cuts off the limestone, no explorations west of this line having reached below the White porphyry. It is to be regretted that the persistent refusal of the owners of the Glass-Pendery to permit an examination of their mine renders the data with regard to this fault, which has such an important bearing upon future explorations, less full than could have been desired. Its probable continuation has been traced, however, southward to a connection with the Carbonate fault, and northward through the Washburne and Saint Mary workings, where it appears to be a combination of minor folds and faults, and into a probable anticlinal fold north of the Niles & Augusta, and west of the Halfway House.

Evening Star group.—In the second group of mines the workings above the fault have developed a second bonanza or ore body, nearly parallel to the one already mentioned, and separated from it by a comparatively barren belt of ground. In the Crescent claim it is rather thin and spread out somewhat irregularly, but concentrates and becomes deeper in the Catalpa, reaching its maximum, both of breadth and thickness, in the Evening Star claim. In the upper portion of the latter the entire body of limestone has been replaced by vein material, a remarkably large proportion of which is pay ore; but to the eastward the ore currents have penetrated to less depth, and in the lower workings unreplaced dolomite is found, at times only separated from the overlying porphyry by a few inches of clay and "Chinese talc." The actual southeastern limit of the bonanza has not yet been reached, however, and present explorations, extensive though they are, cover such a comparatively small proportion of the possible area of ore bodies, and afford such meager data for generalizations, that it is with extreme reluctance that I speak of even possibly barren ground.

A fact worthy of mention here is the occurrence of a narrow dike of Gray porphyry, standing nearly vertical, and having a northeasterly direction, cutting across the ore horizon at the western edge of the bonanza. This may be an offshoot from the heavy sheet of Gray porphyry which has been proved by the lower workings of the mine to underlie the main ore body, and has probably influenced the great concentration of ore in this mine. A second fact worthy of note is the occurrence of ore in the White porphyry near the main shaft of the Evening Star mine. Such instances of the divergence of ore-currents into the mass of the overlying porphyry are extremely rare. In this case the deposit consists largely of pyromorphite and carbonate of lead, with a little sulphide, and forms the binding material of small angular blocks of porphyry. It is therefore in part certainly, and possibly altogether, of secondary origin.

The ground west of the main or Carbonate fault in this central group has been comparatively little explored, as no considerable ore bodies have yet been developed in it. The fault itself has nowhere been cut by underground working, and its existence is only proved inferentially, both here and on the more northern portion of the hill, by the relative difference of level of the contact above and below its assumed line. Its displacement in the Crescent ground, where the workings on either side most nearly approach each other, viz., those of the Crescent incline and the Lower Crescent shaft, is not more than 170 feet. In the Catalpa pay ore is found to extend nearly to the surface above the fault line; its existence below has, however, not yet been thoroughly tested. In the Evening Star the new No. 5 shaft has been sunk through a body of iron into a remnant of unreplaced dolomite, and is probably in the lower half of the Blue limestone or ore-bearing horizon. The lower Evening Star shaft is said to have developed a small body of ore, which would not be more than 100 feet below the bottom of the former, but in calculating the amount of displacement it must be borne in mind that in one case the ore is near the bottom, in the other probably at the top of the Blue limestone horizon. In the Niles & Augusta ground, immediately adjoining the Evening Star on the west, there is evidence of a westerly dip in the formation, so that between the two would be the crest of the anticlinal fold into which the Pendery fault is supposed to merge.

Morning Star group.—The continuation of the Evening Star bonanza has been traced in a northeasterly direction through the upper workings of the Morning Star mine, but too little systematic exploration has been done to give a satisfactory idea of its outlines or limits. It apparently decreases in thickness, and the acid character of its gangue, which is a porous granular quartz containing very little or no iron, is very noticeable. Ore has been found on the same line in the workings of the upper Henriette claim, but the adjoining portions of the Waterloo and Henriette between this and the fault, in which ore bodies may be reasonably looked for, are as yet practically untouched. Ore has also been found on the dip in the Big Chief, indicating a possible widening out of the ore body in that direction. In the lower Morning Star, but still above the line of the fault, is a singular combination of fault and fold, by which the ground opened by the lower shaft has been lifted up, relatively to that nearer the main shaft. There is here also a body of Gray porphyry, which is probably an offshoot from the lower main sheet of Gray porphyry cutting up across the strata. The descent of the strata to the east of this fault is evidently comparable to that in the sharp folds noticed in the Carbonate and Crescent inclines, and the actual faulting movement, so far as could be observed, was very slight. As in these, also, the ground for a certain distance beyond is comparatively barren.

Below the line of the main fault, whose existence here, as already stated, is only proved inferentially, important ore bodies have been developed, and the probable structure as revealed by their exploration is so complicated that its explanation is difficult without the aid of the sections which will accompany the final publication. The Carbonate fault is supposed to pass between the Lower Morning Star and Waterloo shafts, and extend northeasterly across Stray Horse Gulch (there being evidence of a slight displacement in the ridge beyond) in the direction of Upper Fryer Hill, where, in the Dunkin ground, it has passed into a flat anticlinal fold. To the northwest of this line is a flat synclinal fold, which would be a continuation of the synclinal of Fryer Hill. In the ground of the Forsaken, Half-way House, and Lower Henriette, where are at present the principal ore developments, a body of Gray porphyry has cut up across the Blue limestone into the overlying White porphyry, and on either side of this body the dolomite has been replaced by vein material rich in iron, and often carrying pay ore. The edges of the strata, which rise from the bottom of the synclinal toward the fault line, have been planed off by erosion, the overlying White porphyry being left only in the trough of the synclinal. The Lower Henriette and Half-way House shafts, then, have been sunk through a portion of this remaining White porphyry to contact, and their workings have followed an ore body on an eastern dip, over which lies, not the White porphyry, but the cross-cutting Gray porphyry. The new shafts sunk to the eastward, to meet these workings in depth, have passed first through an iron body, the replacement of the dolomite adjoining the Gray porphyry on the east, and through this Gray porphyry to the productive contact, now below, formerly on the west side of this sheet. This explanation is founded mainly on analogy drawn from observations in other parts of the district, since, at the time of visit, no body of unreplaced dolomite had yet been penetrated, from which the dip of the bedding planes could be actually determined. The Jolly shaft, below the Half-way House, finds ore at a lower horizon, and passes through a much greater depth of Wash. This greater depth of Wash denotes the edge of a former shore-line, which may be traced southward along the western flank of the hill, through the Forsaken, Niles & Augusta, Lower Crescent, Pendery, and Glass shafts. Above this line there is no accumulation of Wash, the rock surface being only covered by angular débris resulting from the disintegration of the rocks forming the actual surface above, and locally known as "slide." Wash, on the other hand, as already stated, consists of rounded fragments of rocks, a large proportion of which must have come from considerably greater elevations on the range, and have been brought down by glaciers.

CHAPTER IX.

FRYER HILL MINES.

General structure.—The geological structure of Fryer Hill has always seemed a puzzle to Leadville miners, and with good reason, since the Blue limestone has here been almost entirely replaced by vein material, the only relics remaining, besides two considerable masses of unreplaced dolomite, being occasional blocks or boulders, and small irregular bodies of dolomitic sand scattered through the ore bodies. Moreover, the White porphyry, instead of confining itself to the horizon above the Blue limestone, as on Iron and Carbonate hills, has formed a second distinct body between this and the underlying White limestone, and forced itself into the mass of the Blue limestone, splitting it into two and sometimes three sheets, which, being replaced, form as many different bodies of iron or vein material. In addition to these are irregular bodies of Gray porphyry, evidently of later eruption, which have been intruded in different places, and an interrupted dike which traverses the whole hill in a direction East 18° South.

Nevertheless, the structure and manner of ore deposition are here strictly analogous to those already described for Iron and Carbonate Hills, with the difference that the folding of the beds has been more complicated, the intrusion of porphyry bodies more extensive, and the replacement of limestone by vein material and ore more complete.

It would be impracticable to explain this structure in detail or give minutely the numerous and decisive facts which prove it, without the detailed map, which will be published with the final memoir. On the reduced scale which it was necessary to use for the map of this abstract, Fryer Hill is so small that it is indistinguishable to the eye not already familiar with its topography. Its extreme height is only two hundred feet, and were it not that the richest and hitherto most productive ore deposits of Leadville had been developed here, it would probably not have received any distinctive name.

The simplest expression of the structure is that of two parallel folds, the one a synclinal, the other an anticlinal, whose axes have a northeast and southwest direction. All the beds which are included in this folding partake also of the prevailing northeast dip of the region. When, therefore, the upper portion of the beds thus folded was planed off, as it was in Glacial times by the great glacier which flowed down Big Evans Gulch, the resulting outcrops, as shown on the map, have an S-curve, if one looks in a southeast direction, or at right angles to the direction of the axes of the folds. The apex of the upper re-entering curve of the S indicates the axis of the anticlinal fold, which, as has been already stated, is a continuation of the line of the main Carbonate fault, now become a fold, while the convex lower curve is the outcrop of the flat synclinal. In actual fact this simple structure is complicated by minor irregularities within the folds, so that the dip at any particular point may not always be found to have its normal direction.

Mine workings.—The general disposition of the principal mines, or rectangular blocks of ground which represent their claims, which is familiar to many from maps already published, is, proceeding eastward or up the ridge from its western edge, first, the various claims of the Chrysolite Company, and the New Discovery, then the Little Chief, Little Pittsburg, Amie, Climax, Dunkin, Matchless, Big Pittsburg, Hibernia, and R. E. Lee. The claims of the four first mentioned cover the outcrops of the lower portion of the S or synclinal fold, their side lines running nearly North and South, or North 10° West, while the triangular wedge of the Dives claim, belonging to the Little Pittsburg, gives to the eastern side line of the latter a northeast direction parallel to the anticlinal axis. The Amie claim covers the intermediate arm of the S, the Dunkin and Climax the re-entering curve or apex of the anticlinal, and the Matchless, Lee, and Hibernia its rather irregular top.

White porphyry bodies.—Throughout all this area the existence of an overlying and underlying body of White porphyry, enclosing the main ore horizon, is well proved, the former having been, however, in great measure removed by erosion, and, when found above the ore bodies, being very much decomposed. Intermediate bodies of White porphyry, splitting up the ore-bearing bed into several sheets, are also found. The most important of these are: 1st. In the western Chrysolite workings; here a second ore horizon has been proved in the west drift from Roberts shaft second level, immediately under the Wash at Vulture No. 2 shaft, and in a winze sunk a short distance south of Vulture No. 1 shaft. In the two latter points it was further separated from the main ore body by a sheet of Gray porphyry within the White porphyry. The value and extent of this-lower ore-body still remain to be proved; it may cover a considerable area, but it probably does not extend as far east as the Roberts shaft. 2nd. In the Amie, and extending somewhat irregularly into the Climax and Dunkin ground, are found two lower sheets of vein material in the Lower porphyry. The dividing porphyry in all these cases belongs probably to the Lower porphyry body rather than the Upper.

White limestone.—The outcrops of the underlying White limestone have been proved on the west by Chrysolite No. 6 shaft, and various outlying shafts of the Fairview, Kit Carson, and All Right claims; in Little Stray Horse Gulch on the south, by New Discovery No. 5 shaft, and those of the Gambetta, Big Pittsburg, Eudora, Little Daisy, and others; while the shafts Amie No. 2, Climax No. 5, and Dunkin No. 1, have sunk down to it through the overlying beds; likewise New Discovery No. 6, on Stray Horse ridge, which has passed through Gray porphyry, Lower Blue limestone, and Parting quartzite into the White limestone. The coming to the surface of these lower beds proves that the overlying ore-horizon has been eroded off, and cannot be looked for to the west and south, unless a distinct southwest dip is developed, which would bring down the Blue limestone on the other side of a fold under the Wash and Lake beds which form the present site of Leadville. The probabilities in favor of this supposition will be discussed elsewhere.

Ore in lower horizons.—The question, whether the White limestone and Lower quartzite contain ore deposits of commercial value, is one of especial moment to owners of claims in this region, since its affirmative answer would greatly enlarge the horizontal as well as vertical extent of possibly productive ground. While *a priori* there seems to be at present no valid reason why ore should not have been secreted in the White limestone, especially when, as here, it is directly overlain by a body of porphyry, the fact that the many points where it has been explored, have, with few unimportant exceptions, disclosed no ore deposits of value, renders it safer policy to assume a negative answer and confine explorations to the horizon of the Blue limestone, which is proved to have been more or less replaced by ore over its entire extent, until the labors of those who are leading the forlorn hope of exploring for unknown ore bodies in a vertical direction shall have met with some practical return.

Blue limestone horizon.—The valuable ore deposits of Fryer Hill, thus far developed, have been found either at the outcrops or comparatively near the surface; that is, with but little or no covering of rock-in-place, the maximum thickness of overlying White porphyry remaining being but 80 feet. The existing surface is formed of Wash which has an average depth of 75 to 100 feet, and at no point on the hill is there an actual outcrop of rock-in-place. It is a rather singular fact that the first discovery of ore by A. Rische and his partner was made, by pure chance, at the point where the rock-surface and the surface of the Wash most nearly approach each other. This was at the No. 1 shaft of the Little Pittsburg claim, where a boss of iron, a portion of an immense iron body very rich in silver, projected to within 30 feet of the actual surface of the ground.

The outcrop of the ore-bearing stratum has an average width on the surface (meaning always the rock-surface under the Wash, not that of the hill) of from 100 to 150 feet. From the point of discovery in the Little Pittsburg it extends nearly due west through the Little Chief and New Discovery claims, bending to the northward in the latter; through the Vulture claim at Sliver No. 2 and Vulture No. 1, and then again to the northeast through Carboniferous No. 5, the cropping of the lower iron sheet, which is here split off from the main ore body, being found still further west in Vulture No. 2.

Eastward from the same point it extends through the Amie ground a little south of Amie No. 4, where it has not been much explored, to Climax No. 4, and then bends to the northeast through the Climax claim into the Dunkin. The outcrops thus outlined form a semi-circle, convex to the southwest, and a chord drawn through Carboniferous No. 5 and Amie No. 3 shafts in a southeast direction, would practically define the northern limit of present exploration.

Within this area the ore-bearing material has a maximum thickness of about 90 feet, becoming in places extremely thin. Its definite limits, however, cannot always be determined; these are defined above by a thin bed of quartzite, the base of the Weber shales, and below by the Parting quartzite, which is here generally about 10 feet thick. These siliceous beds, which would be less changed by the action of mineralizing solutions than the included limestone, afford when found a definite horizon, but are often not seen, being separated from the ore body by intervening masses of porphyry through which developments are not pushed; frequently they are merely loose quartz sand, only distinguishable from decomposed porphyry by a more gritty feel.

Vein material.—The vein material of this ore body consists mainly of a hydrated oxide of iron, in which the iron is frequently replaced by its interchangeable base, manganese; with silica, either combined with the iron, or as chert; small irregular masses of sulphate of baryta, or heavy spar; and a mechanical admixture of clay, resulting from the infiltration of decomposed porphyry; with this are unreplaced dolomite masses, either in the form of fine blue sand, or as solid blocks of varying dimensions. The extreme form of the iron is a hard, compact, though generally somewhat cavernous hematite, or, when manganese prevails, a soft, black, clayey material, known as "black iron," often forming large masses, and generally barren of pay ore.

Ore.—Within this mass, which may be considered as a gangue, the pay ore occurs in its original state as argentiferous galena, the secondary products of which are carbonate of lead and chloride of silver, with a varying amount of bromide and iodide; as accessory minerals are anglesite, pyromorphite, and wulfenite. "Hard carbonates" are masses of more or less siliceous iron oxide, in which crystals of carbonate of lead fill cavities in the mass, and the chloride of silver occurs generally in leaflets of such minute size as not to be visible to the naked eye; under this head are also included the masses of unaltered galena, which are more likely to have escaped oxidation in a hard, comparatively impermeable mass. "Sand carbonates" are portions of the ore mass in which silica and iron are not present under conditions favorable to consolidating it into a compact form, and which consequently crumble into sand on removal. As exceptional occurrences are masses of pure, transparent horn silver, one of which in the Vulture claim weighed several hundred pounds.

Distribution of bonanzas.—The distribution of the bodies of pay ore, or bonanzas, is extremely irregular, as is their shape and size. Their vertical dimensions are often 30 or 40 feet, and have in one instance reached 80 feet, but this great thickness seldom extends over any large horizontal area, the lower limits of the pay ore streak generally rising and falling with great rapidity. In general the form of individual bodies is not unlike that of those found within the mass of the limestone in other parts of the region. The rich ore masses are more common in the upper portion of the ore-bearing stratum. In horizontal distribution the larger bonanzas form two longitudinal bodies, rudely parallel with a dike-like mass of Gray porphyry, which has evidently influenced their deposition. The northern of these is practically continuous from the Climax south-workings to the Chrysolite west-workings; the southern extends from Little Pittsburg through New Discovery and Vulture, being connected with the former in the Little Chief ground, and again around the west end of the dike, near the outcrop in Vulture and Chrysolite.

Gray porphyry dike.—The Gray porphyry dike is a somewhat irregular body about 30 feet in thickness, standing at an average inclination of 50° to the north. Its mass is so thoroughly decomposed that it is with difficulty distinguished from the White porphyry except where the large feldspar crystals still remain. Nevertheless, it has been traced continuously through the Chrysolite, Little Chief, Little Pittsburg, and Amie workings, and found again on the same line in the Big Pittsburg, Hibernia, and Lee mines. As shown by the outcrops on the map, it is what we call an interrupted dike. It is supposed to have acted as a dam, causing an interruption of the ore-currents; these currents having flowed from the northeast toward the southwest, the stagnation thus produced has influenced a first deposition on its northeast flank, leaving a barren portion immediately under its southwest side; but through the gaps above mentioned the currents passed slowly depositing as they went, and in the eddy beyond was formed a second accumulation of ore.

Dunkin mine.—In the Dunkin mine, and the adjoining workings of the Climax and Matchless, the richest ore masses have been found near the outcrops, and in these are the principal developments. In the north end of the lower level of the Dunkin, a considerable body of unreplaced Blue limestone has been cut, showing the characteristic markings of this formation. The southern lower workings in both Climax and Dunkin are below the ore-horizon. A slight fold at the south end of the Dunkin claim brings the iron body down again for a short distance in the Little Diamond.

Matchless mine.—The rich ore body developed in this ground adjoining the Dunkin has not yet been thoroughly explored, but probably connects with the upper part of the Lee body. In the southeast corner of the claim, as in the northern edge of the Big Pittsburg and Hibernia claims, work is being done upon a western continuation of the remarkable ore body of the Lee mine. This is the very lowest portion of the ore horizon, the Parting quartzite being found in considerable thickness immediately under the ore. As the formation dips a little north of east the full thickness of the body is found in the Lee ground; whereas on the bounding line of the Matchless and Big Pittsburg claims, there remains only a wedge-shaped remnant of the ore body, included between the actual rock surface and the lower bounding plane of the ore horizon, which is cut off on the south by the dike.

R. E. Lee mine.—The Lee ore body is on a direct line with the northern body in the mines first described, and like that bounded on the south by the Gray porphyry dike; it may therefore be considered an eastern continuation of that body, the intermediate portion on the crest of the fold having been planed off by erosion. The eastern and western limits of the dike, as shown on the map, are provisory, indicating merely the extent to which present drifts have opened it. It still remains to be proved by future exploration whether or not the ore sweeps around the eastern end of the dike, and another large body exists to the south, as in the western group. The existence of such body is rendered probable by the discovery in the Surprise and other claims on the south side of Little Stray Horse Gulch, of pay ore near the outcrop, which is, like that in the Big Pittsburg, near the base of the ore-bearing stratum. Mineralogically, the Lee body differs very essentially from those thus far described; its gangue is principally silica and clay, containing only sufficient iron to color the mass in places a bright red, and little or no manganese. The ore is in the form of chloride of silver and contains practically no lead, either in the form of galena or carbonate; it is also exceptionally rich. It is, therefore, a secondary product, being the redeposition and probable concentration of material resulting from the decomposition of another ore body, now removed by erosion. As it is followed in depth to the east and north, it will probably contain more lead and proportionately less silver.

Denver City body.—South of the above claims, the continuation of the ore stratum is next proved in Denver City, under a great depth of Wash and porphyry, and about 600 feet east of its probable outcrop. In this region the lower body of White porphyry is cutting diagonally across the ore-bearing stratum, which is now largely unreplaced dolomite, and splits it into two wedge-shaped masses, the upper one tapering off to the south, the lower one thinning to nothing on the north. The northern extremity of the latter is proved in the Stonewall Jackson, Pearson, Joe Bates, and other shafts; southward it stretches across the Stray Horse claim, on to Carbonate Hill, soon embracing the full thickness of the body.

The upper body is proved southward in the Robert Emmett, Agassiz, Gone-abroad, Cyclops, Mahala, and Greenback shafts, in the latter of which it has thinned out to seven feet of dolomite, and is separated from the rest of the Blue limestone body, which crops on the west face of Carbonate Hill, by a probable thickness of over 600 feet of White porphyry.

Future explorations and ore prospects.—Within the actually developed area yet unopened ore bodies may still be looked for. Practical experience has already taught miners that no part of the ore-bearing stratum can be considered barren until it is proved so by systematic exploration. Systematic exploration means a definite system of drifts, cross-cuts, and winzes, controlled by accurate surveys in such a manner that the mine superintendent may know that no considerable block of ground has been left untouched, either by himself or his predecessors. The system of burrowing, so much in vogue in the early days of mining in this region, is especially reprehensible in such rich ore deposits.

Future explorations in as yet untouched ground must be carried on in the direction of the dip, not of individual ore bodies, but of the ore-bearing stratum as a whole; that is to the north and east of present developments. The whole northern and eastern portions of the hill are as yet practically untouched ground, the Virginius and Little Sliver being the only important shafts which have penetrated the ore-horizon, besides the Buckeye, which is on its western outcrop. The reason for the non-exploration of this ground lies mainly in the fact that whenever the ore-bearing stratum has been reached, the volume of water pouring in was so great that it could not be controlled by the pumps used. The laws of hydrostatic pressure, and the fact that we are here on the lower rim of a synclinal basin or trough, across whose edges the drainage of both Big and Little Evans runs, amply account for the great volume of water found. It cannot be assumed that the ore bodies, as at present developed, will necessarily be found to extend continuously, or in equal richness to the north and east; indeed, the few developments as yet made have been in comparatively low-grade ore. Still the promise of ore is amply sufficient to justify the expenditure of a large amount of money in exploration. Under the present conditions of ownership of the ground, however, whoever puts in pumping machinery of power sufficient to lower the water-level in his own ground, will probably do the same thing for his neighbors. The exploration must, therefore, be accomplished by a combination of property owners, and the putting down of one or more large union shafts, provided with powerful machinery, such as are in use on the Comstock lode, from which explorations may be carried out into the grounds of all belonging to the combination. These shafts should be located so as to reach the ore-bearing stratum as nearly as possible at the lowest point at which it is expected to be worked. For definitely determining such point, it would be wise to obtain more accurate data than have been available in this work, by sinking additional exploring shafts.

Judging from what is now known, a union shaft for the claims on the western half of Fryer Hill should be sunk along Big Evans Gulch, at the southern extremity of the dividing line between the Little Pittsburg and Amie claims; say at the Little Amie shaft. For the eastern portion of Fryer Hill and the claims in Little Stray Horse Park, the union shaft should be placed near the gulch about midway between the Tip-Top shaft and Lickscumdidrix bore-hole.

There will always be the element of uncertainty in regard to the complete efficiency of this system of drainage that as yet unknown bodies of porphyry may cross the beds in such a way as to interfere with the regular circulation of water in the basin; but in spite of this uncertainty the experiment should be tried, since portions which were thus cut off from the benefits of the common pump might easily be connected with it by a drainage level.

CHAPTER X.

CONCLUSIONS.

In the final publication it is intended to present all the facts collected during this investigation in such full detail that the reader may be enabled to make his own deductions independently as well as to verify the conclusions given here. Although these conclusions cannot claim the merit of any great scientific originality, since similar opinions have already been put forth by investigators in other fields, they have been arrived at purely from an impartial study of the peculiar conditions of this region without any preconceived theory which might tend unconsciously to give a bias to one's observations.

The most important facts of general bearing are:

I. *Sedimentary formations.*—That the Paleozoic and Mesozoic beds are a littoral deposit around the Sawatch Archæan island, and were consequently formed in comparatively shallow waters.

II. *Intrusive bodies.*—The occurrence, on an enormous scale, of intrusive bodies of eruptive rock of Secondary or Mesozoic age, and of exceptionally crystalline structure, which are so regularly interstratified as to form an integral part of the sedimentary series, and yet which never reached the surface, but were spread out and consolidated before the great dynamic movement or mountain-building period at the close of the Cretaceous.

III. *Ore deposits.*—That the original ore deposition took place after the intrusion of the eruptive rocks and before the folding and faulting occasioned by the great dynamic movement.

IV. *Plication and faulting.*—That the plication and faulting which resulted from this dynamic movement were intimately connected with each other, the latter being, in most cases, a direct sequence of the former, when the limit of flexibility of the plicated masses had been reached.

V. *Duration of dynamic movement.*—That while the close of the Cretaceous is properly considered the mountain-building period of this region, being that in which the greater dynamic movements were initiated and their major effects produced, these movements have continued, though on a probably much smaller scale, to recent times, as evidenced by the movement proved to have taken place in the Lake beds since the Glacial period. Evidence, though of less definite character, has also been obtained of movement since the opening of the Leadville mines.

The facts which bear directly upon the ore deposits have a more practical application, and will therefore interest a larger class of readers. The main conclusions with regard to their origin and manner of formation have already been given in the chapter on ore deposits, page 224: they may be briefly summarized as follows:

VI. *Formation of ore deposits.*—The minerals contained in the principal ore deposits of the region were derived from circulating waters, which in their passage through the various bodies of eruptive rocks took up certain metals in solution, and, concentrating along bedding planes, by a metamorphic or pseudomorphic action of replacement, deposited these metals as sulphides along the contact or upper surface, and to greater or less depth below that surface, of beds generally of limestone or dolomite, but sometimes also of siliceous rocks.

VII. *Distribution of ore deposits.*—That in the region immediately about Leadville the principal deposition of silver-bearing minerals took place at the horizon of the lowest member of the Carboniferous group, the Blue limestone formation, commencing at its contact with the over lying White porphyry. But that, while this particular formation has been peculiarly susceptible to the action of ore currents in this region, it is not admissible to assume, as some have done, that in general the beds of any one geological epoch are more favorable than those of any other to the formation of this important type of silver-bearing deposits; since, although they are generally found in greatest abundance in calcareous beds of Paleozoic age, the horizon of such beds is by no means identical in the various mining districts in which they have been thus far developed.

VIII. *Dikes.*—That in this, as in many other mining districts, dikes of eruptive rock, cutting the ore-bearing formation transversely, seem to favor the concentration of rich ore bodies or bonanzas in their vicinity.

IX. *Faults.*—That on fault planes, on the other hand, no considerable ore bodies have been deposited, as might have been assumed *a priori* from the fact that their origin is later than that of the original ore deposits.

X. *Value of these deposits as compared with fissure veins.*—The superior estimation in which true fissure veins are held, as compared with this class of deposits, is, as far as valid scientific reasons go, largely a popular prejudice. While fissure-vein deposits may be more regular and continuous, the bonanzas in this class are generally larger and more easily worked; moreover, I consider that additional and more definite evidence is required before it can be assumed as proven that fissure veins extend indefinitely in depth and are filled directly from below, and consequently see no reason why the area of ore deposition, other things being equal, should be greater in that class than in this.

A rough comparison of the relative areas of ore deposition in the famous Comstock lode and in the Blue limestone of Leadville, which was once as continuous as the former, will illustrate my idea. The Comstock has been worked on a length of 20,000 feet and to a maximum depth of 3,000 feet, or over an area of 60,000,000 square feet. In Leadville, if we take, as the limits within which the Blue limestone has been found productive, a square of which Fryer Hill, Little Ellen Hill, and Long & Derry Hill should be three of the corners, we have an area of over 225,000,000 square feet, or about four times as great as that of the Comstock. Too small a portion of the latter area has yet been explored to attempt any comparison between the relative proportions of productive and unproductive ground in the two cases.

XI. *Legal aspect.*—From the point of view of legal ownership, however, there is an undoubted advantage in favor of the fissure vein, since the owner of a certain number of feet on the outcrop can, under the United States mining law, establish his title to that width as far as the vein extends. In the case of the Leadville deposits, on the other hand, late legal decisions made under the system of trial by jury have practically reversed the law, and given effect to the system of square locations, which, however much may be said in its favor, was certainly never intended by the legislators who made it.

XII. *Practical suggestions to prospectors.*—In general, deposits of this type are to be looked for in regions where sedimentary beds are found associated with numerous dikes and intrusive masses of Mesozoic or Secondary age. In such regions valuable deposits would be first sought in limestone beds, and in preference on their upper surface, or at the contact with overlying eruptive rocks or sedimentary beds of essentially different composition. It should also be borne in mind that limestone deposits are generally irregular in their distribution, and often found within the mass of the rock with relatively few surface indications to guide the explorer.

In the region here treated of the Blue limestone is essentially the ore-bearing bed, and while, owing to the favoring condition of the presence of large masses of intrusive rock impregnated with precious metals, ore has locally been concentrated at other horizons, this particular bed offers the best promise to the prospector. Experience has shown, moreover, that ore deposition has been most active where the Blue limestone is overlain by White porphyry. In the area covered by this intrusive mass, beyond the limits of the accompanying map, exploration has not yet thoroughly tested the horizon; but within these limits it seems to be well proved that no considerable portion of it is altogether barren of useful metals. On the other hand it must be remembered that it is only bonanzas or exceptionally large concentrations of ore which yield a great remuneration to miners, and these are, in the nature of things, limited to comparatively small areas where conditions have been favorable to their concentration. Such portions can here be readily recognized by the presence of large amounts of vein material, either ferruginous or siliceous, replacing the dolomite. By the aid of the accompanying map, and still better by the more detailed one which is to follow, the prospector can therefore determine with approximate accuracy where the Blue limestone horizon has been removed by erosion and where it still exists, and in the latter portions, by the further aid of sections and descriptions herein, where it may be looked for under the surface and at what probable depth it may be found. He should bear in mind that, while generally answering to the description given on pages 218–219, it is sometimes bleached so as even to be confounded with porphyry, from which its effervescence with acids is then the only safe distinction, and that even the porphyry is sometimes so impregnated with carbonate of lime as to effervesce slightly. Also that the Parting quartzite is the formation which marks its base, but that in the decomposed state prevalent in the mines it is often to be distinguished from porphyry only by its gritty feel; that, if for any reason the Parting quartzite is not definitely distinguishable, the finding of White limestone beneath, with its characteristic secretions of white hornstone or chert, is an unmistakable evidence that he is below the horizon of the Blue limestone.

Area under Leadville.—The determination of the existence or non-existence of the Blue limestone beneath the city of Leadville, or the area immediately west of Carbonate and Fryer Hills, is of prime importance, for the reason that so many rich bonanzas have already been developed at that horizon on its eastern borders, which it is reasonable to suppose once extended farther west, and that thus far the richness of the horizon seems to increase with its distance from the crest of the range. The evidence gathered upon this point will therefore be given in considerable detail.

It is sufficiently well proved by the general geological structure of the region that the Blue limestone originally extended to the west of Leadville, its probable limits being a line drawn from the mouth of the East Fork of the Arkansas in a southeast direction to a point just west of Weston's Pass.

If, then, it has not been removed by erosion, it should still be found there, and the question resolves itself into the determination of the amount of erosion over the triangular area included between that line and the known outcrops, and the probable elevation or depth below the present surface at which the Blue limestone was left by the folding action and faulting of the Paleozic series.

Of the amount of erosion, or its practical exponent, the depth of surface accumulations of Wash and Lake beds over the actual rock surface, no data are attainable, except along the eastern shore-line of the ancient lake, or the western edges of the present hills, where rock in place has been actually reached in a few shafts. As it may be reasonably assumed that this was a shelving shore, the only deduction to be drawn from the data thus afforded is that farther west the thickness of Wash and Lake beds is probably greater, and that given on sections D and E, viz., 400 feet, may be taken as a minimum.

With regard to the depth below the present surface at which the Blue limestone was left by folding and faulting, it may be assumed from analogy with the structure of other similar areas in the region, which the few available facts confirm, that this area is occupied by a shallow synclinal fold, cut off in part on its eastern edge by a fault.

If, then, the shore of the Glacial lake was not very much steeper than has been assumed in the sections, and there exists no anticlinal ridge within the basin, it is probable that a continuous sheet of Blue limestone still exists west of the present known outcrops, and probably at no point over a thousand feet below the present surface. The evidence obtained with regard to its form may be very briefly stated.

On the north.—The existence of the Cambrian quartzite dipping southeast at the mouth of the East Fork of the Arkansas, and of Blue limestone on the ridge north of this stream, proves a basining-up in that direction, and that the outcrop of the Blue limestone on that side of the basin runs probably nearly parallel to the river, and one to two thousand feet south of it, with a shallow dip southeast.

East side.—On the west slope of Prospect Mountain it comes to the surface, as already shown, in the Little Evans anticlinal. South of this the Oolite shaft cut the overlying Gray and White porphyries, and found Blue limestone, dipping steeply west, at a depth of about 165 feet. About 1,100 feet west of this the Sequa shaft and bore-hole was sunk 280 feet through porphyry without reaching the contact, proving the western dip to be continuous so far.

Still further south, at the foot of Fairview Hill, a number of now abandoned shafts have struck the White limestone under only 60 to 90 feet of Wash, in one of which, the American Eagle, it is said that the beds dipped both east and west. This would be the axis of the Big Evans anticlinal fold. About 600 feet west of this shaft the Bob Ingersoll drill, after passing through 360 feet of Wash and Lake beds, has been driven from 100 to 150 feet in White porphyry. This proves definitely a western dip here, since no considerable sheet of White porphyry is known to exist below the White limestone. Whether this is the one which occurs above or below the Blue limestone will be determined only when the underlying bed is reached.

On Carbonate Hill, as stated in Chapter VIII, the downward movement was distributed between two faults, the amount of that in the westernmost, the Pendery fault, not having been proved. The fact that the shafts which have been sunk through the Wash along the lower slopes of the hill have invariably struck White porphyry is tolerably satisfactory evidence that the ore horizon is still below them, since in this region the only known sheet of White porphyry is that which overlies the Blue limestone. There is some evidence of a western dip, as there shown, but whether the formation descends to the westward in a regular slope or in a series of short folds or faults is yet to be proved. The former would be more favorable to future developments. The facts that the displacement of the Carbonate fault is so small and that the Pendery fault probably passes into a fold are presumptive evidence that immediately west of the latter line the depth of the Blue limestone below the present surface is not great, and that it probably increases toward California Gulch and decreases toward Stray Horse Gulch. On the south slope of Carbonate Hill the California Tunnel passes through White porphyry west of the fault, which here had an inclination of only 30° to the west, and a shaft and bore-hole near the bed of the gulch, opposite the Harrison smelter, has been sunk 200 feet also in White porphyry.

South side.—The main fault crosses California Gulch in a southwest direction, about 500 feet above the Gillespie & Ballou sampling works, and west of it the Blue limestone may probably exist for some distance further south. Theoretically, it should extend, if not eroded, as far as the convergence of the fault line with the western rim of the basin. Practically, as the Lake beds probably deepen rapidly in this direction, its actual extent is likely to remain a matter of pure speculation for some time to come.

West side.—The western limits of the basin are equally a matter of speculation. The outcrops of the Blue limestone, as drawn on the large map of Leadville, which are assumed after careful consideration of all known facts bearing directly or indirectly upon it, run just west of the city limits.

Within the limits thus rudely outlined the probabilities of the existence of the ore horizon below the Wash and Lake beds seem sufficient to justify the expense of an experimental shaft. This expense must necessarily be great, from the thickness of loosely agglomerated material to be passed through, which will almost certainly admit an enormous amount of water, the drainage of the surrounding hill surface. It must therefore be undertaken with the intention of risking a large sum of money, and as its result, if favorable, will increase the value of property in the whole area, the risk should be shared proportionately among them, as far as possible. From a purely geological standpoint, the most conservative method of exploration would be to reach the Blue limestone horizon somewhere near the eastern rim of the basin, say on the lower slopes of Carbonate Hill, and follow it westward. Other influencing motives may probably make it advisable to sink the experimental shaft further out on the flat, and in this case some position on a north and south line through Capitol Hill, would be a safe location to choose. While there might be advantage in going still farther west, inasmuch as the nearer one approaches the actual outcrop the less will be the overlying porphyry that will have to be passed through, on the other hand, once that outcrop is passed, the shaft would reach only the comparatively barren Silurian, Cambrian, or Archæan; it is therefore advisable to keep within safe limits until more definite data as to the probable breadth of the basin can be obtained. Although the Blue limestone may extend half way to Malta, in a region so complicated by unexpected folds and faults the regular slope of the basin, which would give it that width, cannot safely be counted on.

Other unexplored areas.—Present developments show that on a line running eastward from Fryer Hill replacement action has been exceptionally active. The Blue limestone horizon along this line is therefore worthy of thorough exploration, first in the synclinal basin of Little Stray Horse Park, and again in the area between the Yankee Hill anticlinal and the Weston fault. In either portion, as it is covered by thick porphyry masses, it would be more economical to conduct the exploration from some common shaft, and only sink actual working shafts after the existence of valuable ore bodies had been definitely determined.

In either of these basins the ore horizon extends northward beyond Big Evans Gulch and under Prospect Mountain, and may prove productive there, but it is relatively more difficult of access, and the few points at which it has been reached give less promise of widespread ore deposition than in other regions.

Southeastward from the crest of Yankee Hill the Blue limestone horizon might be expected to be productive from the presence of the cross cutting body of Gray porphyry; on the other hand it may be more difficult to trace, on account of the probably complicated geological structure.

Under the Pyritiferous porphyry of Breece Hill it must exist, but at an as yet unknown depth. On the north slope of this hill the contact eastward from the Highland Chief mine has not yet been thoroughly explored, as prospectors in this region have been hopelessly confused by the complicated structure, and have sunk their shafts indiscriminately above and below it.

On Little Ellen Hill it has been found productive, as already mentioned, but not explored in the valleys to the north and south. East of the Ball Mountain fault, again, the contact crosses South Evans Gulch, but has been opened at comparatively few points.

The prospects of as yet undeveloped ore bodies under Fryer, Carbonate, and Iron Hills have already been discussed in Chapters VII, VIII, and IX. South of California Gulch the extension of the line of the Iron fault probably coincides nearly with the axis of a synclinal basin, east and west of which the formations should rise. The generally shallow depth at which the Gray porphyry sheet between the White porphyry and Blue limestone was found, just west of the Dome fault, afforded an indication that the latter would be found here comparatively near the surface, and this indication has been confirmed by explorations since the completion of field work. East of the Dome fault the outcrop of the Blue limestone is found in the Nisi Prius and adjoining shafts in Iowa Gulch, and its southern continuation has thus far only been struck by the Hoodoo and Echo shafts at the head of Thompson Gulch, leaving a considerable extent entirely unprospected.

Under Printer Boy Hill, east of the Pilot fault, the geological indications are favorable to the existence of ore bodies in the Blue limestone. Its outcrop on the Iowa Gulch side is clearly marked, but on the northern slope toward California Gulch it is obscured by surface débris, or slide, and when last visited was unprospected between the Lovejoy shaft and the Eclipse tunnel. East of this it extends at a depth as yet unprofitable for exploration, until cut off by the Ball Mountain fault; while on Long & Derry Hill it is cut off earlier by the Weston fault, and, as shown on the map, is wanting in the areas further east.

Beyond the limits of the present map the outcrop of Blue limestone can be traced from the western shoulder of Mount Zion northward, gradually descending the hill slope, crossing the mouth of No Name Gulch and Piney Creek to Taylor Hill, at which point the El Capitan mine has developed a valuable body of gold ore. Throughout this extent it is as yet but little prospected. The indications given above, at best but imperfect, are such as seemed most easily explained without the aid of maps; when these are finished they will show the facts we have been able to gather far more clearly than could volumes of written description.

CHAPTER XI.

METALLURGICAL REPORT.

A comparatively brief investigation into the geology of the Leadville district was sufficient to convince me that the magnitude of the work was such as to preclude the idea of my giving any personal attention, within the time allotted, to the extremely important industry of lead-smelting as conducted there. I was fortunate enough, however, to secure for this work the services of Mr. A. Guyard, whose profound knowledge of the chemistry of metals, and practical as well as theoretical acquaintance with metallurgical processes, acquired during a long experience in Europe, rendered him eminently fitted to undertake it. The preparation of this report was therefore entrusted to him, and, while I have been able from time to time to offer some suggestions as to particular points requiring special study, to him alone belongs the credit to be derived from the investigation, as well as the responsibility for the conclusions which have been drawn therefrom.

It is well known that processes which work well in the laboratory do not always succeed on a large scale in smelting operations. It is equally well recognized that the reactions which take place in the furnace are founded on definite chemical laws, whose thorough study necessarily involves careful and accurate examination of all the furnace products in the laboratory. The most successful smelter in the long run is consequently he, who, combining theory with practice, watches most carefully, by means of chemical analysis, the processes going on in his furnace, and thereby renders to himself a systematic account of the reactions which take place there. But, in the press of daily business, most smelters find it impracticable to conduct the minute and tediously accurate chemical investigations, which furnish material for generalizations upon the broader questions that affect the industry as a whole.

It has been the aim of this report, therefore, to gather together, from all available sources, the facts already obtained, and to supplement them by further and more accurate chemical study, which the smelters themselves, either from want of time or of adequate scientific resources, could not pursue; to put together the material thus accumulated in a compact and available form, and deduce from it illustrations and criticisms of the various smelting operations carried on in the district, and offer suggestions for improvements therein if such be possible. If, then, as may readily be the case, any one disagrees with the conclusions thus drawn, the facts from which they were obtained are at his command, and he is enabled to use them as he sees fit for his own deductions.

Too much credit cannot be accorded to Mr. Guyard for the patient and laborious thoroughness with which he has conducted his investigations, of which the report itself will afford the most convincing testimony. The following is a brief abstract of the main features of his report, and of the conclusions which he has drawn from his investigations.

Attention is first given to the external conditions of smelting, commencing with a short discussion of the topographical relations of smelters and mines; next follows an examination of the character of the ores, both mineralogical and chemical; then their distribution and consumption at the various smelters, the resulting production in bullion, slags, etc., and the disposition of the former. In order to present it in as concise a form as possible, this valuable information has been condensed in the shape of nine large tables. Nor have economical considerations been neglected, and full particulars are given of the cost of plant, the number of men employed, their salaries and wages, the price of ores, metals, fluxes, fuel, cost of treatment of ores, and cost of transportation of bullion, with full discussion of cost of smelting and profits derived from it.

Although working with the same materials, and with plant constructed on the same principles, the smelters of Leadville display a great deal of originality in the arrangement of details, some of which constitute real improvements; moreover, American machinery of great perfection is used, which, the reporter thought, might be adopted with advantage in other countries, after being seen successfully at work in so important a smelting region as Leadville. All this necessitated illustrations. In consequence, twenty-three plates of engravings, containing ninety-five figures, drawn to scale, and representing horizontal and vertical sections, as well as elevations and perspective views of plant, furnaces, lead-dust condensing chambers, crushers, blowers, and other implements used in both smelting and assaying, accompany this report, and make the detailed descriptions which it contains clearer and more intelligible.

A complete collection, formed of numerous and varied specimens of furnace products, bullion, slags, speises, mattes, sows, flue and chamber dust, accretions; and of the materials used in smelting, coke, charcoal, hematite, dolomite, made with discrimination at all the smelting works, enabled him to make a thorough investigation of their nature and composition, as well as of their contents in precious metals, and to examine critically the chemical phenomena of lead smelting in blast furnaces.

These researches, which were considered as absolutely necessary, were made in the laboratory of this Division of the Survey, which had been erected in Denver; and resulted in the pointing out, in the furnace products, of most substances existing in the camp, even those that occur only in minute quantities, and which it would have been most difficult to trace or to detect with certainty in the ores.

No less than fifty-six complete analyses, some of which are the most exhaustive that have been made of ores and metallurgical products, give accurate notions as to their nature and composition, and illustrate all the fundamental and most of the accessory reactions of lead smelting in Leadville, which, according to these researches, are very numerous. Each important analysis, or group of analyses, and each group of assays, which are also very numerous, is preceded or followed by discussions of the most interesting analytical results or of the extraordinary or doubtful ones, much, however, having been left to the reader to study and criticise.

An interesting chapter of this report contains a very complete enumeration of the reactions of lead smelting, according to various authors, and points out each of these reactions as shown in normal or accidental products of the blast furnaces of Leadville, in which they were revealed by chemical investigation. This important chapter shows that many reactions which were found in laboratories, and which were considered by their authors as purely theoretical, are in reality normal reactions of the blast furnaces, which have, so to speak, "taken a body" in products which flow normally from the furnaces or are found in them.

Lastly, a most complete and exhaustive discussion of the blast furnaces is made, in which the weights of all the elements introduced in them, while in full blast, is given, as well as the reactions which take place in the various zones, and the losses of weight of charges resulting from these reactions. These calculations, based entirely on data obtained in Leadville, are both interesting and useful, and the chief conclusion resulting from them is that the weight of blast used in smelting is about equal to the weight of solid charges which enter the furnaces. The volume of this weight of blast is also given, which is much greater in Leadville than it would be at lower altitudes, showing that lead smelting in the "City of the Clouds" offers some interesting peculiarities.

CONCLUSIONS.

The chief conclusions arrived at by Mr. Guyard are:

1. That smelting in Leadville is a profitable operation, but that the aggregate smelting capacity of the working smelters is about equal to the present mining product of the camp.

2. That lead smelting, in Leadville, has, on the whole, been brought to a state of great perfection, with regard both to the plant adopted, which is constructed on the most approved principles, and to the manner in which fuel, fluxes, and ores are mixed for smelting, giving slags which are remarkable for their fluidity, and not too highly charged with

either silver or lead (especially when it is remarked that the bullion produced is very rich); and from which bye-products, such as speises and mattes, are easily detached.

3. That the quantity of bye-products, other than lead fumes, resulting from smelting in Leadville, amounts to but little.

4. That the camp is provided with the necessary plant to work profitably such bye-products, which are generally rich in silver, and either completely neglected, or treated imperfectly and with a considerable loss of silver.

5. That the mode adopted at a great many smelters, of mixing and re-smelting with caustic lime the flue dust formed in considerable quantity, is the best that could have been devised, and that it would be advisable to substitute pure lime for the dolomitic lime used in Leadville for this operation.

6. That the numerous imperfections noticeable at various smelters are mostly intentional and based on economical grounds, and not on ignorance, for smelting is conducted in Leadville by very clever superintendents and smelters.

7. That the smelting of lead ores, in presence of ironstone, has here been brought to a state of great practical perfection, and is carried on most successfully, from one year's end to the other, with the greatest regularity at a dozen smelters, and that superintendents of smelters do not hesitate to introduce in the charges sometimes very large quantities of galena, which are reduced with the greatest facility.

8. That owing to the peculiar nature of the Leadville ores, and to the great altitude at which smelting is performed, which increases the volatility of lead compounds, attempts ought to be made to substitute caustic lime, free from magnesia, for the raw dolomite universally used in Leadville, in order to avoid as much as possible the formation of volatile lead compounds.

9. That, *cæteris paribus*, dolomite forms as good a flux as calcitic limestone, so far as the actual working of the blast furnaces is concerned, and that the fluidity of the slags thus formed is not only irreproachable but quite remarkable.

10. That besides the substances existing in large quantities in the camp, such as silica, sulphur, carbonic acid, lime, magnesia, alumina, oxides of iron and manganese, lead, silver, chlorine, and phosphoric acid, the following substances exist in small quantities: sulphuric acid, titanic acid, bromine, iodine, zinc, baryta, gold, nickel, molybdenum, arsenic, antimony, and copper; and that traces of the following substances may be detected: tin, bismuth, cobalt, iridium, selenium, tellurium, cadmium, and a new metal which has been imperfectly studied as yet, and which appears to be intermediate between the metals of the iron group and those of the lead group.

11. That the ores of Leadville are either rich in lead and poor in silver, rich in silver and poor in lead, or equally rich in both silver and

lead, and very variable in composition; but that by judicious admixtures of various ores, ore beds of sensibly the same composition are made at the smelters, which are needed to insure regularity in the smelting operations.

12. That the quantity of lead completely lost in the atmosphere is sensibly twice as large as the quantity of lead caught in the dust chambers generally used.

13. That the crude bullion extracted in the blast furnaces of Leadville by the process referred to in § 7, is of very fair quality, and that a little of its silver and some of its lead exist there in the state of sulphurets.

14. That mattes (both iron and lead mattes) which had hitherto been considered as entirely formed of sulphurets are crystallographic compounds of sulphurets of iron and lead, and crystallized magnetic oxide of iron. (This last observation, however, interferes in no way with the fact that in various smelting operations mattes entirely formed of sulphurets are produced.)

15. That slags cannot very well be compared with minerals, from which they differ essentially; that they contain minute quantities of carbonates which have escaped destruction, and small quantities of carbon or carburets, two products which hitherto had not been generally known to exist. That slags are formed of crystallographic compounds of silicates of iron, manganese, zinc, lead, lime, and magnesia, on the one hand, and on the other of a peculiar matte which is designated by the name of *calcium matte*, and which like its congeners is formed of a sulphuret (sulphuret of calcium) and magnetic oxide of iron, which can be isolated in the pure crystalline state.

16. That at least three distinct metallurgical kinds of speises, containing two distinct chemical arsenio-sulphurets of iron, are formed in lead smelting, and that they always contain small quantities of nickel and molybdenum entirely concentrated in them, showing that the metallurgy of molybdenum could be conducted jointly with that of lead, with ores containing only traces of molybdenum.

17. That a very curious and a hitherto unsuspected reaction takes place in the blast furnaces of Leadville, by means of which cobalt is completely separated from nickel (nickel being concentrated in speises and cobalt in the skimmings of the lead pots of blast furnaces), and showing that the metallurgy of both metals and their separation could be effected in lead furnaces by operating under conditions similar to those observed in Leadville.

18. That iron sows are a variety of speise and present a great analogy with the latter products.

19. That lead fumes are very complicated products, characterized in Leadville by the presence of no inconsiderable amount of chloro-bromo-iodide of lead and phosphate of lead, and that they contain, contrary

to the opinion formed in Leadville, but small quantities of arsenic and antimony.

20. That owing to that erroneous notion, the practice of roasting the dust in order to free it from arsenic and antimony, as adopted at one smelter, is a useless and costly one, which is unnecessary and ought not to be generalized in Leadville.

21. That accretions are products of sublimation, and that these products, which line the shaft of the furnaces and interfere seriously with a regular run, might be, to some extent, avoided, or made less troublesome, by a slight modification of the manner of charging the furnaces, and by the adoption of caustic lime, instead of raw limestone, in smelting.

22. That some accretions are characterized by the concentration, in sometimes large quantities, of metals such as tin, arsenic, antimony, and zinc, which exist but in small quantities in the ores.

23. That the charcoal used in smelting is of very good, and the coke of bad quality; but that the fuel obtained by mixing them contains 10 per cent. of ash, and that it requires a maximum amount of 32 to 33 parts of this fuel for 100 parts of ore, and 24 parts for 100 parts of charges to effect smelting; but that at several smelters these percentages are considerably lowered.

24. That for every 100 parts of carbon thrown in the furnaces with the smelting charges, only 52.25 parts reach the zone of combustion at the tuyeres, the balance being consumed chiefly by carbonic acid formed in the zone of combustion, involving, as is well known, an absorption of heat.

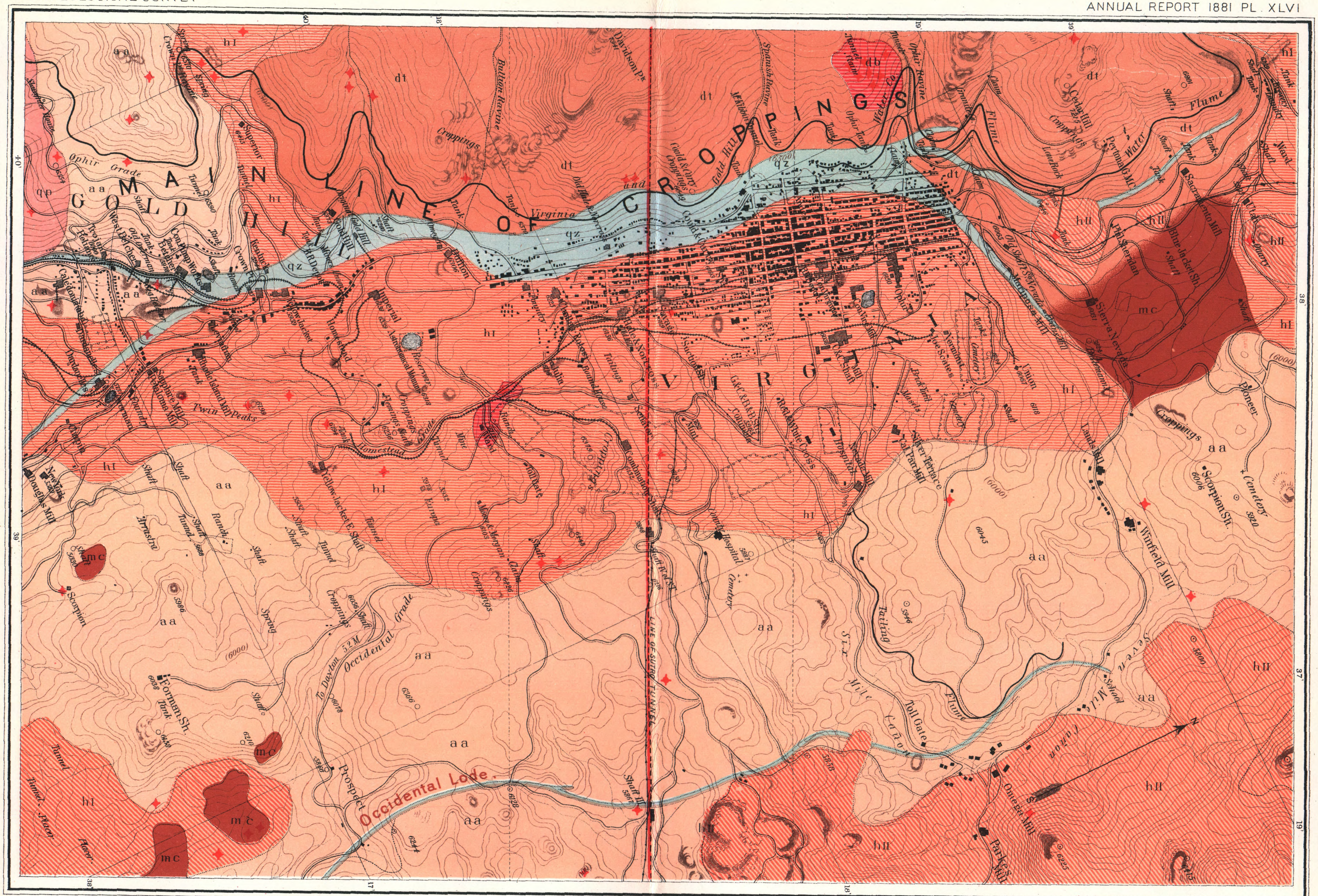
A SUMMARY

OF THE

GEOLOGY OF THE COMSTOCK LODE AND THE WASHOE DISTRICT.

BY

GEORGE F. BECKER.



Topography by U.S. Geo. Surveys West of 100th Mer.

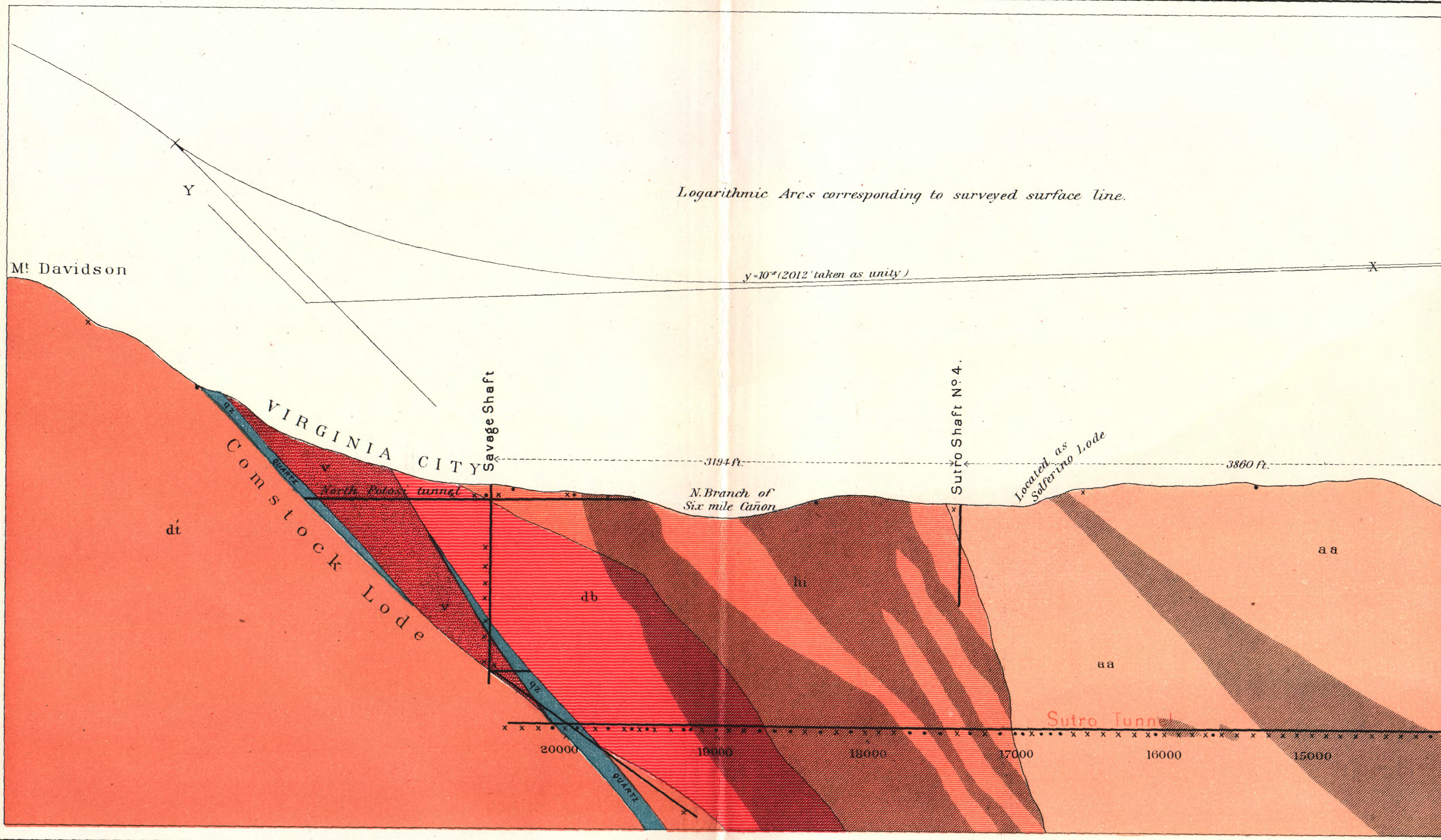
T. Sinclair & Son, lith. Phila.

Geology by G. F. Becker, Geologist in Charge.

Quartz Vein	Later Hornblende And.	Augite Andesite	Earlier Hornb. And.	Diabase	Quartz Porphyry	Mica Diorite	Diorite	Localities Determined Microscopically.
qz	hII	aa	hI	db	qp	mc	dt	✦

Scale 1 Inch = 1500 Feet – Contours Fifty Feet Vertical Interval.

GEOLOGICAL MAP OF VIRGINIA, NEV. AND IMMEDIATE VICINITY



Mapping by R. H. Stretch.
T. Sinclair & Son, Lith. Phila.
Geology by G. F. Becker, Geologist in Charge.

Quartz	Angite Andesite	Earlier Hornb. And.	Diabase	Diorite	Solfataric Decomposition	Vein Matter	Specimens	Microscopic Determinations
qz	aa	hi	db	dt		v	×	•

Scale 1 Inch = 800 Feet or $\frac{1}{9600}$.

PARTIAL SECTION OF THE WASHOE DISTRICT ON THE SUTRO TUNNEL LINE.

A SUMMARY OF THE GEOLOGY OF THE COMSTOCK LODE AND THE WASHOE DISTRICT.*

By George F. Becker.

The Comstock lode lies on the east slope of the Virginia Range, a northeasterly offshoot from the range of the Sierra Nevada. The region is a desert, supporting scarcely any vegetation besides the sage-brush. Potable water is found only in quantities too small to supply a settlement, and the town now depends for its supply on a point in the Sierra Nevada, thirty miles away. The mines were first opened in this inhospitable region in 1859, but have since been pushed with such vigor that their product is supposed seriously to have affected the silver market of the world. They have produced about $315,000,000 worth of bullion, of which $175,000,000 was silver (at the rate of one ounce equals $1.2929). Of the total yield, $115,871,000 has been disbursed in dividends.

The last great ore body discovered yielded $111,707,609.39, of which $74,250,000 was paid in dividends. The number of men employed in the mines on June 1, 1880, was 2,770, and the sum annually disbursed in wages is now $4,550,000. The aggregate horse power of the machinery of the mines is 24,130. The total length of shafts and galleries exceeds 150 miles, and the greatest depth reached is above 3,000 feet.

As has long been known, the Comstock lode presents scientific questions of an interest commensurate with its economical importance, and a number of famous geologists have written more or less fully on the subject. Besides numerous scattered papers, several important memoirs have been printed. Baron von Richthofen made an examination in 1865, the results of which were printed by the *Sutro Tunnel* Company, but were not published in the proper sense of the word. It is a very remarkable paper, and the portions relating to the geology are reproduced in this report almost in full. In 1867 Baron von Richthofen also published a paper entitled "A Natural System of Volcanic Rocks,"

* The report on the Comstock lode and the Washoe district is nearly completed, and the views expressed in this summary are not likely to undergo any considerable alteration; but, should occasion arise, of course changes will be made up to the last moment. It will be understood that this is a *résumé* of results, and that the nature only, and not the details, of the evidence of the positions taken can be indicated.

as a memoir of the California Academy, in which the system proposed is avowedly based to a great extent on the geology of Washoe. At the date of these papers microscopical lithology was still in embryo, and Mr. Sorby's experiments were attracting attention as possibly promising important results. It is not wonderful, therefore, if the present inquiry, in which the microscope has been used as a field instrument, has led to different lithological results; while, so far as the structure and vein formation are concerned, the greater part of this geologist's views are confirmed in a remarkable manner. In 1867–'68, Mr. Clarence King, who was in charge of the exploration of the 40th parallel, made an examination of the lode, down to the 800-foot level.* He accepted von Richthofen's propylite, though stating a doubt whether it might not eventually prove identical with andesite. The quartzose rock of the district, which von Richthofen had determined as a pre-Tertiary quartz-porphyry, King regarded as quartz-propylite. The most prominent feature of this memoir is the graphic description of the vein phenomena from the surface down. In 1875, Prof. F. Zirkel examined the lithological collections of the 40th parallel.† Among the slides which he describes are thirty-three from the Washoe district. He confirmed the independence of propylite and quartz-propylite as lithological species, regarded the quartzose rock as dacite, corrected the determination of the granular diorite (it had been considered syenite), and added augite-andesite, rhyolite, and a strange variety of basalt to the list of rocks previously recognized.

In 1877, Mr. J. A. Church, in connection with the United States Surveys West of the 100th Meridian, under Captain Wheeler, examined the workings down to the 2,000-foot level. Mr. Church accepted the lithology of his predecessors, with some exceptions a little difficult to follow, but though he mentions slides of the rocks, describes none. His memoir contains a number of ingenious hypotheses, prominent among which are the following:

That diorite was a thin flowing lava, and spread over the country in successive thin horizontal beds;

That propylite and andesite were laid down in the same manner on the diorite, and the whole bedded mass was tilted or folded in such a way that the eruptive strata assumed their present position with an inclination of about 45°;

That the ore was deposited by substitution for propylite, relegating the COMSTOCK to the class of Fahlbands;

That the heat of the COMSTOCK is due to the kaolinizing action of surface waters on the feldspar of the country rock.

A topographical map of the district was published by the Expedition of the 40th Parallel, but a more detailed contour map, on a larger scale,

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* Exploration of the 40th Parallel, Vol III

† Exploration of the 40th Parallel, Vol. VI.

was made in 1879, under orders of Captain Wheeler, by Mr. A. Karl. This map forms the topographical basis of the present examination.

DECOMPOSITION OF ROCKS.

The economical importance of the district, the obscure character of some points in its geology, and the great weight of the authorities whose investigations had already been published, made it essential that the work done under the new United States Geological Survey should be supported by the strongest and most detailed evidence. The collections embrace nearly 2,500 specimens and 500 microscope slides. The locality of each specimen was fixed with great care on the maps at the time of collection, and no time or pains was spared in preparing the geological maps and sections. In laying down the various formations the microscope was in constant use, slides being ground as the occasion arose, and the results obtained from them finding immediate application in the extension of the work.*

The area in which the COMSTOCK lies is characterized by a widespread and profound decomposition of the rock masses, and a study of the lithology of the district resolves itself primarily into an investigation into decomposition. In spite of the most painstaking choice of specimens, there is not one in fifty of those collected underground which contains a particle of any of the characteristic bisilicates, secondary minerals replacing them throughout. Even the feldspars are rarely intact, and are sometimes wholly decomposed. When the steps of these processes of degeneration are once understood, it is comparatively easy to infer the original composition and structure of the rock. Some of the results obtained concerning the decomposition of the Washoe rocks are the following:

Hornblende, augite, and mica generally pass into a chloritic mineral, which, so far as can be judged by any optical tests now known, is almost without exception the same, from whichever of the primary bisilicates it may have originated. This chlorite is generally green, but in especially compact masses appears greenish-brown under the microscope. It is strongly dichroitic, but, except in dense masses, appears nearly black between crossed Nicols. It is fibrous, often spherolitic, and invariably extinguishes light parallel to the direction of the fibres. It thus bears a considerable resemblance to fibrous green hornblende, but the cases are very rare, if they actually occur, in which a careful examination will not serve to discriminate between the minerals. This chlorite is decidedly soluble. It occurs in veinlets and diffused through the ground mass and through other minerals when these have become

* My assistants were Dr. Carl Barus, physicist, and Mr. F. R. Reade, assistant geologist. I also engaged with Mr. R. H. Stretch to assist me in mapping the underground geology.

pervious through decomposition. It is especially striking as an infiltration in the feldspars, where, of course, it is readily visible. All the stages can be traced, from the first inconsiderable attack of the bisilicates, through rocks in which chlorite occurs wholly or almost wholly as admirable pseudomorphs after the bisilicates, and up to cases in which the secondary mineral is wholly diffused through the mass of other products of decomposition.

Epidote is usually in Washoe a product of the decomposition of chlorite. Comparatively very few occurrences of epidote are explicable on the supposition that the mineral is the direct result of the decomposition of the primary bisilicates; none are inexplicable on the supposition that chlorite represents an intermediate stage in the alteration, and hundreds of cases show beyond question epidote developing in chloritic masses, and sending characteristic denticles and fagot-like offshoots into the comparatively homogeneous chlorite. A considerable number of drawings, which are photographic in their fidelity, have been made, illustrating these processes. Epidote, too, appears to be soluble, but to a much slighter extent than chlorite. The veinlets of epidote are often, though probably not always, a result of the alteration of chlorite. No evidence has been obtained that feldspars are ever converted into epidote, and the dissemination of fresh hornblende particles in feldspars in any considerable number has not been observed. In many cases, on the other hand, it can be shown that feldspars have been impregnated with chlorite, from which epidote has afterwards developed. Chlorite does not always change to epidote, and appears often to be replaced by quartz and calcite. This is frequently visible in slides, which also show its alteration to epidote. No certain evidence of the alteration of epidote has been met with.

In the decomposition of the feldspars, the first stage appears to be the formation of calcite. This sometimes leaches out, leaving small irregular cavities, and these cavities are not infrequently filled with liquid, sometimes carrying a bubble, which is commonly stationary, but occasionally active. Thus secondary liquid inclusions are formed, which may mislead in the diagnosis of a rock. Primary liquid inclusions are either more or less perfect negative crystals or vesicular bodies. The vesicles often assume strange forms through pressure, such as are often observed in air-bubbles in the balsam of a slide, but their outlines are composed of smooth curves. The secondary fluid inclusions are bounded by jagged lines. Inclusions of this kind are never met with unaccompanied by other evidences of decomposition, and thus are abundant in the altered outer crust of andesite masses, the inner portions of which show none of them. There is every reason to suppose that the same secondary inclusions would form in older rocks, and similar occurrences have been noticed.

Kaolin possesses so few characteristic optical properties that it is not identified with ease or certainty under the microscope. No kaolin has been identified in the Washoe rocks, and while it is by no means asserted that they contain none, it seems hardly possible that, had it formed a prominent constituent, it would have escaped observation. The presence of enormous masses of "clay" on the COMSTOCK does not prove the existence of much kaolin, for so-called clays are largely attrition mixtures. But of this later.

An increase of volume appears to accompany the decomposition of the Washoe rocks. This is perceptible where dense masses, such as the more compact andesites, are subjected to the process. Angular blocks are then converted into a series of concentric shells of comparatively soft matter, which approach the spheroidal shape more and more as the diameter diminishes. Often a nodule of undecomposed rock is found at the center, and such masses afford the very best opportunity for studying the macroscopical appearances resulting from degeneration. When the attacked mass is large, erosion often exposes the fresh core, which then, offering greater resistance, projects as a "cropping," or, if it has an elongated form, like a dike above the surrounding country; and as the tendency of the mere action of atmospheric agencies is to the production of ferric hydrate rather than chlorite from the bisilicates, the first impression which such a mass produces is that of an older and a younger rock in conjunction. Nevertheless, sufficiently thorough examination will reveal a transition. When the rock is not solid, but brecciated or loose-grained, sufficient space seems often available to permit the requisite increase of volume without disintegration. Large and often prominent masses of very strongly cohesive decomposition-products derived from breccia are common in the district.

The mineralogical character and the microscopical phenomena of decomposition seem to be identical in the different rocks. Those refined manifestations of physical character by which it is so often possible to discriminate between older and younger rocks, and between the various rock species when fresh, are nearly or quite obliterated by the decomposition process, which impresses its own character on the product.

PROPYLITE.

The present investigation of the geology of the Washoe District has failed to establish the existence of propylite. Full proof of this responsible statement cannot of course be given in this summary of results. It consists in a process of exhaustive elimination. A study of each of the rocks of the districts, in all stages of decomposition, has led to the identification of all of them with other and previously recognized species. The reduction of rocks of originally different aspect to apparently uniform character by chloritic decomposition is strikingly evinced by a mere list of the species in the district, which have been grouped under the terms propylite and quartz-propylite. These are granular diorite, porphyritic diorite, diabase, quartz-porphyry, hornblende-andesite, and augite-andesite. The peculiar "habitus" which is always referred to in descriptions of propylite appears to consist in the impellucidity of the feldspars, the green and fibrous character of the hornblende, the greenish color which often tinges feldspars and ground-mass, and a certain blending of the mineral ingredients. The impellucidity of the feldspars (which surprisingly alters the appearance of rocks originally containing transparent unisilicates) is due to incipient decomposition, especially, as it seems, to the extraction of calcite. The "green hornblendes" are simply pseudomorphs of chlorite after hornblende or augite, as the case may be. Excepting the granular diorite, not one of the rocks from which propylite forms has ever been found in the Washoe District containing green hornblende, (barring uralite). The other characteristics are due to the diffusion of chlorite and the formation of epidote from it. The description of propylite as a species arose from the erroneous determination of chlorite as green hornblende—a very natural mistake before the microscope was brought to bear on the subject, since even with that instrument the same error may be committed if color and dichroism are exclusively relied upon as diagnostic tests. The microscopical characteristics of propylite are illusory. Finely disseminated hornblende in the ground-mass of a Washoe rock is very rare, and far rarer is the presence of particles of hornblende in feldspars. The propylites contain glass inclusions and primitive liquid inclusions, or not, according to the rock from which they were derived. Base is rare in propylites; where it originally formed a constituent of the rock, it has for the most part undergone devitrification.

A re-examination has been made of all the slides of propylites from other localities as well as from the Washoe District, descriptions of which have been published in different government reports. These, too, can be referred to other rock species with great probability in spite of advanced decomposition, and the writer does not hesitate to affirm that there is no proof yet known of the existence of a pre-andesitic Tertiary eruption in the United States.

The term propylite should not be retained in the nomenclature of American geology even to express certain results of decomposition, for the equally loose term greenstone seems to cover the same ground and has priority.

THE ROCKS OF THE WASHOE DISTRICT.

The rocks occurring in the Washoe district are granite, metamorphic schists, slates, and limestones; eruptive diorite of three varieties; metamorphic diorite, quartz-porphyry, an older and a younger diabase, an older and a younger hornblende-andesite, augite-andesite, and basalt.* The report contains a discussion of each of these rocks, embracing a detailed description of about seventy-five slides well illustrated. Here they can be dismissed with a very few remarks.

Concerning the granite and basalt there has scarcely been a question. They are eminently characteristic occurrences. The metamorphic diorite sometimes resembles eruptive diorite, and has been taken both for diorite and granite; usually it bears some resemblance to augite-andesite or basalt, and has been determined microscopically as an unusual variety of the latter rock. It is composed essentially of oligoclase and hornblende. The hornblende was originally colorless, but through some change (perhaps absorption of water) it is in large part converted into an intensely green variety. The hornblende polarizes in unusually intense colors.

The quartz-porphyry underlies both hornblende-andesite and diabase. The microscope, Thoulet's method of separation, and analysis show that the predominant feldspar is orthoclase. It is characterized by the association of liquid and glass inclusions usual in quartz-porphyry, to which also the ground-mass corresponds. In one locality, near the *Red Jacket*, the quartz is nearly suppressed, and the rock is excessively fine-grained. It is a felsitic modification of the ordinary variety. This rock, which Baron v. Richthofen determined correctly, has since been called quartz-propylite, dacite, and in its felsitic modification rhyolite. Most of the quartz porphyry is greatly decomposed.

The eruptive diorite is sometimes granular, sometimes porphyritic. In the porphyritic diorite mica sometimes predominates over hornblende. Quartz is irregularly disseminated through the rock. In the granular diorite the hornblende is sometimes green and fibrous, sometimes brown and solid. In some cases it can be shown that the latter variety of hornblende is altered to the former, and possibly this is ordinarily the

* The signification attached to these names has varied somewhat as the science of lithology has progressed Some of the main points of their definitions as here understood are as follows

Granite, pre-Tertiary non-vitreous crystalline rock, of which the principal constituents are orthoclase, quartz, and mica or hornblende

Diorite, pre-Tertiary non-vitreous crystalline rock, of which the main constituents are plagioclase and hornblende It may or may not contain quartz.

Quartz-porphyry, pre-Tertiary glass-bearing porphyritic rock, of which the main constituents are orthoclase, quartz, and hornblende or mica

Diabase, pre-Tertiary, more or less porphyritic rock, of which the main constituents are plagioclase and augite

Andesite, Tertiary or post-Tertiary, glass-bearing, more or less porphyritic rock, of which the main constituents are plagioclase and hornblende, mica, or augite. The andesites in which augite is the characteristic bisilicate appear to be separate eruptions, while mica and hornblende replace one another to a variable extent in the same eruption. In the andesites feldspar predominates.

Basalt, Tertiary or post-Tertiary plagioclase augite rock, with predominant augite, usually characterized by the presence of olivine, case. Augite is not uncommon, and a part of the fibrous green hornblende is very likely uralite, but in the granular rock the outlines of the crystalline grains are rarely sufficiently regular to determine this point. In the porphyritic diorites the fresh hornblende is always brown. Even in this latter variety of the diorites well-developed feldspars are rare. The porphyritic diorites have for the most part been regarded as propylite, and some occurrences of the granular rock have been classed in the same way. Some of the fresher porphyritic diorites have been mistaken for andesites, the resemblance to which is sometimes strong.

The older diabase is porphyritic. Almost the whole of this rock is in a very advanced stage of decomposition, and when fresh considerably resembles an augite-andesite, but its ground-mass is thoroughly crystalline; it contains no glass inclusions, but frequent fluid ones; the augites show both pinacoidal and prismatic cleavages, and a tendency to uralitic decomposition. It is also manifestly older than the other diabase. An important characteristic is the lath-like development of the porphyritic feldspars, for in cases of extreme decomposition of the bisilicates this characteristic at least serves to suggest whether the rock is dioritic or diabasitic. The older diabase has been considered as propylite or andesite, according to the stage of decomposition.

The younger diabase ("black dike") is very highly crystalline and not porphyritic. It is bluish when fresh, but in course of a few hours turns to a smoky brown. It is identical with many of the diabases of the New England and the Middle States.

The older hornblende-andesite and the augite-andesite where fresh are typical rocks macroscopically and microscopically. When decomposed they have been taken for propylite.

The younger hornblende-andesite which overlies the augite-andesite is a cross-grained, soft, reddish or purplish rock, with large glassy feldspars. It has always been supposed to be trachyte; but, when endeavoring to determine the different species of feldspar under the microscope, the writer was unable to include any satisfactorily determinable orthoclases in the list. Dr. G. W. Hawes was kind enough to undertake the separation of the feldspars by Thoulet's method, and the analysis of the resultant feldspars. The specimen selected was the most trachytic in appearance, that of Mount Rose, but no feldspar whatever was found corresponding either physically or chemically to orthoclase. There is much reason to believe that trachyte occurs less often than had been supposed in the Great Basin area

STRUCTURAL RESULTS OF FAULTING.

The evidence of faulting on the COMSTOCK is manifold, and has been recognized by all observers. The irregular openings in the vein, the presence of horses, the crushed condition of the quartz in many parts, the presence of slickensides and of rolled pebbles in the clays, are all conclusive on this point. Both to the east and west of the vein, too, the country rock shows a rude division into sheets, and along the partings between the plates evidences of movement are perceptible, decreasing in amount as the distance from the vein increases, according to some law not directly inferable. All the evidence points to a relative downward movement of the hanging wall.

The question of the character of the contact surface, whether it is a faulted surface or a continuation of a former exposure of the east front of Mount Davidson, is not to be settled by mere inspection. A cross-section to scale taken from Mr. King's maps shows immediately that while the dip of the lode is 45° or more, the maximum slope of Mount Davidson is about 30°. This fact, taken in connection with the character of the west wall when exposed, indicates that the surface is the result of faulting. A natural surface sloping for a long distance at an angle of above 40°, too, is very unusual. On the other hand, the coincidence between the contours of the west wall and those of the exposed surface has been notorious from the earliest days of mining on the lode, and it seems a less violent supposition that the steep flank of the mountain passes over into the still steeper wall of the vein than that the range has experienced an erosion modifying its angle 15° and more, and has still retained the details of its topography otherwise unaltered.

It is plain that the elucidation of the faulting action on the COMSTOCK is a very important structural problem, and that it is most desirable to account quantitively for the results, as well as to prove the existence of a notable dislocation.

The most striking and wide-spread evidence of the faulting is the apparent relative movement on the contact surfaces between more or less regular sheets of the east and west country rocks for a long distance in both directions from the lode. Each sheet appears to have risen relatively to its eastern neighbor, and to have sunk as compared with the sheet adjoining it on the west. The consideration of a sheet or plate of rock under the influence of friction of a relatively opposite character on its two faces, therefore, forms the natural starting point for an examination of the observed conditions.

It will be shown in the report that if a country divided like the COMSTOCK area into parallel sheets experiences a dislocation on one of the partings under a compressive strain equal at each parting, a vertical cross-section will show a surface line represented by two logarithmic equations:

$$y = A\,(m^{-x} - 1) - x \tan \vartheta$$
$$y = A\,(1 - m^{x}) + x \tan \vartheta$$

in which A is one-half of the throw of the fault, and ϑ is the angle which the x-axis makes with the original surface. The y-axis coincides with the dip line of the parting on which the fault occurs, and the origin is at the cropping of the fault-fissure. The coördinates are rectangular. The correctness of this equation is confirmed by a very simple and satisfactory experiment. Fig. 22 shows a cross-section such as might result from a fault on the line Y A, supposing the original surface to have been level.

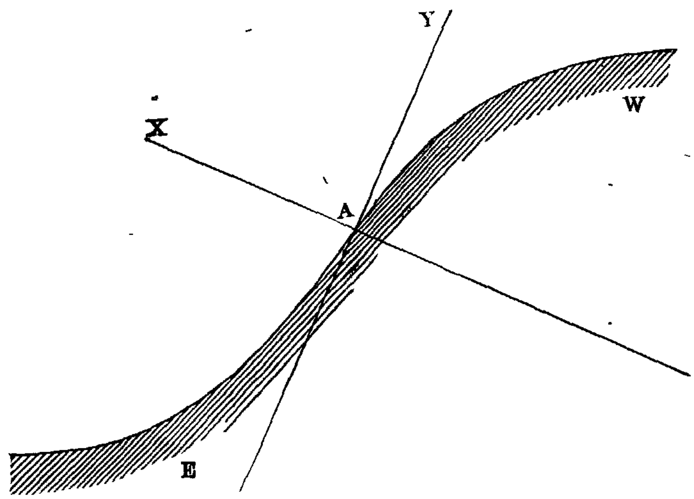

FIG 22.—Fault curve

The discussion is also extended to the case in which the compressive strain is not uniform, but varies proportionally to the distance from the fault-plane. This case also results in a logarithmic equation of a more complex character.

A discussion of the logarithmic equation as an expression of faulting action leads to some very interesting results, some of which are as follows:

Where a fault of the class under discussion has occurred, and where the resulting surface has not been obscured by deep erosion, the original surface can be reconstructed or calculated, and the amount of dislocation determined. This is also true where more than one rock is involved.

Where, as is nearly always the case, the movement on the fault-plane is equivalent to a rise of the foot wall, the hanging wall seen in cross-section will assume the form of a sharp wedge, and this wedge will be very likely to yield to the compressive strain, and break across.

If the movement of the footwall on the fault-fissure were downward, a surface line would form, which is scarcely ever met with in nature, and the inference is that faults of this kind are of extreme rarity. This not only confirms the observations made in mines, but places the fact on a wide basis of observation.

If a fault, accompanied by compressive strain, takes place on a fissure in otherwise solid rock, the walls are likely either to be distorted, if they are composed of flexible material, or to be fissured into parallel plates if the material is rigid. In the latter case the sheets of rock will also arrange themselves on logarithmic curves.

If the intersection of a fault-fissure with the earth's surface is not a straight line, but is sinuous or broken, the secondary fissures will be parallel to the original one, and in the resulting surface each inflection of the trace of the fissure on the original surface concave toward the lower country will be represented on the faulted surface by a ravine, and each inflection convex towards the lower country will result on the faulted surface in a ridge. This is illustrated in Fig. 23, which is a contour map of the country represented in Fig. 22, if the fault-fissure is supposed to have intersected the original surface on the undulating line A B. There is also a direct relation between the contours of the footwall of such a fissure and the surface contours. If the original surface was a horizontal plane, the surface contours will be identical with the footwall contours.

A fault may be the result of a single extensive movement, or of successive slight movements in the same sense, with intervals of quiescence. It can be shown, with a high degree of probability, that the result of an intermittent dislocation will be sensibly the same as that of a continuous one.

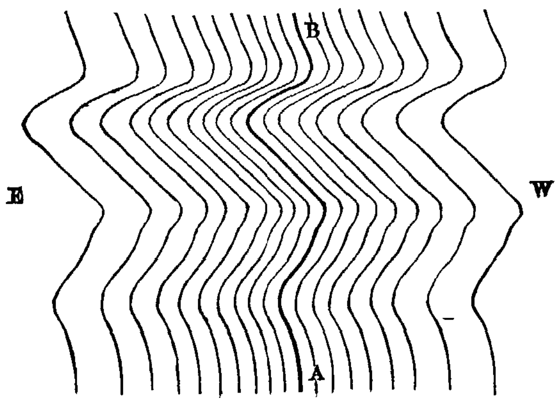

FIG 23 —Faulted surface

The theory, though worked out independently of the COMSTOCK, applies to it with much precision. Equations can be given representing very closely the surface line of a cross-section, the amount of the fault can be determined, etc. It can be shown that the erosion since the beginning of the fault is very slight, that the cañons of the range were produced by faulting, and have been only slightly modified by erosion, whence the correspondence of the contours of the footwall with those of the surface. The east fissure is a result of the faulting, and the ore has been deposited since Washoe became a region of insignificant rainfall. The sheeted structure of the country is, in all probability, due to the fault.

It is, of course, most unlikely that the COMSTOCK is the only vein in which the deposition of ore is recent and has been accompanied by faulting, and some conclusions as to the occurrence of veins in such cases may be welcome to some of the readers of this paper.

In a locality modified by faulting action under pressure the fact will appear in the parallelism of the exposed edges and faces of rock sheets. If erosion has not seriously modified the surface resulting from the faulting action, the logarithmic curve will be recognizable to the observer looking in the direction of the strike.

The main cropping of the vein is to be sought at the point of inflection of the curve, which will be found nearly or exactly midway between the top and bottom of the hillside. One or more secondary vein-croppings should be looked for below the main cropping, and these, so far as yield is concerned (but not in regard to location of claim), may prove even more important than the main fissure.

The dip of the vein will be to the same quarter as the slope of the surface, but, of course, greater in amount. The flatter the surface curve the smaller the angle of dip will be. The mean strike will be nearly or quite at right angles to the direction of the spurs and ravines of the faulted area.

If, besides the movement of one or other wall in the azimuth of the dip, there has been a dislocation in the direction of the strike, chimneys will open, all of them on the same side of the different ravines. Surface evidences will often enable the prospector to determine on which side the chimneys are to be found. On the barren sides evidences of crushing and of closure of the fissure are probable.

The fissure is more likely to have a constant dip (barring the secondary offshoots) than a constant strike, but, of course, irregularities of dip, like those in strike, will open chambers which may be productive.

Offshoots into the hanging wall may occur at any depth, but none, except those near enough to the main cropping to reach the surface where it has a very considerable slope, are likely to be continuous.

Finally it is shown that the law of land slips is also capable of expression by logarithmic equations, and that a large part of the details of the topography of grassy hills is formed in obedience to this law.

OCCURRENCE AND SUCCESSION OF ROCKS.

Granite occurs on the surface only in a very limited area near the *Red Jacket* mine, but it is certain that it has a considerable underground development, for it has been struck at the *Baltimore*, the *Rock Island*, and by a tunnel to the southwest of the latter beyond the limits of the map.

The granite is overlaid by metamorphic rocks, which, however, are less metamorphosed close to it than at a distance from it, and the probabilities are that the sedimentary strata were laid down upon the massive rock. The sedimentary rocks are limestones, crystalline schists, and slate. They are badly broken and highly altered, and the search for fossils was not rewarded by success. The general geology of this part of the Great Basin, however, leaves little doubt that they are Mesozoic. A considerable area of metamorphics has been exposed in the southwest of the region by the erosion of the overlying eruptive masses. North and east of Silver City, however, the surface shows scarcely any metamorphics, while they play a large part in the underground occurrences as far as the *Yellow Jacket*. In the Gold Hill mines black slates form the footwall of the lode. They are intensely colored with graphite, and often very highly charged with pyrite. They are frequently mistaken for "black dike," but a moment's inspection in a good light shows their sedimentary origin. The presence of such carbonaceous rocks at greater depths would explain the formation of hydrogen sulphide. There is also an obscure occurrence of metamorphic limestones in the *Sierra Nevada* mine between granular and micaceous diorite. It appears to be conformable to the face of the granular diorite. The metamorphics in and about Gold Hill appear both to overlie and to underlie diorite, and there is little doubt that sedimentary strata were present at the period of the diorite eruption.

Between the metamorphics and the quartz porphyry in the southwest portion of the area is a considerable extent of a black, crystalline rock, the relations of which are somewhat obscure. It has already been referred to as a metamorphic diorite. Cases of transition into distinctly metamorphic rocks no doubt occur, but none of an indubitable character were discovered. On the other hand, in some occurrences the rock is a distinct breccia, and bears a strong resemblance to augite-andesites or basalts. The point to which most weight has been given in determining its origin is its association with the quartz-porphyry, and the distinctly metamorphic rocks. It appears to be exposed wherever the quartz-porphyry is eroded, and is frequently also associated with underlying metamorphics. Its resemblance to a volcanic rock, too, is greatest on its upper surface, and its analysis shows a composition which would be strange for an eruptive diorite. Besides the surface occurrences, it is found particularly well developed in the *Silver Hill* mine.

The principal exposure of diorites is on the west of the LODE through Virginia City, but there are several outlying occurrences about the *Forman Shaft*, and again far to the east at the *Lady Bryan* mine, which show that the underground development of the rock is a very extensive one. It forms the footwall of the LODE from the *Yellow Jacket* north. The diorite is excessively uneven in its composition, and in almost any area of a hundred feet square several modifications are to be found. This fact, taken in connection with the microstructure of the rock, is pretty conclusive evidence that it has never reached a higher degree of fluidity than the plastic state. The varieties can be roughly classified as granular diorite, porphyritic-hornblendic diorite, and porphyritic-micaceous diorite. But intermediate varieties are of constant occurrence. There seems, nevertheless, to be a certain amount of order in the disposition of the different varieties. Mount Davidson, from Bullion Ravine to Spanish Ravine, is almost altogether granular on the west of the LODE, but to the north and south of these limits porphyritic forms prevail. In the neighborhood of the *Utah* mine mica becomes the predominant bisilicate, and the last variety is also the one which occurs in the neighborhood of the *Forman Shaft.* How this orderly disposition of the various diorites came about is a somewhat obscure question.

The diabase appears but to a very trifling extent upon the surface, though it is by no means unlikely that an exposure of this rock occupied the position now covered by Virginia City. Underground it is extensively developed from the *Overman* to the *Sierra Nevada,* and from the LODE to the *Combination Shaft,* as is seen in the cross-section on the *Sutro Tunnel* line, Plate LVII. Its great importance is due to the fact that all the productive bodies of the COMSTOCK have been intimately associated with it, as, indeed, are many of the famous silver mines of the world. This diabase is of a rather unusual character, being more than commonly porphyritic, and containing comparatively little augite, a trifle less than twenty per cent. In appearance it is often not dissimilar to the andesites, but the resemblance does not extend to details. Almost the whole of this diabase is greatly decomposed, and has hitherto escaped recognition on that account.

Between the east country diabase and the west wall of the COMSTOCK occurs a thin dike, which has long been known as "black dike." It is only in the lower levels that fresh occurrences of this material have been met with. The "black dike" appears to be identical with the Mesozoic diabases of the Eastern States, from which it is scarcely distinguishable microscopically, macroscopically, or chemically. This younger diabase forms a remarkably thin and uniform dike, nowhere more than a few feet in thickness, extending from the *Savage* southward to the *Overman,* and then branching off to the southwest as far as the *Caledonia* shaft. This is the only dike in the district, in spite of the prevalence of eruptive rocks. Its presence shows that the fissure on which the COMSTOCK LODE afterward formed was first opened in pre-Tertiary times, and its uniform thickness shows that its intrusion antedates any considerable dislocation on the contact. This inference receives strong confirmation from the evidence already explained that the faulting is a comparatively recent phenomenon.

The occurrence of the two diabases also goes a long way toward demonstrating the nature of the fork in the vein, which has always been a mysterious point in the geology of the lode. The prolongation of the "black dike" beyond Gold Hill is toward American Flat, whereas the older diabase extends in the direction of Silver City.

Much the larger part of the surface of the district is occupied by andesites, of which there are three varieties distinguishable both lithologically and geologically. These are a younger and a later hornblende-andesite, the latter of which has hitherto been considered a trachyte, and an augite-andesite intermediate in age. The older hornblende-andesite has in part long been recognized as such and is deceptive only when highly decomposed. It occupies a belt immediately east of the older diabase (see *Sutro Tunnel* section), a large area on the heights immediately west of the diorites, and a considerable area at and north of Silver City. The latter occurrence is noteworthy for the unusual size of the hornblendes, which are sometimes several inches in length. The augite-andesite occupies a second belt of country east of the lode and beyond the earlier hornblende-andesite, and is also extensively developed to the north and south of the diorite. The *Forman Shaft* penetrates 1,200 feet of this rock before passing into the hornblende-andesite.

The reasons are given elsewhere for considering the rock heretofore regarded as trachyte to be an andesite. It is rough but soft and its red and purple colors and large glassy feldspars made the mistake an easy one. The Flowery Range, the Sugar Loaf, Mount Emma, and Mount Rose, are all of this rock, which also occurs in two little patches close to the *Sierra Nevada* mine. These latter have been cut off from the quarry above the *Utah* by the erosion of Seven-Mile Cañon. The patches of rock near the *Combination Shaft* and the new *Yellow Jacket Shaft*, which have sometimes been regarded as trachyte, are merely decomposed older hornblende-andesite.

The occurrence of basalt is exceedingly limited and is confined within the area of the map to two small localities, one at Silver City and the other a mile west of it. It is a fine, fresh and typical basalt, but there is no evidence of any direct connection between its eruption and the vein phenomena.

CHEMISTRY.

The chemical history of the COMSTOCK is no doubt a very complex one, nor are there by any means sufficient data to trace it in detail. All that can be attempted here is to show that the results observed might naturally follow from highly probable causes.

The decomposition of the rocks shows three important features. The formation of pyrite from the bisilicates, the decomposition of the bisilicates into chlorite (which is in part further altered to epidote), and a partial change of the feldspar.

The pyrite appears to have formed at the expense of the bisilicates. The really fresh rocks contain no pyrite, but minute crystals often occur in or attached to partially decomposed bisilicates. Sometimes distinct pseudomorphs of pyrite after augite or hornblende are visible, but this is not common because the average size of the pyrite crystals is about one-half that of their hosts. A macroscopical comparison, too, of series of rocks increasingly decomposed shows that the pyrite is to all appearances associated with the bisilicates, and in extreme cases replaces them with an entire correspondence of distribution, so that the cumulative evidence is all in one direction. It is well known that ferrous silicates in contact with waters charged with hydrogen sulphide produce pyrite.

The transformation of the bisilicates into chlorite is not obscure in its general features, though its details are far from clear; like those of most similar decompositions chlorite is essentially a silicate of aluminium, iron, and magnesia. Chlorite contains nearly equal quantities of alumina and magnesia; whereas augite, for example, contains nearly four times as much of the protoxide base. If the amount of alumina is supposed to remain unchanged, the alteration must be accompanied by a separation of all the lime and of the greater part of the silica and the magnesia. The relations of the other bisilicates to chlorite are similar and their conversion to chlorite is a familiar fact, particularly in the neighborhood of silver ores.

The triclinic feldspars of the Washoe District retain their striæ and optical properties in a recognizable form much longer than the bisilicates. Among the mine rocks it is very rarely that bisilicates occur undecomposed, but it is the exception when a slide of a tolerably hard rock does not show recognizable feldspars. When the feldspars are altered they are replaced by an aggregate of polarizing grains, which appear to be quartz and calcite with some opaque particles, but with no transparent amorphous material. Two generically distinct processes of decomposition of feldspar have hitherto been recognized. The one results in the formation of kaolin, or a less hydrous aluminium silicate. The other is characterized by the introduction of magnesia and a little water, and the separation of soda and lime. Everything seems to point to the latter change as the characteristic one in the Washoe District. Kaolin could hardly be present in large quantities without being recognized microscopically. The analyses of the clays, too, show that when allowance is made for the presence of hydrous chlorite there is not enough water to correspond with any large percentage of kaolin. In fact the analyses of the clays so exactly correspond to the composition of the firm rocks that the great masses of clay evidently represent only equal volumes of disintegrated rock. On the other hand, the magnesia, which plays a part in the alternative decomposition of plagioclase, is furnished by the conversion of the bisilicates to chlorite, the microscopical phenomena are just what might be expected, and the analyses correspond. On the whole, therefore, it appears improbable that there has been any large amount of kaolinization in the Washoe District.

Epidote is very common on the surface, while under ground it seems rare and confined to the neighborhood of the fissure. The conversion of chlorite to epidote must be accompanied by a substitution of lime for magnesia, and by the conversion of ferrous to ferric oxide. It might very readily occur in the presence of solutions containing carbonic acid and free oxygen, or when surface waters mingled with waters rising from lower levels; for epidote is far less soluble than chlorite, and under these circumstances would form in obedience to the general law of precipitation. Its occurrence is usually compatible with this supposition, but it is not so decisive as to warrant a positive assertion that the conditions of its formation are those indicated.

As is well known, Prof. F. Sandberger has very ably maintained what is known as the lateral-secretion theory of ore deposits.* With a view to testing the probabilities of this theory, with reference to the Comstock, the rocks of the district have been assayed with all possible precaution.† The rocks found to contain precious metals were also separated by Thoulet's method, and the precious metals traced to their mineralogical source. The results of this investigation show many interesting facts, among which are the following: The diabase shows a noteworthy contents in the precious metals, most of which is found in the augite. The decomposed diabase contains about half as much of these metals as the fresh rock. The relative quantities of gold and silver in the fresh and decomposed diabase correspond fairly well with the known composition of the COMSTOCK bullion. The total exposure of diabase is sufficient to account for far more bullion than has been extracted from the mines.

The gangue on the COMSTOCK is almost exclusively quartz, though calcite also occurs in limited areas. The ore minerals elude investigation for the most part because they are so finely disseminated as merely to stain the quartz, but it is fairly certain that they are principally argentite, and native silver and gold, accompanied in some cases by sulphantimonides, etc. The chloride has rarely been identified. Where ore is found in diorite, or in contact with it, it is usually of low grade, and its value is chiefly in gold. The notably productive ore bodies have been found in contact with diabase, and they have yielded by weight about twenty times as much silver as gold.

It would perhaps be legitimate to infer from the chemical phenomena enumerated that waters charged with carbonic acid and hydrogen sulphide had played a considerable part on the COMSTOCK. This is not, however, a mere inference, for an advance boring on the 3,000′ level of the *Yellow Jacket* struck a powerful stream of water at 3,065 feet (in the west country), which was heavily charged with hydrogen sulphide and had a temperature of 170° F., and there is equal evidence of the presence of carbonic acid in the water of the lower levels. A spring on the

* Berg und Huttenmännische Zeitung, vol. 39, 1880, 402 et antea.

† The assays and separations were made by Mr. J. S. Curtis, United States geologist, who has had much experience as an assayer. He also superintended the manufacture of a special lot of litharge for this purpose.

2,700′ level of the *Yellow Jacket*, which showed a temperature of above 150° F., was found to be depositing a sinter largely composed of carbonates.

Baron v. Richthofen was of opinion that fluorine and chlorine had played a large part in the ore deposition on the COMSTOCK, and this the writer is not disposed to deny; but, on the other hand, it is plain that most of the phenomena are sufficiently accounted for on the supposition that the agents have been merely solutions of carbonic and hydrosulphuric acids. These reagents will attack the bisilicates and feldspars. The result would be carbonates and sulphides of metals, earths and alkalies, and free quartz; but quartz and the sulphides of the metals are soluble in solutions of carbonates and sulphides of the earths and alkalies, and the essential constituents of the ore might, therefore, readily be conveyed to openings in the vein where they would have been deposited on relief of pressure and diminution of temperature. Some of the physical conditions of the process will be elsewhere considered.

It has been claimed that the ore and quartz have been deposited by substitution for masses of country rock. This hypothesis is exceedingly doubtful on chemical grounds, but there is also at least one insuperable physical objection to it. In all processes involving the solution of angular bodies, it is a matter of common observation that points and corners which expose a greater surface than planes are first attacked, consequently masses exposed to solution, substitution, weathering, and the like, always tend to spheroidal forms. Now, nothing is more common than to find masses of country rock included in the ore-bearing quartz. These masses are, in all cases which have come under the observation of the writer, angular fragments, in form precisely such as result from a fresh fracture; not a single instance has been observed in which a spheroidal rock was surrounded by more and more polyhedral concentric shells of quartz and ore.

HEAT PHENOMENA OF THE LODE.

One of the famous peculiarities of the COMSTOCK LODE is the abnormally high temperature which prevails in and near it. This manifested itself in the upper levels, and has increased with the depth. The present workings are intensely hot. The water which flooded the lower levels of the Gold Hill mines during the past winter had a temperature of 170° F. This water will cook food, and will destroy the human epidermis, so that a partial immersion in it is certain death. The air in the lower levels more or less nearly approaches the temperature of the water according to the amount of ventilation. The rapidity of the ventilation attained in the mines is something unknown elsewhere, yet deaths in ventilated workings from heat alone are common, and there are drifts which, without ventilation, the most seasoned miner cannot enter for a moment. Except where circulation of air is most rapid, and in localities not far removed from downcast shafts, the air is very nearly saturated with moisture. It is a serious question how far down it will be possible to push the mines in spite of the terrific heat.

The relation of the temperature to the depth from the surface is evidently one of great interest, but not entirely simple. If the rock were wholly uniform in character and unfissured the relation of temperature to depth would be wholly regular, and would be represented by a curvilinear locus. As the source of the heat was approached the rate at which the temperature rose would rapidly increase, and under the ideal conditions supposed, it would be possible to deduce the constants of the equation and to calculate the position of the source of heat. But unless the source of heat were so close to the surface that the errors introduced by the presence of fissures, the lack of homogeneity of the rock, and the percolation of surface water, were insignificant in comparison with the rate of increase of the temperature, such a calculation would not be possible. A careful record of temperatures has been kept at three of the newer shafts to a depth of above 2,000 feet. On plotting these records as ordinates and the depths as abscissæ no indication of regular curvature appears, being wholly obscured by the fluctuations due to the disturbing causes mentioned. In other words, there is as yet nothing in the observations to show any but local divergences from a strict proportionality between depth and temperature. The source of heat must, consequently, lie at a very great distance from the surface as compared with the depth yet reached, and the curve is to be regarded as still sensibly coincident with its asymptote.

In order to eliminate the fluctuations of temperature as far as possible, Mr. Reade and Dr. Barus have computed the observations made at the *Forman*, *Combination*, and *New Yellow Jacket* shafts by the method of least squares, and also, for comparison with them, the observations of Mr. J. A. Phillips at the *Rosebridge Colliery*. The report will contain the details for each of these localities. Here it is sufficient to state that the mean data for rock and water on the COMSTOCK result in the equation

$$t = 53.7 + 0.0327d$$

while the *Rosebridge Colliery* observations result in the equation

$$t = 56 + 0.0150d$$

t representing degrees F., and d the depth from the surface in feet.

Since no evidence of curvature can yet be traced in the locus representing the relations of temperature to depth, these equations may be expected to hold good for depths greatly exceeding the present, but if more than local variations occur at any depth they will be in the sense of a more rapid increase of temperature. Boiling water will probably be encountered on some parts of the COMSTOCK before the mines reach a depth of 5,000 feet, while the water of the *Rosebridge Colliery* will not boil before twice that depth is attained.

Two causes have been suggested in explanation of the high temperature of the COMSTOCK—the kaolinization of the feldspar contained in the country rock, and residual volcanic phenomena.

The theory that kaolinization is the cause of the heat appears to rest upon two positive grounds—that the solidification of water liberates heat and that flooded drifts have been observed to grow hotter. It is also claimed in favor of the kaolinization hypothesis that there is no evidence of any other chemical action proceeding with sufficient activity to afford an explanation, and that the retention of igneous heat in the rocks is a sheer impossibility; while the hypothesis that the heat is conveyed from some deep-seated source to the mines by means of currents of heated water is characterized as somewhat violent and as unnecessary.

So far as the present writer is aware, there are no theoretical grounds upon which the heat involved in kaolinization can be estimated. The decomposition of feldspar into kaolin and other products (supposing kaolin to result from the decomposition of plagioclase) involves several processes, of which some are more likely to absorb than to liberate heat. But supposing an anhydrous aluminium silicate formed without loss of heat, the thermal results of its combination with water are by no means certain. Were the water contained in kaolin not water of hydration, but chemically combined, it would be possible from known experiments to compute approximately the heat which would be produced. It will be shown in the report that the corresponding temperature would be so high as to be utterly at variance with known facts. The water is therefore the water of hydration. Of the heat involved in the hydration of salts we know that it is usually small, that it is sometimes negative, and that the different molecules of water combine with differing amounts of energy, but of the heat of hydration of kaolin we know nothing.

With a view to testing the theory of kaolinization as far as possible, Dr. Barus, at the writer's request, undertook some very delicate experiments presently to be described. The result of these experiments, in a word, was that finely divided, almost fresh east country diabase, exposed to the temperature of boiling water and the action of saturated aqueous vapor for a week at a time, and for several weeks in succession, showed no rise of temperature perceptible with an apparatus delicate to the $\frac{1}{1000}$ of a degree C.

It is by no means certain that kaolinization was effected by this experiment. The particles of rock were indeed coated with a white powdery substance, but in such small quantities that its nature could not be determined. It is still possible that when kaolinization occurs, heat is liberated. It is also possible that at temperatures above the boiling point and pressure greatly exceeding 760^{mm}, feldspars are kaolinized; but it appears no longer reasonable to ascribe the heating of drifts, which are at nearly normal pressure, to the reaction on the rocks of water below the boiling point. The scene of active and heat-producing kaolinization, if it exists at all, must, therefore, be at remote depths. As was explained in a previous paragraph, the present examination has not resulted in tracing any considerable amount of kaolinization on the COMSTOCK; while, had the heat of the lode been maintained ever since its formation at the expense of the feldspars, but little undecomposed feldspar could now remain. In short, while it cannot be demonstrated that the heat of the COMSTOCK is not due to the prevalence, at unknown depths and pressures, of a chemical change of unknown thermal relations, the writer has failed to find any proof that the heat of the COMSTOCK is due to kaolinization.

Of the origin of the heat of solfataras not very much is known; yet, as they commonly occur either as an accompaniment of volcanic activity, or in regions characterized by the strongest evidences of past volcanic activity, it is usual and seems rational to connect them as cause and effect, or as different effects of a common cause. There seem to be no special opportunities on the COMSTOCK for an elucidation of the whole theory of vulcanism, but considerable grounds for connecting the heat there manifested with that chain of phenomena.

That solfataric action, as commonly understood, once existed on the COMSTOCK is certain. That the time at which the LODE was charged with ore is not immeasurably removed from the present, appears to be demonstrated by the trifling character of the erosion which has since taken place. The water entering the bottom of the *New Yellow Jacket* shaft in the winter of 1880–'81, at a temperature of 170° F., was highly charged with hydrogen sulphide. The Steamboat Springs, only a few miles west of the COMSTOCK, lie in a north and south line like the COMSTOCK, close to the contact of ancient massive rocks and andesites. Some of them are boiling hot, are charged with solfataric gases, and are now depositing cinnabar and silica as at the time of Mr. Phillips' visit many years ago. Finally, there is reason to suppose that the hot waters of the COMSTOCK come from great depths.

No meteorological station exists at Virginia City, but the rainfall is so small that the country is a sage-brush desert, and the precipitation is insufficient to account for the water met with on the LODE. The main influx of water, and especially of hot water, is from the west wall, and when encountered it is found under a head often of several hundred feet. Between the COMSTOCK and the main range of the Sierra Nevada, the whole country is covered by massive rocks, principally andesites, with occasional croppings of granite. The general structure of the country, and the exposures of sedimentary rocks in the mines, lead to the supposition that the underlying strata dip eastward, and the inference is that the COMSTOCK fissure taps water-ways leading from the crests of the great range. If the heat is conveyed to the LODE by waters from great depths, the variations in temperature are readily explained. The distribution of the heated waters would be determined by the presence of cracks, fissures, and clay-seams, and the uniformity of distribution of heat would further be disturbed, even at considerable distances from the surface, by the infiltration of surface water. One published observation, which is important in this connection, is that a large proportion of the rocks in the Virginia mines are dry. This is very true in the sense in which dry is used in mining, *i. e.*, there are many places where water does not drip from the walls; but the present examination has failed to reveal rocks which are not moist. Indeed, the occurrence of really desiccated rock thousands of feet below the surface, near vast quantities of water, would disprove the generalization of the perviousness of rocks, which is one of the best established in geology. Unless, therefore, very strong proof to the contrary can be adduced, the conduction of heat on the COMSTOCK must be considered as taking place in moist rock.

THE LODE.

The detailed structure of the upper portion of the LODE was minutely and graphically described by Mr. King, and Mr. Church has followed the vein phenomena down to the 2,000-foot level. Below this point only one very small ore-body has been found, and the position of the vein is marked only by barren quartz or by a mere clay seam. The old upper workings, and many of those visited by Mr. Church, are now wholly inaccessible; and the present writer's task, so far as the mere description of the vein is concerned, is limited to showing what light is thrown on the recorded phenomena by the present investigation.

The COMSTOCK from the surface down is a remarkably regular fissure. This is shown by the close correspondence between the contours of the west wall and the lower levels with those of the surface near the LODE, and when the presence of a large fault is taken into consideration, is also indicated by the closeness with which the east wall follows the west in many parts of the mines. A most important feature near the surface was the existence of the east fissure, or, so called, *Virginia* vein. This was referred by v. Richthofen to its proper cause, a fracture through the hanging wall, caused by faulting; and the present examination has shown how the edge of the east country came to assume a sharp wedge-like form, especially favorable for the formation of a cross-fracture. Above the junction of the primary and secondary fissures both were largely occupied by quartz, but while the quartz of the main fissure carried but little metal, concentrations of ore or bonanzas were plentifully distributed through the east fissure. Below the junction of the two the east as well as the west wall became regular in dip, and both have continued so ever since.

The secondary fissure and evidences of great fault extend from the lower portion of Gold Hill to the *Sierra Nevada* mine, as may be seen by reference to Mr. King's sections. Beyond these points the signs become less marked, and the dislocation has been distributed. The true vein is probably to be considered as limited to the contact between diabase and the underlying rocks. To the north of the *Union* shaft a considerable extent of this contact seems to be still unexplored. The fissure which has been followed on the *Sierra Nevada* upper levels appears to be wholly in diorites, though a small stringer of diabase also occurs here, and a similar one still further north, in the *Utah* mine, while the main contact between the diorite and the diabase swings off to the northeast in *Union* ground. So, too, to the south of the *Overman* there seem to be two fissures. While the main productive ground has been at or close to the diabase contact, ore has been found at many other points in the district. The gold-quartz mines of Cedar Hill stand in such a relation to the COMSTOCK as proves, almost beyond a question, that they owe their existence to the same dynamical and chemical phenomena, modified only by the lithological character of their walls. The *Occidental* lode is evidently referable to the same causes which produced the COMSTOCK, and it is probable that the numerous occurrences of ore on various contacts in the district (though they have seldom proved remunerative) have the same origin. It is possible that this may even be the case with the east and west veins in hornblende-andesite (at their croppings) which occur just north of Silver City. It is the combination of dynamical and lithological conditions, and of the chemical relations dependent upon the latter, which, taken together, separate what is unanimously conceded to be the COMSTOCK LODE from the other ore-bearing formations of the district.

From the surface down, the filling of the vein has consisted essentially of more or less metalliferous quartz, with here and there a little calcite, broken and decomposed rock, and clay. The presence of rock and clay is easily accounted for when the method of formation of the vein is considered. The great horses near the top were masses broken from the east country, but innumerable smaller fragments must have formed at the same time, filling or more or less obstructing the fissure. It is certain that openings formed in this way would have been held open to a greater or less extent, at least within moderate distances below the surface, but it is also certain that a large amount of the rock would have been triturated. When decomposition set in, conversion of the finely-divided rock into clay would have followed. The decomposition of all the fragments, too, would be likely to be more energetic on the fissure than elsewhere, on account of the activity of circulation. It may not be superfluous to repeat here that clays by no means necessarily contain any considerable percentage of kaolin.

The quartz was found to a very large extent in a highly crushed condition, resembling nothing so much as ordinary commercial salt. Some doubt has been thrown on the manner in which this fine division has been produced, though it has ordinarily been assumed to be the result of crushing. Samples mounted in balsam and examined under the microscope show that the material is composed of fractured crystalline quartz. The edges and points of the spiculæ are sharp, and of course the crystalline character is perfectly evident in polarized light, while crystal faces as well as fractures are recognizable. Besides crushing, the only action which could have produced this state of division is some internal force, such as tension produced by heat. That such is not the cause, however, is demonstrated by the fact that bunches of crystals of considerable size often occur, through each individual of which the same crack can be traced, showing a common and an external force. Small vugs must have formerly existed where these crystals occur. Taking into consideration the brittle character of this mineral it can readily be shown that there was force enough available during the dislocation of the country to effect its comminution. The eastern bodies are much more generally reduced to "sugar quartz," as it is commonly called, than the masses which lie near the west wall. This is as would be expected.

As has been seen, there is good reason for believing that the decomposition of the east country has not been effected by surface waters. Granting this, it is almost necessary to suppose that at some depth or other there is a zone on the fissure which is closed water-tight; for were it otherwise the waters ascending from great depths would rise along the open fissure. Even at the levels already reached, the vein is in places only represented by a clay-seam, practically impervious to water, and as the liability to stoppage will certainly increase with the depth, it is by no means an extravagant supposition that further down on some straight or sinuous line the fissure is impenetrable by water from one end to the other. As the east country is penetrated throughout by capillary fissures, of which those parallel to the LODE probably possess great continuity, the heated waters entering the fissures below the stoppage would rise through the broken east country, but higher up would again tend towards the fissure as offering the path of least resistance.

The ore-bearing solutions must have taken the same course as those which decomposed the east country rock, and the vein must therefore have been filled through the east wall, even if the diabase is not regarded as the source of the metals. Had the vein been filled through the fissure from great depths, "comb-structure" must have been visible in the ore on both walls, for while "comb-structure" may not be incompatible with lateral secretion, it can hardly be maintained that minerals would crystallize out from ascending solutions otherwise than on the sides of the fissure and on included fragments. This structure is actually visible on the COMSTOCK, where narrow intervals between rock masses have induced such a method of deposition in miniature. On the other hand, a flow of mineralized solutions from the east country into the fissure would be exceedingly apt to interfere with the definiteness of the east wall, both mechanically and chemically. In point of fact, as is well known, although the east wall is well defined in some places, it is often ill defined and sometimes indistinguishable. At the intersection of the *Sutro Tunnel* with the *Savage* claim nothing could be more perfect than the east wall, but this also happens to be the only spot discovered where a considerable mass of diabase exists in an undecomposed condition.

Unless, contrary to the conclusions to which this examination has led, a great mass of material has been eroded from the surface since the deposition of the ore, the ore-bearing solutions must have taken an upward course, since remunerative ore was comparatively well distributed in the first thousand feet of the LODE. If precipitation was the result of the decrease of temperature and pressure, the tendency to precipitation must evidently have been greater near the surface. In this connection it is worthy of note that the character of the ores in portions of the croppings differed from that of those found at greater depths, being to a much larger extent galena, blende, and sulphur salts.

Collectively, the various observations made, if they are correct and the inferences from them sound, throw considerable light on the history of the LODE. After the eruption of the diorite the first event of importance, so far as the vein is concerned, was the outburst of diabase, which involved a rupture and dislocation of the earlier diorite, leaving a smooth contact between the two rocks at an angle of about 43°. The contact was afterwards slightly opened to admit the younger diabase, or black dike. Eruptions of earlier hornblende-andesite and of augite-andesite afterwards occurred, which probably produced fractures and dislocation in the eastern portion of the diabase, but have left no traces of action on the COMSTOCK fissure. The country was subsequently so eroded as to reduce the surface of these four rocks to a gently sloping plane, with an inclination of a little more than two degrees to the west. After the commencement of the dry period (dry, that is to say, so far as this region was concerned) a great movement began, which may possibly have been a sinking of the hanging wall, but was more probably a rise of the foot wall. This dislocation involved an enormous friction, one result of which was a separation of the foot wall and the hanging wall for a long distance from the fissure into sheets parallel to it. A secondary effect of the same force was to form innumerable cracks in these sheets nearly perpendicular to their partings. The edge of the east country necessarily assumed the form of a wedge, and was broken completely through at a point a few hundred feet below that at which the primary fissure reached the surface. The total dislocation amounted to a little less than 3,000* feet, measured on the dip of the fissure; but the movement was not effected continuously. After the secondary east fissure had been opened, large masses of ore-bearing quartz were deposited by alkaline solutions of carbonates, sulphides, and silica flowing in from the east country. These were subsequently crushed by renewed

* This is distributed both in east and west country. At and near the *Sutro Tunnel* section, any point on the hanging wall of the fissure was originally opposite a point about 1,500 feet higher up on the foot wall, the distance being measured on the dip.

movements of the walls. The nature of the ore-bearing solutions and of their contents no doubt varied from time to time. It is evident that currents following the same channels would gradually exhaust either the metalliferous minerals exposed to their action or the supply of the necessary alkaline solvent, and that a renewed movement would open up fresh material to attack. Pressure, too, if not temperature, may have varied from time to time. This necessary variation in the process of extraction sufficiently accounts for the great variety in the grade of the ore.

Most of the ore-bodies which have hitherto been discovered are situated in the east fissure. From the very nature of the case this opening must have been exceedingly irregular. Above it lay only the shattered edge of the east country, approximately retaining its position only by gravity, while the mass of the east and west country were both in motion. The deposition of ore in this fissure was no doubt dependent upon the disposition of openings, and it appears to the writer a hopeless attempt to reduce to order, either *a posteriori* or *a priori*, the openings which may have been left in this fissure at different stages of the fault. In a very general way they would have been more likely to occur opposite ravines than opposite ridges. And in an equally general way such was the distribution of the ore-bodies in the east fissure. Two of the most important bonanzas have been found below the junction of the east fissure and the lode. One of them was in the *Crown Point* and *Belcher*, and the other was the famous body of the *California* and the *Consolidated Virginia*. The former appears to have been deposited in one of the ordinary lens-shaped openings which so frequently occur in all veins from a slight nonconformity of the walls. The latter appears to have had a somewhat different origin. A portion of the foot wall seems to have given way at this point, carrying a large amount of rock from the hanging wall with it, and the ore has been deposited in the space thus formed. Of course, the space referred to was not actually empty, but was filled with fragments, leaving considerable interstices between them. These fragments, however, after decomposition, acted as absorbents for the mineralized solutions, and became charged with argentiferous minerals. For the most part (with entire propriety) they have been mined and milled as ore.

No warning can be had of approach from above to a body of this character, because the attendant phenomena will be found below the ore, as in this case; and such bodies may occur at almost any point on a vein of which the hanging wall is like that of the COMSTOCK. Openings of a related character, however, may not improbably occur at the bottom of masses of broken and dislocated rock. An enormous volume of such material exists at the contact of the diabase and the diorite all the way from the *Gould & Curry* to the *Sierra Nevada;* and nothing would be less surprising than the discovery of one or more ore-bodies at the lower portion of this mass. Perhaps the quickest way to reach them, if they exist, would be to sink immediately to the lower portion of the mass, where they are most likely to be found. Attendant upon the ore-bodies, and to the east of them, though perhaps somewhat below them, there will probably be areas of the east country more heavily charged with pyrite than usual, as has been the case opposite former bodies. The flooding of the Gold Hill mines during the past winter unfortunately prevented an examination of their lower levels, and nothing can therefore be said as to their probabilities.

The COMSTOCK is likely to be an ore-bearing vein as long as it continues to be the contact between a large body of diabase and the older rocks. Should a point be reached at which the diabase contracts to a narrow dike between diorite walls, the prospects will be less hopeful; but such a point, if it exists, may be many thousands of feet below the present workings.

On the *Occidental* lode scarcely any work was done during the progress of this investigation, and no considerable examination could be made of it. Its croppings are laid down on the map mainly to exhibit their remarkable parallelism to the COMSTOCK, and for the sake of consequent inferences as to the structure of the whole intervening country. That the *Occidental* lode dips to the east at an angle similar to that of the COMSTOCK is certain, but whether the barren stringer cut by the *Sutro Tunnel* is really the *Occidental* lode is perhaps not unquestionable, nor are there any means known to the writer of settling this point until it has been more extensively explored.

PHYSICAL INVESTIGATIONS.

It is well known that Fox, Reich, and others made experiments of great interest upon the electrical phenomena of ore-bodies. Bernhard von Cotta earnestly recommended* that these experiments should be further pursued, as they seemed to him likely to lead to results of practical importance in the discovery of ore-bodies. If this recommendation has ever been followed out, no account of the investigation has been published. It was the writer's earnest desire to see the subject pursued, and Dr. Barus was invited to join the survey on account of his special fitness for this inquiry. All the plans and details of the electrical surveys made are due to Dr. Barus, the general scope of the work and the localities only being prescribed; and a résumé of his results is given below in his own words. Neither of the localities chosen were the best possible for the purpose. It was evidently necessary in such an inquiry to begin by the examination of ore-bodies already exposed. At the date of the examination there was very little ore in sight on the COMSTOCK. At Eureka large bodies of ore were exposed, but being in an oxidized

* Erzlagerstaetten, part I, p. 238

condition would be likely to give weaker currents than sulphides of similar quantity and distribution. These two localities, however, were the only ones practically available, and at the same time accessible through extensive workings. The results are nevertheless of great interest, and a considerable advance has been made towards a solution. It is one of the plans for the future to repeat these experiments under more favorable conditions. Dr. Barus also gives a summary of the experiments which he carried out on the subject of kaolinization, and which have been sufficiently alluded to in a foregoing paragraph.

ON THE ELECTRICAL ACTIVITY OF ORE-BODIES.

The discovery of local electrical currents in metalliferous veins is due to Fox. The remarkable results contained in his original paper (1830) suggested a series of subsequent experiments made by Fox himself and Henwood in England, von Strombeck and Reich in Germany. In all of these, however, the results contained refer principally to the currents observed on joining with the prolonged terminals of a galvanometer two points lying at different distances apart on the same or different metalliferous veins.

Special mention is due to a second paper of Reich (1844), insomuch as the author assumes that lode currents are hydroelectric, that contiguous ore-bodies (or different kinds of ore in the same body) and the country rock have the same relation to each other as the metals and liquid of an ordinary galvanic cell, and that therefore—this is his main point—currents must exist in the rock itself. It would follow herefrom that important practical inferences might be drawn from a careful study of the latter, and it was with this conviction that Reich made a number of experiments. Unfortunately he did not pursue his argument into its full consequences.

After this, further study of the subject seems to have been altogether abandoned; at least a published account of an attempt to advance our knowledge in this direction could not, with some pains, be found. We can hardly suppose, however, that during this long interval of upwards of 37 years no experiments should have been made. The matter is rather to be ascribed to the necessary non-concordance of interpretations made from purely qualitative results, with facts.

* * * * * * *

The problem offered is not apparently a difficult one, and consists simply in determining the variation of earth-potential at as many points within and in the vicinity of the ore-body as may be desirable; or, in other words, of tracing the equipotential surfaces in their contour and position relative to it.

We are, however, able, *a priori*, to systematize the method of research. In the first place, the hypothesis that lode-currents, if present, are due to hydroelectric action is quite a safe and natural one. It is known that a number of ores—especially sulphides—possess metallic properties. The presence of two or more of these in the same ore-body is not an uncommon occurrence, and we are justified in anticipating electric action at their surfaces of contact. The currents thus generated have a very close analogy to those technically known as "*local currents*" in batteries, and which are due to impurities in the zinc.

In the second place, it is obvious that if currents are met with in a region of ore deposits, such currents, insomuch as electrical action has been going on for an indefinite period of time, must be *constant*, both in intensity and direction. The equipotentials corresponding to this flow will, therefore, have fixed and invariable positions relative to the ore-body.

Suppose, now, that from a point remote from the ore-body a line has been drawn towards it and prolonged beyond to about the same distance. It is not necessary for the present consideration that this line should actually pierce the deposit; only that certain of its parts are sufficiently near ore, and more so than its extreme points, and that it lies wholly within or upon the surface of the earth.

Suppose, moreover, that the ores are so associated as to generate electrical currents.

If, then, we commence at one end of our line and determine the values of earth-potential at consecutive, approximately equidistant points, it is obvious, insomuch as we pass *by* the seat of an electromotive force, or, in other words, *through* the field of sensible electrical action, that our progress from one extremity of the line to the other must be accompanied by a passage of the values of earth-potential corresponding, through a *maximum* or *minimum*, or both, or a number of such characteristic variations. In short, we may regard the earth-potential at any point as a function of the distance of this point from the assumed origin of our line. The assertion that this function will pass through a characteristic change of the kind specified is only another way of expressing that our line may be chosen so long, that in comparison with its extent, the field of sensible electrical action will be local, or its linear dimensions in the direction in question small. *Maxima* in a general sense are, therefore, to be regarded as criteria, and as indicating the part of the line nearest to the electrically active ore-body.

This is about the idea underlying the experiments made in the bonanza mines on the COMSTOCK LODE, Nevada, and in those of the *Richmond* Company, Eureka District, Nevada.

Practically, since we possess no means of measuring potential absolutely, it will be sufficient to assume a value (zero) for one of the points of our series. The electromotive force between this and any of the other points is then the potential of the latter.

In making the actual measurements, the simple problem above enunciated became quite complicated, because the small lode-electromotive forces were distorted by a number of errors, which in the aggregate might possibly produce an effect in the same order. On the COMSTOCK, where the mines at the time were, without exception, working in very barren parts of the vein, no definite evidence of currents due to the lode itself was obtained. But even at Eureka, in spite of the enormous ore-bodies in sight, the range of variation of potential, corresponding to a distance of 2,000 feet, in the underground experiments very rarely reached 0.1 volt; whereas usually this variation lay within a few hundredths volt. These limits, in a case where we have to do with such disturbances as action between terminals, polarization, earth currents (normal), bad insulation of circuit at any point, difference of potential between liquids in contact, incidental effects due to masses of metal—machines, tracks, turn-tables, water and air pipes, etc.—distributed throughout the mine are to be considered as comprehending a rather dangerously small interval. This matter is to be attributed to the *earthy* character of the Eureka ores. For the manner in which such discrepancies were to a large extent eliminated, the reader must be referred to the forthcoming report.

By way of example, the results obtained on the 600-foot level. west drift, *Richmond* mine, where the circumstances were particularly favorable, will be graphically given. The consecutive points tapped may be regarded as lying on a horizontal straight line, extending in an east-westerly direction.

In the following figure, distance in *feet* is given as abscissa, the corresponding value of earth-potential in *volts*, as ordinate.

The line of points lay completely *out of* the ore-bodies, the latter occupying positions above and to the south of it, at a mean distance of several hundred feet, and extending from east to west about as far as is indicated by the *heavy* black line below the curve. This line of electrical survey passes from shale, probably free from ore, at its westernmost extremity, into limestone, encountering therein a region of electric action to be attributed to the ore-bodies; but it does *not* pass through this region, local circumstances preventing. If we pass from west to east on the dotted prolongation of the heavy black line just mentioned, we shall find ore all along our path and finally get into the immense deposits of the *Eureka Consolidated* Mining Company.

Contact with the earth was secured at the points tapped by means of a closed bag of beefgut, containing a solution of zinc sulphate into which a strip of amalgamated zinc, forming the terminus of the metallic circuit, had been introduced. The bag during the experiments was placed in a suitable cylindrical hole drilled in the rock and filled with water. These terminals were exchanged twice for each observation.

It is to be especially borne in mind that with the exception of the first, in shale, the holes were in solid rock, in limestone throughout—a matter which has been indicated by the dotted line above the curve.

The results for earth-potential, now to be given, are the means of two independent *sets* of observations, the second of which was made at an

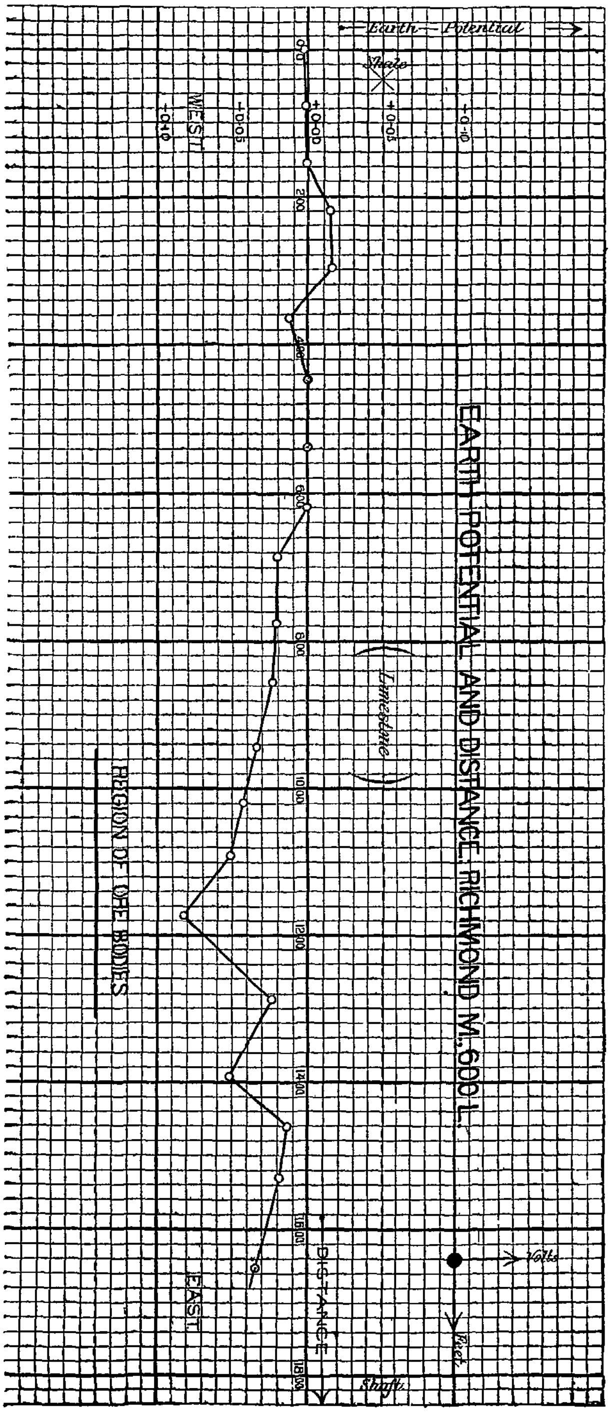
EARTH POTENTIAL AND DISTANCE, RICHMOND M. 600 L.
Earth Potential
Shale
Limestone
REGION OF ORE BODIES
WEST
EAST
DISTANCE
Volts
Feet
Shaft
−0·10
−0·05
+0·00
+0·05
+0·10
200
400
600
800
1000
1200
1400
1600
1800

FIG. 24

interval of 130 days after the first, and agreed fairly with it. A variety of methods of measurement were employed.

The irregular progress of the curve is not due to such errors as might be supposed to result from the accidental condition of the holes in the rock. It was proved by using suitable terminals (bladders, otherwise like the above), which were allowed merely to *recline* against the walls of the drift, that the progress of the values of earth-potential in passing from hole to hole is *continuous.*

It is safe to regard this curve as containing an unknown disturbing effect, superimposed on the larger electrical effect due to the ore-body itself.

In the experiments thus far made, the variation of potential along a *single* line of electric survey only has been determined. It is obvious, however, that in order to derive the full benefits from such a method a number of these surveys must be co-ordinated. We should endeavor by passing toward and from the ore-body, in *all* directions, actually to determine the contours and position of the equipotential surfaces. It is not improbable that the interpretation of these results would give us clews for the economical exploitation of the mine, comparable in value to those of a purely geological character. Both should go hand in hand. Under ground, this general method of research is not always feasible, as it presupposes the mine to have been already widely exploited. On the surface of the earth, however, it may to some extent be applied. We here endeavor to obtain the traces of the equipotential surfaces on the former.

Suppose, for instance, that the potential at every point of a given part (several square miles) of the earth's surface were known. Then let this surface be projected on a fixed horizontal ("*X Y*") plane, and the value of earth-potential corresponding to each of the points be constructed as "*Z*." In this way we will obtain a new (*potential*) surface, coextensive horizontally with the first.

Terrestrial electrical action would manifest itself upon our new surface *as a whole* and would, not affect its regularity. *Local* action, on the other hand, would produce an effect local and circumscribed in comparison with the horizontal extent of the area under consideration. We should expect to find a *hillock* or *depression*, or both, or a number of these variegations in our imaginary potential surface.

The experiments made cannot be said to have settled the question as to whether lode currents will or will not be of practical assistance to the prospector. Indeed, we cannot as yet even assert with full assurance that the currents obtained are due to the ore-bodies. We have simply observed a local electrical effect, sufficiently coincident in position with the ore-bodies themselves to warrant us to some extent in assuming that these contained the cause.

They certainly, however, give high encouragement to further research in this direction.

ON THE THERMAL EFFECT OF KAOLINIZATION.

Mr. Church has endeavored to account for the heat of the COMSTOCK LODE by assuming a *thermal* effect of kaolinization.

This view is new and ingenious, but unfortunately purely speculative; for while, on the one hand, there is no direct evidence to support it, we have, on the other, to do with a process so complicated, so little understood, that there is abundant room for difference of opinion.

To avoid ambiguity and vagueness, it will be well to give a *quantitative* signification to the effect in question at the outstart. We will define the thermal effect of kaolinization (abbreviated *T. E. K.*) as the quantity of heat generated by the action of aqueous vapor on the unit mass of the given feldspathic rock in the unit time. With this understanding, *T. E. K.* is then to be considered as a function of the percentage quantity of feldspar originally contained in, and the temperature of the given rock, as well as of the time during which the action has been going on. *A priori*, *T. E. K.* may be either positive, zero, or negative.

The above theory having been enunciated in connection with the heat of the COMSTOCK, it became necessary to endeavor to see in how far its fundamental principle (*i. e.*, *T. E. K. positive*) was in agreement with facts. In the second place, however, such a research was desirable because of the intrinsic interest which attaches to it.

Considered from a physical point of view, the question is quite a difficult one, and of a kind in which satisfactory results can only be reached by a process of gradual and laborious approximation. As *T. E. K.* will probably, even in the final experiments, escape detection, the problem may be more accurately said to consist in reducing the limits (respectively positive and negative) within which *T. E. K.* must lie to the smallest interval possible. Under all circumstances a mathematical analysis, based on some rational assumption of the dependence of *T. E. K.*, for a given rock, on time and temperature, and utilizing the limits just mentioned, will be the last resort.

Our object, therefore, in making the qualitative experiments, briefly to be reviewed herewith, was more that of obtaining a precursory view of the difficulties which present themselves in actual practice than that of obtaining results of a decisive character.

In processes of the kind before us, the action may usually be *accelerated* by increasing the temperature at which it takes place; provided, of course, the latter is not chosen so high as to interfere with the products of decomposition resulting in a normal case. The idea was, therefore, to act on the rock with steam at a temperature from the boiling point of water upward. But, with the primitive facilities at our disposal in Nevada, the experiments with superheated steam had to be abandoned.

The apparatus in which the rock was subjected to the action of steam

(Fig. 25) so closely resembles that usually employed for the determination of the "boiling point" of thermometers that but a brief description will be necessary.

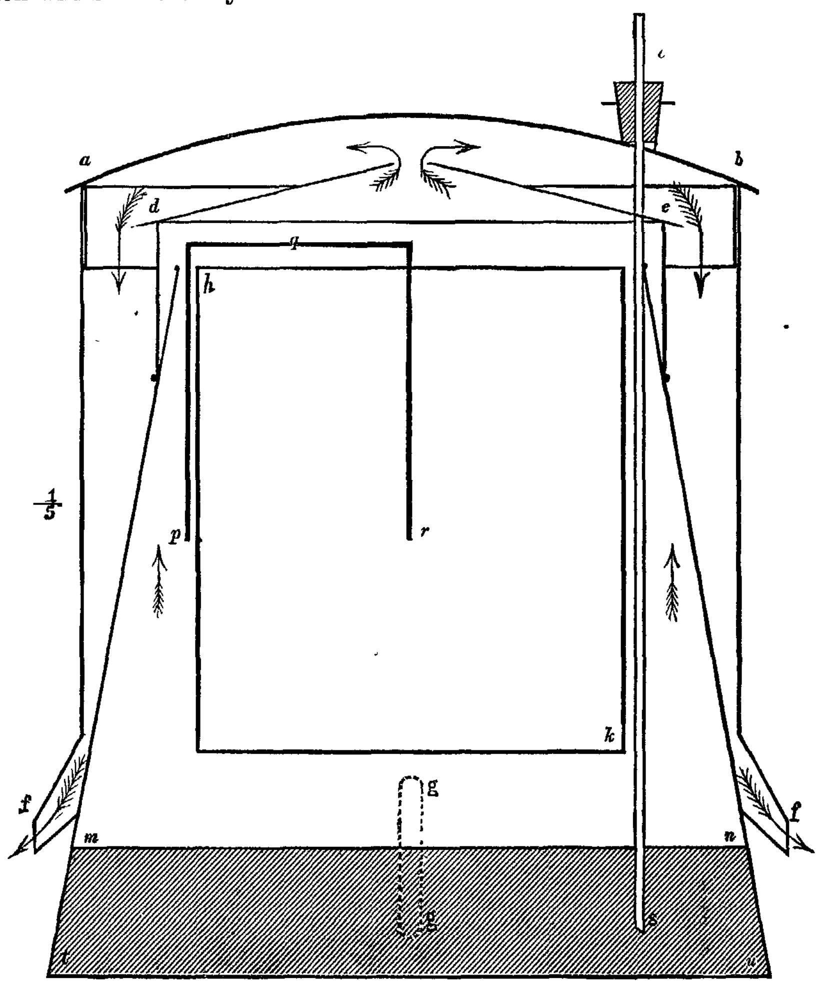

FIG 25 —Boiler used in kaolinizing

Steam is generated in the interior conical compartment *tdoeu*, the lid *doe* of which is removable from water to the level *mn*, and passes through the hole *o* into the exterior compartment *fabf'*, jacketing the former, thence through the tubulures *f* and *f'* into the air. The lid *ab* can also be removed. The whole boiler is, moreover, covered with a thick (¾–1 inch) layer of cotton batting. In the interior compartment, finally, the cylindrical receptacle for the rock *hk*, open at its top, having a properly strengthened wire-gauze bottom, and supported on a suitable tripod (not shown), is situated.

The rock to be acted on was crushed fine and packed into *hk* tightly, so that the atmosphere of steam enveloping it could reach the interior by a process of *diffusion* only, and that convective action from currents of steam passing through *hk* was not to be apprehended. The object was, in short, to allow the heat, possibly generated in the mass of rock in consequence of kaolinization, to accumulate.

The difference of temperature between the interior of the rock and that of the steam surrounding it was determined by the aid of a thermopile, *p q r* (terminals omitted), consisting of three bismuth-platinum couples. The influence of fluctuations of the barometer—the increment of temperature of the junction *r*, in consequence, lagging behind that of *p*—may, in a long series of experiments (number of weeks), be eliminated mathematically.

If *a* and *b* are constants, *e* the thermoelectromotive force corresponding to the temperatures *T* and *t* of the junctions *r* and *p*, respectively, we may put

$$T-t=\frac{e}{a+b\,(T+t)}=\frac{e}{a+2\,b\,t},$$

since *b* is very small. *t* is calculable with sufficient approximation from the mean barometric height during the interval in which the experiments are made. Usually 2 *bt* is negligible (correction). *e* was measured by a method of compensation; *a* and *b* frequently rechecked; but it is undesirable to go into the diverse details necessary in measurements of this kind here. The whole enabled the observer still to detect a variation of $T-t$ as small as 0·001° *C*.

The boiler was heated by two petroleum stoves (each containing two broad wicks), which could be replenished with oil, etc., without interfering to an appreciable extent with the flames. The water lost by evaporation was re-fed into the apparatus, drop by drop, through the tube *cs*, by means of a pneumatic arrangement (not shown) placed on the lid *ab*. A vertical glass tube, *gg*, the ends of which were in communication with the water and steam, respectively, of the interior compartment, indicated the height of the water-level.

The whole aim was to make the process a *continuous* one, and had it not been for accidents the nearly constant source of heat and nearly constant water-level would have enabled us to keep up an ebullition of nearly constant intensity for an indefinite period of time.

The rock used was earlier diabase from the hanging wall of the LODE collected in the main *Sutro Tunnel*. It had undergone only a trifling amount of decomposition.

The experiments were continued during an interval of nearly *five* weeks, unfortunately with an accident between the first and second, and another between the second and third. On the average, three observations of $T-t$ were made during each twenty-four hours.

In order to derive a comprehensive view over the large number of data obtained it will be sufficient to assume the empirical relation,

$$T-t=\alpha+\beta\chi$$

where α and β are constants to be calculated by the method of least squares, χ the time in hours corresponding to any particular $T-t$, and dated from the commencement of the series of experiments to which the results belong. Under variation of α, an apparent thermal effect not due to kaolinization may be conveniently understood.

For α a mean value of $-0.05^{\circ}C$ was found. The interior of the rock was, therefore, invariably *colder* than the surrounding steam. It follows, also, that it is impossible, even after the lapse of a great interval of time, to heat so large a mass of material to an equal temperature throughout. The variation of α will add itself algebraically to β; and unless the *T. E. K.* produces a comparatively large result, will entirely vitiate the signification of the latter constant.

β gives us nominally the rate of increase of the temperature of the interior of the rock in consequence of a *T. E. K.* Instead of reporting β however, it will be more perspicuous to give the corresponding rate B referred to a *year* as the unit, viz:

$$B=876_5\,\beta.$$

For reasons which will appear in the report, the experimental material may be conveniently divided into two halves. In the first of these was found,

$$B=+1^{\circ}.5\pm0^{\circ}.1$$

in the second,

$$B=-0^{\circ}.9\pm0^{\circ}.1.$$

Herefrom it appears that the variation of α alone was observed. The values of B are to be regarded as an *index* of the errors incident to the method in its present form, and it is moreover probable that the effect of kaolinization is negligible in comparison therewith.

The limits set for the present article preclude a discussion of this abnormal behavior of B. It may be well to add, however, that the experiments made have suggested the following mode of attacking the question:

A and *B* (Fig. 26) are two strong hermetically sealed receivers of metal similar in every respect and capable of withstanding great internal pressures. With the exception of the cavities α and β below, both are completely filled with the same quantity of finely pulverized feldspar, this material being tightly packed. Into α a little water has been introduced, so that the whole space *A* is at all temperatures thoroughly permeated with aqueous vapor. *B*, on the contrary, has before sealing been well *dried*, and the interstices between the granules of feldspar contain dry air only.

A and *B* are placed in an appropriately jacketed elongated receiver, *TTT*, through which vapor at the boiling point of the liquid corresponding continually circulates.

A thermoelement can hardly be used with advantage here, as the couple chosen would either be insufficiently sensitive, or else give rise to too many experimental complications. A resistance thermometer* has therefore been substituted. The bridge adjustment, diagrammatically added, explains itself.

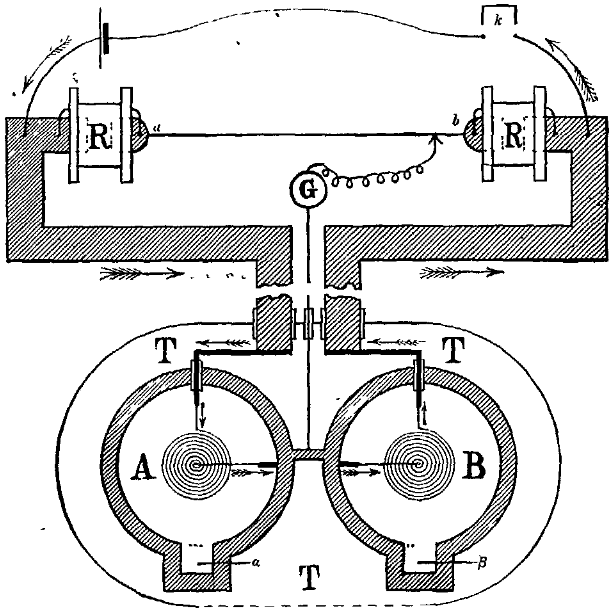

FIG 26.—Proposed apparatus for experiments on kaolinization

The wire *ab* (for interpolation) had best be wrapped, after the ingenious manner of Kohlrausch, on a correspondingly grooved cylinder of serpentine, whence it projects outward much like the threads of a screw. In this way the apparatus becomes more compendious, and the whole may be easily so modified as to admit of complete submersion in an oil bath. *R* and R^1 are adjusted so as to correspond to the approximately equal resistance (fine platinum wire) in *A* and *B*, and the whole problem is reduced to a measurement of lengths, etc.

The method just described is advantageous in the following respects:

1. Both electric thermometers (respectively junctions of the thermoelement) are placed in and heated under circumstances as nearly *identical* as practicable.

2. The thermometer is in very *intimate* contact with the pulverized feldspar.

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*Confer remarkable results of Prof. S. P. Langley, Beibl. 3, 1881, p 191. Chem. News, 43, 1881, p. 6 & 7; Am. Journal, March, 1881, p 187. The problem which Professor Langley proposed to himself is, however, somewhat different from the one occurring here It will be remembered, moreover, that the difficulty encountered in the present case is more that of obtaining a sufficiently *constant* temperature than of measuring the same.

3. *T. E. K.* may be studied in its relation to temperature. (*Confer* remarks above.) To this effect the region $T\ T\ T$ is to be heated consecutively with steam (100°C.), aniline vapor 185°, etc.

4. A disposition by which CO_2 may be allowed to act on the rock simultaneously with aqueous vapor is easily made.

5. Although a change of mechanical state ("after-action") of the spirals in A and B is of more serious consequence here, than in the case of a thermoelement, we have on the other hand the advantage of being able to examine each of them electrically, while the experiment is in progress.

PRODUCTION OF THE PRECIOUS METALS

IN

THE UNITED STATES.

BY

CLARENCE KING.

LETTER OF TRANSMITTAL.

NEW YORK, *November* 1, 1881.

Hon. J. W. POWELL,

Director of the U. S. Geological Survey, Washington, D. C.:

SIR: I have the honor herewith to transmit a tabulated statement of the production of the precious metals in the United States for the census year, between June 1, 1879, and May 31, 1880. This statistical statement is offered in advance of my report upon the production of the precious metals on account of its immediate interest to legislators, financiers, and metallists. It will form the concluding chapter of a forthcoming volume devoted to the technological aspect of the precious metal industry. That volume will contain an elaborate discussion of the distribution of precious metal mines and their methods of exploitation, together with abundant data on the mechanical, chemical, and metallurgical processes employed in the industry, all classified and treated from a statistical point of view.

For the purposes of the present publication, it is only necessary to report the organization and personnel of the investigation.

The general direction of this branch of the census inquiry was committed by the Superintendent of Census to the undersigned, then Director of the United States Geological Survey.

For purposes of convenient administration, I divided the United States into three leading divisions:

The division of the Pacific, consisting of the States of California, Nevada, and Oregon, and the Territories of Arizona, Idaho, Utah, and Washington; an area made up of the States and Territories bordering on the Pacific Ocean and the political divisions of the Great Basin. The leading reason for this arbitrary grouping of political divisions is that they are for the most part tributary to the great mining center of San Francisco. A very large portion of the capital employed and of the personal ownership center in San Francisco, which is also the source whence the greater part of the mining machinery, appliances, and materials are drawn.

PERSONNEL OF THE PACIFIC DIVISION.

The headquarters of this division was placed in San Francisco, and the direction of the work confided to Mr. George F. Becker, United States Geological Survey, geologist in charge of the Pacific division.

Mr. J. M. Cunningham, for the eastern portions of Washington and Oregon, and the northeastern part of California.

Mr. J. S. Curtis, Nevada, south of the line of the Central Pacific Railway.

Mr. J. H. Hammond, central and eastern counties of California.

Mr. D. B. Huntley, Utah, Southwestern Nevada, and portions of California.

Mr. H. W. Leavens, the tract lying west of the Cascade and Coast ranges in Washington, Oregon, and Northern California.

Mr. Walter Nordhoff, Southeastern and Middle Arizona.

Mr. H. W. Sander, Western Arizona.

Mr. Luther Wagoner, Southern California.

Mr. Albert Williams, jr., Idaho, Nevada north of the Central Pacific Railway, and the Comstock lode.

PERSONNEL OF THE DIVISION OF THE ROCKY MOUNTAINS.

The division of the Rocky Mountains adjoins the division of the Pacific on the east, and extends eastward as far as the 100th meridian, including the State of Colorado and the Territories of Dakota, Montana, New Mexico, and Wyoming. At the head of this division was placed Mr. S. F. Emmons, United States Geological Survey, geologist in charge, with headquarters at Denver.

Mr. W. B. Fisher, portions of Lake, Chaffee, Clear Creek, and Gilpin Counties, in Colorado, and Beaverhead County, in Montana.

Mr. William Foster, Montana and Wyoming.

Mr. J. E. Hardman, the smelting works in Lake County, Park and Summit Counties, and portions of Clear Creek and Gilpin Counties, in Colorado.

Mr. Charles Potter, New Mexico.

Mr. E. H. Schaeffle, Dakota and portions of Colorado.

Mr. W. G. Sharp, San Juan, Hinsdale, Gunnison, La Plata, Huerfano, Ouray, and Rio Grande Counties in Colorado, and portions of New Mexico.

In addition to the census experts the following-named gentlemen acted as temporary assistants: Messrs. Herman Garlichs, J. C. Hine, H. B. Price, H. L. Simmons, and W. H. Whittlesey, in Colorado, and W. F. Wheeler, in Montana.

PERSONNEL OF THE EASTERN DIVISION.

The eastern division comprises the whole territory lying east of the 100th meridian. Prof. Raphael Pumpelly, United States Geological Survey, was placed in charge, with headquarters at Newport, R. I.

Mr. George H. Eldridge, Southern States and reduction works east of the 100th meridian.

Prof. N. S. Shaler, with the assistance of Messrs. Joseph M. Wilson and J. E. Wolff, New England States.

To each of these three chiefs of division was committed the responsibility of choosing his own assistants, who were in due form appointed by the Superintendent of Census as special experts.

All the leading precious-metal districts of the United States were visited by the corps of experts, and their observations were entered in the field upon a uniform system of printed schedules.

The following list shows the number and character of reports returned, which form the basis of the statistical tables in this publication:

Deep mines	1,967
Placer mines	325
Amalgamating mills, concentration works, chlorination and leaching establishments	327
Smelting works	86
Arrastras	25
Total number of reports	2,730

The entire work of compilation and tabulation has been performed under the personal direction of Mr. Albert Williams, jr., special expert in charge of compilation.

Very respectfully, your obedient servant,

CLARENCE KING.

PRODUCTION OF THE PRECIOUS METALS.

By Clarence King.

METHOD FOLLOWED IN COMPILATION.

Three principal methods have been adopted by statisticians in studying the bullion production of the United States.

The first and most obvious plan has been to use as a basis the receipts of domestic bullion reported by the several mints and United States assay offices, ascertaining the probable total product by adding to the figures thus obtained the amount shipped abroad, as shown by the custom-house returns, and the probable amount consumed in the arts. The objections to this method are: The amount coined within a certain period does not necessarily correspond to the production for that period. In the same way the proportion of the domestic product exported may be largely affected by the stock of precious metals on hand at any given time. Both of these variations depend primarily upon fluctuations in the bullion market and international balance of trade. An average of a long series of years would give tolerably accurate results, but for any stated period, the figures of coinage, export, and consumption in the arts are apt to be deceptive.

Assuming the source of the bullion deposited at the mints to be correctly stated, there are still serious and unavoidable defects in the custom-house statistics, notwithstanding the care taken to secure accuracy. No account is taken of bullion transported overland into Canada, nor are the export figures for doré bullion, base bullion, ores, and matte shipped abroad always to be depended upon. This difficulty is particularly manifested in the last three instances. The regulations prescribed by the custom-house authorities are not followed by penalties sufficient to insure accurate invoicing of the values thus exported. It is well known that during the period of intense speculation in gold a very large proportion of both receipts and exports even of gold coin was entirely hidden from official scrutiny, with a still greater margin in the bullion movement; and although the inducements to a concealment of the actual movement do not now exist in the same force, it is still doubtful whether the official figures are entirely reliable. A less important source of error is the undisputed fact that not infrequently bullion of domestic production, after having been shipped abroad, is, from changes in the silver-bullion market or from the necessities of coinage, reimported into the United States.

It will thus be seen that the best results which can be hoped for from the most careful application of the "consumption and export" method are close approximations extending over considerable periods, but not the exact product for any given year. The system also fails to segregate the yield according to the productive source; and while the geographical distribution by State and Territorial lines may be shown, it is hardly possible to carry the analysis further and ascertain in this way the yield of single districts or even counties.

The Director of the Mint has examined the bullion product of the country critically from the "consumption and export" point of view, employing as a supplementary means of information the details obtainable by correspondence and circulars scattered through the mining districts. The substantial accuracy of the estimates of the total production thus reached has been fully borne out by the results of the present investigation.

The second, or "transportation," method consists in estimating the product from the statistics of the express companies, freight lines, and banks which have the handling of the product from its original sources. This plan would give more satisfactory results if, in the first place, all the bullion, ores, etc., were transported from the producing points through these different channels alone; and if, in the second place, none of the product were reshipped from point to point, and thus twice recorded. As a matter of fact, there is a considerable portion of the gold yield sent through the mails as registered matter, and a large proportion passes from the productive source into the market through private channels. Both of these means of conveyance are affected by proximity to main lines of communication, or, on the other hand, by the absence of express or railroad facilities; and in neither can the exact effect of these circumstances be very definitely counted upon. In the Pacific States and Territories the great bulk of the mine output is handled by Wells, Fargo & Co.'s express, and upon the detailed returns of the many offices of this company Mr. J. J. Valentine, general superintendent, has been enabled to furnish very valuable estimates of the bullion production, covering a long series of years. The business connections of this express company in portions of the country not covered by their agencies have rendered it possible for Mr. Valentine to frame approximate estimates of the product of the mining territory outside of that from which Wells, Fargo & Co. are the principal transporters of bullion. But the impossibility of assigning to other channels the due proportion of the outflow through them; the fact that no record is made of the value of the gold bullion and dust sent through the mails; that no reliable allowance can be made for the undervaluation of gold dust and unassayed bullion by consignors, amounting in many cases to from five to ten per cent.; that there is no satisfactory means of checking the reshipments which are twice or more times recorded, combine to create a large margin which can hardly be definitely accounted for in making the total estimates. The looseness in the distinction observed between silver bullion and doré metal allows a considerable portion of the gold contents of doré bullion to escape the record, the whole value of such bars often being credited to silver; while, on the other hand, of course no account is taken of the value of the silver alloyed with placer dust and gold bullion, though this is a less important source of error. Notwithstanding these palpable but unavoidable defects in the system, much credit is due Mr. Valentine for the painstaking care with which he has prepared his annual estimates.

The third system is one which, were it practicable to pursue into complete details, would lead to results more satisfactory than could be obtained in any other way. This may be termed the direct method. It would consist, if properly carried out, in obtaining from each bullion producer a statement of the quota contributed. The aggregate of the details thus reached would represent the actual total product of the country, and would, moreover, segregate it according to districts. In the census work conducted by the United States Geological Survey, the plan indicated has been followed to as minute detail as it was possible to extend it with the means at command. No attempt had ever been previously made which aimed at securing individual returns throughout the whole United States with the same degree of thoroughness; though the successful adoption of the direct method by Mr. A. Del Mar, in his investigation of the silver product of Nevada in 1876, showed the advantages of the plan. But even with all the care and time expended by the experts engaged in collecting these statistics, it was found to be impracticable to do more than obtain returns from the larger producers. In some instances well-based and careful estimates were submitted by the experts, covering aggregates of a large number of small mines, for whole districts. In other cases, and more especially so in portions of the country where placer-mining on a small scale furnished a large proportion of the yield, reliance had to be placed on extraneous data.

The chief obstacles encountered in the collection of bullion statistics directly from the producers were—

First. The wide extent of the field to be covered, and the vast number of mines to be reported upon. Even were the mines located in easily accessible places, the wide range of territory over which they are scattered would render the labor of personally visiting each productive district a tedious matter. But when it is considered that they are for the most part to be found in rugged mountainous tracts, often at high altitudes, and, when destitute of railroad communication, to be reached only by stage or on horseback, some idea may be gathered of the amount of work involved.

Second. The fact that a considerable yield is derived from small mines, the product from each of which, however insignificant in itself, goes to form part of an important aggregate, and should not be neglected.

Third. The reluctance of some mine owners and superintendents to give a full account of their operations, notwithstanding the strictly confidential manner in which these individual statements have been treated. On explanation of the purposes for which the statistics were collected, such objections were in most cases overruled, however, and invariably great courtesy was personally manifested.

Fourth. The fact that in a large majority of cases no systematic accounts are kept by mine owners, who were often unable to state from memory the precise output of their properties for a period which had elapsed some time before the inquiry was made.

Fifth. Many mines having changed hands during the census year, it was frequently impossible to obtain from the present holders a statement of the operations conducted prior to the change in ownership, or to communicate with the former owners if they had removed.

Sixth. When in the case of mines worked during only a portion of the census year, or during a season limited by the weather, water supply, or other causes, operations had been suspended at the time the district was visited by the examining expert, it was often impracticable to communicate with the only persons able to supply information.

Seventh. The variation in the fiscal year of the incorporated companies makes it a matter of much difficulty to reduce the returns to a different period from that for which the books are kept.

With means still less adequate than were lately at command, the census authorities in 1870 found it impossible to trace the bullion product of the country at that time. The best results reached by the deputy marshals in certain instances hardly amounted to a moiety of the actual product, as known through other sources of information. In the case of the census of 1880, even with greatly increased facilities, there were many gaps in the testimony, which had to be filled out by estimates derived from other data than those collected directly by the experts. Where such estimates have been applied in the tabulation, they have been indicated by an asterisk (*). In all cases a careful scrutiny has been exercised in the selection and comparison of material. It is believed, in view of the more extended and fuller details accessible, as compared with previous researches of the same nature, that the results arrived at in this compilation are as close an approximation to absolute accuracy as it is possible to attain without a far greater expenditure of money and time than the subject demands.

In compiling the material at hand the following system was adopted: The returns given in the individual mine schedules were first abstracted and grouped into aggregates for districts. Information as to the operations of the different establishments being in many cases confidential, publication of the results begins in the census report with the district exhibits, which, in the following pages, have been condensed into tables for counties, and finally into abstracts for whole States and Territories. Where a marked discrepancy existed between the schedule returns and other reliable data, the necessary additions were entered and the fact that they were estimates indicated. It is hardly necessary to remark that the schedules would show deficiencies rather than an excess as compared with correlative data. At the same time the schedules of reduction works were examined, and furnished a valuable check upon the figures derived from the mine reports. In some instances the yield was quoted in ounces of fine metal, as is customary in localities where the ore is reduced by smelting; in others, in ounces of crude bullion, as in the case of placer gold; in still others, in dollars calculated from the assay value of the bullion; and more rarely, in dollars representing the net proceeds after deducting the discount upon silver and other charges. In order to present the whole in harmonious shape, it became necessary to reduce these various denominations to a uniform standard. That adopted is the troy ounce of fine metal and its assay value in United States money. The terms are interchangeable and appear side by side in the tables of production. As a preliminary step a series of conversion tables were prepared.

CLASSIFICATION OF MINES.

Mines of the precious metals are grouped under two comprehensive heads: deep mines and placer mines. The former are workings in primary deposits, in which the ore usually, though not invariably, occurs in a vein, and while the earlier operations in mines of this class may begin at or near the outcrop of the vein, the tendency is always downward. The leading varieties of deep mines are:

1. Mines of free gold, or gold alloyed with a small proportion of silver.
2. Mines of silver ores, containing only traces of gold.
3. Mines yielding doré bullion from milling ores containing both gold and silver in appreciable quantities.
4. Mines yielding base bullion from smelting ores in which the precious metals are associated with larger quantities of lead, copper, etc.

All these divisions shade imperceptibly into each other.

Placer or gravel mines are workings in secondary or fragmentary gold deposits, including gravels and sands, and are either surface or shallow workings. The leading types are:

1. Hydraulic mines.
2. Dry washings.
3. Booming and shovel-sluicing.
4. River mines.
5. Pocket mines.
6. Drift mines.

7. Branch mines.
8. Black sand littoral deposits.

In the tables of production the classification under these two main heads is observed.

CLASSIFICATION OF REDUCTION WORKS.

In some of the following tables a distinction is made between the production as shown by the different reduction works, which, like the mines, are divided into two principal classes. These are, first, amalgamating mills, including—

1. Gold-quartz mills.
2. Mills in which silver ore is treated in the raw state.
3. Mills in which roasting is practiced before amalgamation.
4. Concentration works.
5. Chlorination and leaching establishments.
6. Arrastras.

The second class includes the several varieties of smelting works in which the production of base bullion, matte or speiss is a preliminary step toward the final extraction of the precious metals.

Placer mines, with the exception of pocket mines and branch mines, require no reducing process; and in the two exceptions named the mill process is not always a necessary concomitant; in the former, in fact, but rarely. Various systems of reduction by chlorination and amalgamation have also been applied to black-sand deposits and refractory conglomerates containing placer gold, but not to an extent affecting the general principle of classification here maintained.

[NOTE.—In each of the tables of production and throughout this discussion the following explanations apply:

The short ton of 2,000 pounds is invariably used.

The ore tonnage is stated in gross tons; the assay values are of net tons, without allowance for moisture.

Mint values are assumed in all cases. The weight of bullion is given in troy ounces of fine metal. The gold ounce is taken at $20.671834 and the silver ounce at $1.2929. A statement of the estimated market value of the silver is elsewhere appended.

No account is taken of the value of the silver alloyed with placer gold in the primary production tables, as, with very few exceptions, no allowance is made for it in selling. This is treated of separately and the proper addition made in the final summary.

The bullion yield is given according to the county in which the ore producing it was raised, without regard to the locality where the ore was reduced. This method of stating the product apportions it with reference to the original source so far as it is practicable to trace it.

Were the yield to be credited to the reduction works, Omaha, Chicago, Saint Louis, Newark, New York, and other points remote from the mines, would appear as large producing centers.

Individual estimated amounts are designated by an asterisk (*), and where such estimates form a considerable proportion of the totals the fact is similarly indicated.]

STATISTICS OF THE PACIFIC DIVISION.

CALIFORNIA.

In production of gold California still holds the first place. The vast deposits of auriferous gravel continue to yield largely, though their final exhaustion, in view of the enormous hydraulic operations now being prosecuted, is to be looked for at no very distant day. Previous to the discovery of the Bodie district the placer mines furnished more than two-thirds of the total gold output of the State, but the large yield of that district, amounting to over two and three-quarter millions in gold during the year, in addition to the considerable silver product, has placed the deep mines about on a par with the placers in point of productiveness. The amount of silver contributed by California is relatively small, and comes mainly from two adjoining counties, Inyo and Mono.

There are a larger number of actively working mines in California than in any other State or Territory, as, owing to the settled condition, transportation facilities, and comparative cheapness of labor and supplies, it is possible to mine deposits of lower grade than could be made profitable in localities having less advantages of position. The result is that there are, besides a few large incorporated companies, a great many mining properties worked on the small scale, but still profitably, by individual owners. The collection of accurate statistics regarding these smaller claims is a very tedious and also somewhat uncertain matter. Schedule returns were received from 128 deep mines, 147 placer mines, 57 amalgamating mills, concentration and leaching works, 9 arrastras, and 4 smelting works in this State. These include most of the more important establishments, and are supplemented by general reports covering in some cases whole districts. But, with all the care taken by the census experts to thoroughly cover the ground, the subject was by no means exhausted, and in several cases in the accompanying tabulation resort has been had to information from outside sources.

California furnishes 71.47 per cent. of the total placer product of the United States, and 40.09 per cent. of the total gold product of the deep mines, or 51.38 per cent. of the total gold product of the country (from all sources). The yield in silver, however, is only 2.80 per cent. of the total, California standing sixth in rank as a producer of the latter metal. In proportion to its area, again, California leads in production of gold, with an average of $108.30 per square mile; is sixth in its silver yield of $6.84 per square mile; and third as to its output of both metals, $115.14 per square mile. As the population of the State has largely increased, while the mine production has remained nearly at a standstill for some years, the showing in relation to population is less favorable, the yield of gold being only $19.84, silver, $1.25, and that of both the precious metals only $21.09 per capita, placing California fifth as to gold, and eighth as to silver and the total, in the rank of the States. The prosperity of the State is not, however, dependent upon its mines in the same degree as formerly, agriculture and manufacturing having outstripped the earlier industry.

TABLE I.—CALIFORNIA—*Production of deep mines for the year ending May 31, 1880.*

County	Ore raised during census year.	Average assay value per ton			Total assay value of ore raised during census year.				
		Gold	Silver	Gold and silver.	Gold		Silver.		Total.
	Tons.	Dolls	Dolls	Dolls	Ounces.	Dollars.	Ounces	Dollars	Dollars.
Amador	114,618	14 62	.....	14 62	81,056.4	1,675,585	.....	.....	1,675,585
Calaveras	42,628	10 74	.....	10 74	22,162 1	458,131	.....	.....	458,131
El Dorado	4,520	26 76	.....	26 76	5,832 3	120,564	.....	.....	120,564
Fresno	578	150 00	13 00	163 00	4,194 1	86,700	5,812	7,514	94,214
Inyo	6,714	5 01	69 66	74 67	1,627 0	33,634	361,779	467,744	501,378
Lassen	2,079	21 08	63	21 71	*2,120.2	*43,828	*1,009	*1,305	*45,133
Los Angeles	200	.....	160 00	160 00	.....	.....	24,750	32,000	32,000
Mariposa	16,660	17 10	.....	17 10	13,783 0	284,920	.....	.....	284,920
Mono	57,211	51 95	10 59	62 54	143,772 9	2,972,053	468,826	606,145	3,578,198
Nevada	58,433	21 91	49	22 40	61,937 6	1,280,365	22,328	28,868	1,309,233
Placer	3,000	25 00	.....	25 00	3,628 1	75,000	.....	.....	75,000
Plumas	113,879	9 03	09	9 12	49,773.6	1,028,913	7,848	10,146	1,039,059
San Bernardino	489	20 45	170 90	191 35	483 7	10,000	64,640	83,573	93,573
San Diego	16,513	22 36	.....	22 36	17,862 4	369,250	.....	.....	369,250
Shasta	8,010	*15 96	*13 48	*29 44	*6,182 3	*127,800	*83,533	*108,000	*235,800
Siskiyou	22,290	12 20	44	12 64	13,153.9	271,914	7,217	9,331	281,245
Trinity	800	*35 00	.....	*35 00	*1,354 5	*28,000	.....	.....	*28,000
Tuolumne	10,406	15 11	38	15 49	7,603 9	157,186	*3,094	*4,000	161,186
Total	479,028	18 84	2 84	21 68	436,528.0	9,023,843	1,050,836	1,358,626	10,382,469
Additional production, estimated from transportation statistics	*65,213	*18 84	*2 84	*21 68	59,434.1	*1,228,613	143,248	*185,205	*1,413,818
Grand total	544,241	18 84	2 84	21 68	495,962 1	10,252,456	1,194,084	1,543,831	11,796,287

TABLE I.—CALIFORNIA—*Production of deep mines, &c.*—Continued

County.	Ore raised and treated	Average yield per ton.			Bullion produced from ore raised and treated during census year.				
		Gold	Silver.	Gold and silver	Gold		Silver		Total
	Tons	Dolls	Dolls	Dolls	Ounces	Dollars	Ounces	Dollars	Dollars.
Amador	108, 136	12 49	......	12 49	65, 332 7	1, 350, 546	....	....	1, 350, 546
Calaveras	40, 503	8 58	......	8 58	16, 817 5	347, 650	....	.. ..	347, 650
El Dorado	4, 520	21 21	......	21 21	4, 686 6	96, 880	....	... .	96, 880
Fresno	578	120 00	10 40	130 40	3, 355 3	69, 360	4, 649	6, 011	75, 371
Inyo	6, 714	3 83	35 62	39 45	1, 243 4	25, 704	184, 968	239, 145	264, 849
Lassen	2, 079	16 71	50	17 21	1, 680 5	34, 739	802	1, 037	35, 776
Los Angeles	200	......	147 00	147 00	.. ... .	... ..	22, 740	29, 400	29, 400
Mariposa	16, 660	10 69	..... .	10 69	9, 096 9	188, 050	. .....	... . ..	188, 050
Mono	57, 108	48 44	8 33	56 77	133, 816 6	2, 766, 238	367, 875	475, 626	3, 241, 864
Nevada	58, 433	15 21	33	15 54	43, 000 9	888, 908	14, 737	19, 053	907, 961
Placer	3, 000	20 00	......	20 00	2, 902 5	60, 000	..... .	... .	60, 000
Plumas	113, 879	6 63	06	6 69	36, 536 5	755, 277	5, 608	7, 251	762, 528
San Bernardino	389	....	164 55	164 55	....	....	49, 540	64, 050	64, 050
San Diego	16, 513	14 40	....	14 40	11, 506 0	237, 850	....	....	237, 850
Shasta	7, 880	12 08	*11 34	23 42	4, 605 3	95, 200	*69, 145	*89, 397	184, 597
Siskiyou	22, 290	9 11	31	9 42	9, 830 0	203, 204	5, 273	6, 818	210, 022
Trinity	800	27 50	......	27 50	1, 064 2	22, 000	....	... . .	22, 000
Tuolumne	10, 406	12 32	29	12 61	6, 204 5	128, 260	2, 320	3, 000	131, 260
Total	470, 088	16 10	2 00	18 10	351, 679. 4	7, 269, 866	727, 657	940, 788	8, 210, 654
Additional production, estimated from transportation statistics	*65, 213	*16 10	*2 00	*18 10	*50, 790. 1	*1, 049, 925	*100, 879	*130, 426	*1, 180, 351
Grand total	535, 301	16 10	2 00	18 10	402, 469 5	8, 319, 791	828, 536	1, 071, 214	9, 391, 005

County.	Ore raised but not treated.	Assay value of ore raised during census year and remaining on hand at close of year					Bullion produced during census year from ore previously raised.				
		Gold		Silver.		Total.	Gold.		Silver.		Total
	Tons	Ozs	Dollars	Ozs.	Dolls	Dollars	Ounces	Dollars	Ozs	Dollars	Dollars.
Amador	6, 482	1, 251 5	25, 870	.....	......	25, 870	2, 733. 2	56, 500	......	... ...	56, 500
Calaveras	2, 125	1, 312 1	27, 125	....	....	27, 125	48 4	1, 000	.....	... ..	1, 000
Fresno	.....	... .	.. ...	......	.....	......	156 7	3, 240	217	281	3, 521
Mariposa	.....	....	.. ...	....	......	.. ...	6, 493 1	134, 225	.	.... ..	134, 225
Mono	103	138. 1	2, 854	939	1, 213	4, 067	....	. ...	696	900	900
Placer	......	... ...	.. ...	.....	.....	......	387 0	8, 000	....	... ..	8, 000
Plumas	......	.. ...	... ...	....	.....	.. ..	2, 152. 6	44, 498	21	27	44, 525
San Bernardino	100	483 7	10, 000	6, 342	8, 200	18, 200	....	.... ..	824	1, 065	1, 065
Shasta	130	628 9	13, 000	......	.....	13, 000	58 1	1, 200	6, 914	8, 939	10, 139
Tuolumne	.. ..	.. ...	.. ..	......	......	.. ...	73. 1	1, 511	146	189	1, 700
Total	8, 940	3, 814. 3	78, 849	7, 281	9, 413	88, 262	12, 102 2	250, 174	8, 818	11, 401	261, 575

* Estimated

TABLE II.—CALIFORNIA—*Production of hydraulic, placer, drift, and river mines for the year ending May 31, 1880.*

County.	Gold.	
	Ounces	Dollars
Butte	15,730 3	325,175
Calaveras	4,665 8	96,450
Del Norte	6,208 0	128,331
El Dorado	*24,877.7	*514,269
Humboldt	3,724 9	77,000
Mono	1,219.0	25,200
Nevada	2,062 3	42,631
Placer	13,998 2	289,369
Plumas	7,946 0	164,259
Shasta	21,789 7	450,433
Siskiyou	23,413.1	483,991
Stanislaus	3,030 7	62,650
Trinity	37,635 7	778,000
Tuolumne	*27,081 7	*559,828
Yuba	*50,423 6	1,042,349
Total	243,806 7	5,039,935
Additional production, estimated from transportation statistics	*171,298 3	*3,541,054
Grand total	415,105 0	8,580,989

* Estimated.

NEVADA.

The production of this State shows a considerable decline, as compared with that of the preceding six years. This is not due to any general falling off in the prosperity of the mining industry of the State, but to the decrease in the yield of the leading source, the Comstock lode. From 1871 to 1879, Nevada had outranked all the other States and Territories in its output of the precious metals; but in the present census year it has fallen to the third place, having been passed by both Colorado and California. With the yield of the outside districts maintained at the existing rate of production, an important discovery of ore in the Comstock would perhaps raise Nevada again to the first rank. And even without any striking new developments, there is still a reserve of low-grade ore and tailings remaining unworked, sufficient to give a large and steady product for many years to come.

In 1876 the yield of the Comstock, according to Mr. Del Mar's careful analysis, was: gold, $18,002,906; silver, $20,570,078; total, $38,572,984.

During the census year the product of the whole Comstock district, including the Virginia, Gold Hill, and Devil's Gate subdistricts, the outlying veins, such as the Occidental, etc., and the yield of tailings worked at various points throughout the entire tract known as the Washoe country, was: gold, $3,109,156; silver, $3,813,174; total, $6,922,330. Showing a decline of $31,650,654, or 82.06 per cent., since 1876.

The bullion product of Nevada represents an average of $44.16 gold, $112.29 silver, and $156.45 gold and silver for each square mile of its area. In this respect Nevada is surpassed by Colorado, the figures for which are $25.98 gold, $159.22 silver, and $185.20 total. But with reference to its population, Nevada, even with the reduced output, remains the richest of the mining States and Territories, as its annual product, if distributed equally per capita, would give $78.51 gold, $199.63 silver, and $278.14 total to every man, woman, and child within its borders. Notwithstanding the large proportion of adult males, it will be seen that this would be a fair income for the actual working population. The Nevada mines, however, are largely owned outside the State, and although they have not, taken as a whole, been profitable during the year, the local disbursements in wages, etc., continue steadily, so that the inhabitants have a direct interest in the prosecution of work, independently of the question of ownership.

TABLE III.—NEVADA—*Production of deep mines for the year ending May 31, 1880.*

County	Ore raised during census year	Average assay value per ton			Total assay value of ore raised during census year				
		Gold	Silver	Gold and silver	Gold		Silver		Total
	Tons	Dolls	Dolls	Dolls	Ounces	Dollars	Ounces	Dollars.	Dollars
Elko	13,221	11 71	122 82	134 53	7,492.0	154,873	1,255,965	1,623,837	1,778,710
Esmeralda	29,731	5 44	53 49	58 93	7,825 9	161,776	1,229,931	1,590,178	1,751,954
Eureka	82,013	19 23	38 84	58 07	76,304 5	1,577,356	2,464,082	3,185,812	4,763,168
Humboldt	11,458	8 24	34 83	43 07	4,566 5	94,397	308,666	399,074	493,471
Lander	8,166	.....	161 22	161 22	.....	.....	1,018,315	1,316,579	1,316,579
Lincoln	14,399	1 31	54 81	56 12	910 9	18,829	610,466	789,271	808,100
Nye	23,817	1 33	30 75	32 08	1,527 6	31,579	566,431	732,339	763,918
Storey and Lyon	161,700⅓	21 75	26 47	48 22	170,155 1	3,517,422	3,310,015	4,279,519	7,796,941
White Pine	11,547	53	61 00	61 53	294 9	6,096	544,867	704,459	710,555
Total	356,052⅓	15 62	41 06	56 68	269,077 4	5,562,328	11,308,738	14,621,068	20,183,396

County	Ore raised and treated	Average yield per ton.			Bullion produced from ore raised and treated during census year				
		Gold.	Silver.	Gold and silver	Gold		Silver		Total
	Tons	Dolls	Dolls	Dolls.	Ounces.	Dollars	Ounces	Dollars.	Dollars
Elko	11,721	9 31	99 27	108 58	5,281 4	109,177	899,928	1,163,517	1,272,694
Esmeralda	29,361	4 45	44 88	49 33	6,324 3	130,735	1,019,318	1,317,876	1,448,611
Eureka	79,392	16 37	34 88	51 25	62,893 4	1,300,122	2,141,621	2,768,902	4,069,024
Humboldt	10,644	6 14	28 49	34 63	3,160 7	65,337	234,562	303,265	368,602
Lander	7,751	.....	143 19	143 19	.....	.....	858,439	1,109,876	1,109,876
Lincoln	10,398	22	48 78	49 00	111 3	2,301	392,355	507,276	509,577
Nye	23,817	1 11	26 16	27 27	1,284 0	26,542	481,883	623,026	649,568
Storey and Lyon	161,700	16 31	19 85	36 16	127,616 4	2,638,067	2,482,512	3,209,639	5,847,706
White Pine	11,547	42	50 83	51 25	235 9	4,877	453,944	586,905	591,782
Total	346,331	12 35	33 47	45 82	206,907 4	4,277,158	8,964,562	11,590,282	15,867,440

TABLE III.—NEVADA—*Production of deep mines, &c.*—Continued

County	Ore raised but not treated.	Assay value of ore raised during census year and remaining on hand at close of year.					Bullion produced during census year from ore previously raised				
		Gold		Silver.		Total	Gold		Silver.		Total.
	Tons.	Ozs	Dolls	Ozs.	Dolls.	Dolls	Ozs.	Dolls.	Ozs	Dolls.	Dolls
Elko	*1,500	*858 7	*17,750	*135,594	*175,310	*193,060					
Esmeralda	370	26 1	540	19,357	25,026	25,566			1,129	1,459	1,459
Eureka	2,621	1,789 9	37,000	62,689	81,050	118,050					
Humboldt	814	505 5	10,450	14,502	18,750	29,200					
Lander	415			*76,108	*98,401	*98,401					
Lincoln	4,001	774 2	16,004	154,730	200,050	216,054					
Nye									6,932	8,962	8,962
Storey&Lyon							27,142 6	*561,089	551,886	*713,535	*1,274,624
White Pine									89,721	116,000	116,000
Total	9,721	3,954 4	81,744	462,980	598,587	680,331	27,142 6	*561,089	649,668	*839,956	*1,401,045

* Estimated

PLACER MINES.—The placer yield of Nevada is insignificant. No important gravel deposits having suitable water supply are known to exist. The ground worked is in most cases merely the wash from the croppings of quartz veins. Operations are conducted on a small scale at Tuscarora, Tulé Cañon, points in the neighborhood of the Comstock, and in a few other isolated spots. The aggregate yield for the year is estimated roundly at $50,000.

UTAH.

The bullion product of Utah is remarkably steady, varying latterly but little from year to year. This Territory presents facilities for arriving at a true valuation of the product which are wanting in many other mining localities. The mines are more concentrated, the yield coming from a comparatively few but rich claims, and the bulk of the ore is treated by a few large smelting works and mills, where accurate accounts are kept. It is therefore easier to collect full statistics of the product than in places where the bullion is derived from a vast number of sources, each one of which furnishes only a small quota, as is the case where placer mining forms an important factor. The census figures for Utah are also the more reliable from the fullness and clearness with which the schedules were prepared by the special expert for the Territory.

The tabulation of the product is based on returns from 535 deep mines, one placer mine, 18 amalgamating mills, 34 smelting works, and 10 miscellaneous metallurgical establishments, consisting of sampling, concentration, and leaching works. Many of these sources were, however, unproductive during the census year.

The following table shows the amount of ore raised in the several counties, with the bullion product, so far as traceable by counties. The table includes a statement of ore sold, with the price obtained for it. The larger part of the bullion here stated is from milling ores. The silver-lead ores sold to the smelters are in many cases transported for reduction out of the district in which they were raised; and as their identity is lost in the mixture of ores from all portions of the Territory, and even from other States and Territories, it is impossible to segregate the bullion yield by districts.

TABLE IV.—UTAH—*Production of deep mines for the year ending May* 31, 1880.

County.	Ore raised during census year.	Average assay value per ton			Total assay value of ore raised during census year				
		Gold	Silver	Gold and silver	Gold.		Silver.		Total
	Tons	Dolls	Dolls	Dolls	Ozs	Dolls.	Ozs.	Dolls.	Dolls
Beaver	19,665 75	0 43	45 47	45 90	412 4	8,525	691,708	894,309	902,884
Juab	6,256	15 05	38 60	53 65	4,554 3	94,146	186,805	241,520	335,666
Piute	130	40 72	105 92	146 64	256 1	5,294	10,650	13,769	19,063
Salt Lake	52,506	3 09	20 39	23 48	7,865 7	162,598	827,991	1,070,510	1,233,108
Summit	16,918 33	......	126 12	126 12	......	......	1,650,400	2,133,802	2,133,802
Tooele	7,319 20	......	56 99	56 99	......	......	322,630	417,129	417,129
Utah	1,957 50	......	31 59	31 59	......	......	47,828	61,837	61,837
Washington	49,895	......	26 71	26 71	......	......	1,030,744	1,332,649	1,332,649
Scattered	*180	......	*77 57	*77 57	......	......	*10,800	*13,963	*13,963
Total	154,827 78	1 75	39 91	41 66	13,088.5	270,563	4,779,556	6,179,488	6,450,051

County.	Ore raised and treated (in the same counties).	Average yield per ton			Bullion produced from ore raised and treated during census year, as traced by counties.				
		Gold	Silver	Gold and silver.	Gold.		Silver.		Total
	Tons.	Dolls	Dolls	Dolls	Ozs	Dolls	Ozs	Dolls	Dolls.
Beaver	18,015 75	42	37 14	37 56	369 5	7,638	517,463	669,028	676,666
Juab	3,548	16 98	3 15	20 13	2,914	60,237	8,663	11,200	71,437
Salt Lake	12,000	9 69	53	10 22	5,627.4	116,329	4,880	6,310	122,639
Summit	12,508	.....	97 04	97 04	......	......	938,762	1,213,725	1,213,725
Tooele	250	.....	34 00	34 00	......	......	6,575	8,500	8,500
Washington	46,795	.....	21 66	21 66	......	......	784,065	1,013,718	1,013,718
Total (*a*)	93,116.75	1 98	31 38	33 36	8,910 9	184,204	2,260,408	2,922,481	3,106,685

County	Ore raised but not treated	Assay value of ore raised during census year and remaining on hand at close of year					Bullion produced during census year from ore previously raised				
		Gold.		Silver.		Total	Gold		Silver		Total
	Tons	Ozs.	Dolls.	Ozs	Dolls.	Dolls.	Ozs.	Dolls	Ozs	Dolls.	Dolls
Beaver	750	......	......	30,000	38,787	38,787	74 6	1,542	4,984	6,444	7,986
Juab	450	135 5	2,800	5,260	6,800	9,600	......	......	......	......	......
Piute	50	......	......	1,547	2,000	2,000	......	......	......	......	......
Salt Lake	2,650	29	600	26,500	34,262	34,862	......	......	......	......	......
Summit	3,845	......	......	370,269	478,720	478,720	......	......	107,911	139,518	139,518
Tooele	1,200	......	......	12,839	16,660	16,600	....	......	......	......	......
Utah	100	......	......	3,867	5,000	5,000	....	......	......	......	......
Washington	3,100	......	......	57,227	73,989	73,989	....	......	......	......	......
Total	12,145	164 5	3,400	507,509	656,158	659,558	74 6	1,542	112,895	145,962	147,504

* Estimated

a Including only the product which could be segregated by counties The balance, not thus traceable, is added in the summary for the United States, bringing the corresponding figures up to $270,013 gold, $4,596,957 silver, and $4,866,970 total.

TABLE IV.—UTAH—*Production of deep mines, &c.*—Continued.

County.	Ore sold.	Cash receipts from ore sold. (Bullion accounted for in returns of smelting works.)	
		Av price per ton	Total receipts
	Tons	Dolls	Dolls.
Beaver	900	8 00	7,200
Juab	2,258	45 11	102,860
Piute	80	98 06	7,845
Salt Lake	37,856	22 76	861,789
Summit	565.33	13 13	7,420
Do	300	40 00	a12,000
Tooele	5,869 20	50 42	295,947
Utah	1,857 50	29 68	55,135
Scattered	*180	*60 00	*10,800
Total	49,866 03	27 29	1,360,996

*Estimated a For 300 tons concentrations.

The following is an exhibit of the proportionate amounts of ore milled and ore smelted:

TABLE V.—UTAH—*Statement of ore milled and smelted.*

County.	Ore milled.	Ore smelted	Total ore treated	Percentage of ore milled	Percentage of ore smelted
	Tons.	Tons.	Tons.		
Beaver		18,915 75	18,915 75		100
Juab	3,548	2,258 00	5,806 00	61	39
Piute		80 00	80 00		100
Salt Lake	12,000	37,856 00	49,856 00	24	76
Summit	12,508	565 33	13,073 33	96	4
Tooele	250	5,869 20	6,119 20	4	96
Utah		1,857 50	1,857 50		100
Washington	46,795		46,795 00	100	
Scattered		180 00	180 00		100
Total	75,101	67,581 78	142,682 78	53	47

The most noticeable feature shown in the foregoing table is the large proportion of milling ore which Utah furnishes, compared with her base ores, although a Territory generally supposed to be dependent upon her smelting works. It should be noted, also, that of the ore smelted there was a considerable amount which might have been treated by amalgamation, but which, because of the absence of proper milling facilities, or because of unusual richness, it was advisable to sell to the smelters. But while the percentage by weight of ore milled was 53 per cent., as against 47 per cent. for ores smelted, the same proportion does not hold with regard to value, the percentage of bullion extracted being only 51.08 per cent. for the product of amalgamating mills as against 48.92

per cent. for that from smelting works—a nearly even ratio. This difference is accounted for by the fact that, as a rule, the ores smelted, on account of the greater expense usually involved, are richer than the ores which will bear the milling expense; and also because of the higher proportion of the assay contents of the ore extracted by the smelting process, as compared with the milling results. The following analysis of the total bullion product of the Territory shows the relative amounts coming from each source:

TABLE VI.—UTAH—*Analysis of product.*

Classification of source.	Gold	Silver.	Total.
Amalgamating mills, from ore raised during census year.	$175,024	$2,247,009	$2,422,033
Amalgamating mills, from ore raised prior to census year.	....	139,518	139,518
Total from mills	175,024	2,386,527	2,561,551
Smelting-works, from ore raised during census year	94,989	2,349,948	2,444,937
Smelting-works, from ore raised prior to census year	1,542	6,444	7,986
Total from smelting-works	96,531	2,356,392	2,452,923
Total from mills and smelting-works	271,555	4,742,919	5,014,474
Placer mines	20,000	....	20,000
Total	291,555	4,742,919	5,034,474

The average product of the Utah milling ores and ores smelted, and the average yield of all the Utah ore reduced by either process during the census year, was as follows:

TABLE VII.—UTAH—*Comparative results of treatment.*

	Average yield of—		
	Ores milled	Ores smelted	All ore treated.
Gold, per ton	$2 33	$1 40	$1 90
Silver, per ton	29 92	34 78	33 24
Total	32 25	36 18	35 14

The next table shows the base bullion product of the Utah smelting works, with the precious metal contents. It includes the yield of ores sent from Idaho, Montana, and Nevada to the Utah smelters, and also the product of a small quantity of ore which was raised prior to the census year.

Deducting from the crude bullion product 322,170 pounds, produced from Idaho, Montana, and Nevada ores smelted in Utah, the remainder, 27,891,331 pounds, is the yield of Utah ores smelted in the Territory. To this should be added 865,500 pounds of crude lead bullion, the estimated yield of Utah ores smelted in Chicago and Omaha. The total crude bullion product of Utah for the census year is, therefore, 28,756,831 pounds.

TABLE VIII.—UTAH—*Base bullion production of smelting works for the year ending May 31, 1880.*

County.	Refined lead.	Crude bullion, including weight of silver and gold contents	Precious metals contained in base bullion.				
			Gold		Silver.		Total.
	Pounds.	Pounds	Ounces	Dollars	Ounces	Dollars.	Dollars
Beaver		8, 312, 957	444 1	9, 180	522, 447	675, 472	684, 652
Salt Lake	2, 586, 370	16, 781, 778	3, 731 4	77, 135	1, 159, 583	1, 499, 225	1, 576, 360
Tooele		3, 118, 766	335 9	6, 944	131, 876	170, 502	177, 446
Total	2, 586, 370	28, 213, 501	4, 511 4	93, 259	1, 813, 906	2, 345, 199	2, 438, 458

The gross precious metal product of the Utah smelting works, given in the preceding table, is segregated as follows:

TABLE IX.—UTAH—*Product of ores smelted in Utah during the year ending May 31, 1880.*

			Bullion.				
			Gold.		Silver		Total.
			Ounces.	Dollars	Ounces.	Dollars.	Dollars
Product of smelting works (precious metals contained in base bullion)			4, 511 4	93, 259	1, 813, 906	2, 345, 199	2, 438, 458
Deduct product of Beaver County smelting works (accounted for in Table IV)			444 1	9, 180	522, 447	675, 472	684, 652
Product of smelting works, less product of Beaver County smelting works			4, 067 3	84, 079	1, 291, 459	1, 669, 727	1, 753, 806
From this deduct:	Ounces	Dollars					
Product of Nevada ores smelted in Utah (a)	14, 994	19, 386					
Product of Idaho ores smelted in Utah (b)	16, 916	21, 870					
Product of Montana ores smelted in Utah (c)	5, 116	6, 615					
Product of Nevada sulphides of leaching works	15, 469	20, 000					
Total	52, 495	67, 871			52, 495	67, 871	'67, 871
Net product of Utah ores smelted in Utah, less product of Beaver County smelting works			4, 067. 3	84, 079	1, 238, 964	1, 601, 856	1, 685, 935

(a) 359 tons containing 25 per cent lead Estimated product, 80 775 tons lead
(b) 162 tons containing 45 per cent lead Estimated product, 65 61 tons lead
(c) 49 tons containing 30 per cent lead. Estimated product, 14 7 tons lead.

In addition to the bullion product from ores which were treated in the Territory, there was also a considerable yield from ore and matte shipped to Chicago and Omaha and reduced at these points. As nearly as ascer tainable this additional product was:

TABLE X.—UTAH—*Bullion produced from Utah ores and matte treated elsewhere than in the Territory.*

Ore and matte shipped to Chicago and Omaha.	Assay value.					Estimated product, to be included in total production of Utah				
	Gold.		Silver		Total.	Gold.		Silver.		Total
Tons	Ounces.	Dollars	Ounces	Dollars	Dollars	Ounces.	Dollars.	Ounces	Dollars	Dollars
1,180	93	1,922	49 689	64,243	66,165	83 7	1,730	44,720	57,819	59,549
241	......	.. ..	12,050	15,579	15,579	.. ..	... .. .	11,448	14,801	14,801
1,421	93	1,922	61,739	79,822	81,744	83 7	1,730	56,168	72,620	74,350

From the preceding tables the following *résumé* is derived:

TABLE XI.—UTAH—*Résumé*

Classification of product.	Bullion.				
	Gold.		Silver		Total.
	Ounces	Dollars	Ounces	Dollars	Dollars
Bullion product traceable by districts from Utah ore raised during census year	8,910 9	184,104	2,260,408	2,922,481	3,106,685
Bullion product traceable by districts from Utah ore raised prior to census year	74 6	1,542	212,895	145,962	147,504
Net bullion product from Utah ores sold to and treated by Utah smelting works during census year	4,067 3	84,079	1,238,964	1,601,856	1,685,935
Estimated bullion product of ores and matte shipped to Chicago and Omaha during census year	83 7	1,730	56,168	72,620	74,350
Product of placer mines (of West Mountain district, Salt Lake County) during census year	967.5	20,000	... ...	....	20,000
Total	14,104 0	291,555	3,668,435	4,742,919	5,034,474

UTAH PLACER GOLD.—The small placer product of the territory ($20,000 in the census year) was from West Mountain district, in Salt Lake County.

MARKET VALUE OF UTAH BASE BULLION.—The gold and silver contents of the base bullion are sold at a price which allows for the refining charge on each metal, with, of course, the market discount on the silver. Thus the gold contents brought from $19 to $20 per ounce, and the silver an average of $1.10 per ounce during the census year.

The average price of refined lead at Salt Lake City during the same period was 4¾ cents per pound, and that of unrefined lead $47.50 per ton.

Market value of 2,586,370 pounds refined lead	$122,853
Market value of 28,756,831 pounds unrefined lead	682,975
Total	805,828

This represents roughly the value at the seaboard after deducting freight charges, commissions, etc. There were also $14,160 worth of copper sold, the product of Utah ores worked for the extraction of the precious metals. Adding the market value of the lead and copper, all of it an accessory product of the precious-metal industries, to the mint value of the precious metals, the total product of the Utah mines is raised to $5,854,462. This does not include the value of iron ore sold for flux, and some other small items.

ARIZONA.

A marked impulse has been given to the mining industry of Arizona by the fine showing of the new Tombstone district, in Pima County. The bullion production of this district had only begun in the period covered by the census year. A few months later, with increased milling facilities, a considerably higher rate of production was maintained.

The accompanying tables contain a probable error of at least 20 per cent., owing to the fact that no schedule data were available for estimating the production from the following sources: Various districts in Apache County. In Maricopa County, the Vulture mine (a large producer) and Myers district. In Mohave County, Aubrey, Hope, and San Francisco districts. In Pima County, Aztec, De Frees, Huachucha, Patagonia, Santa Catarina, and Tyndall districts; also several important mines in Tombstone district. In Pinal County, Mineral, Pinal, Randolph, and Summit districts; also the Silver King mine in Pioneer district and the Silver Era mine in Globe district. In Yavapai County, Agua Fria, Greenwood, Hassayampa, Lynx Creek, Martinez, Pine Grove, and Turkey Creek districts. In Yuma County, Bill Williams' Fork, Eureka, Harcuvar, La Paz, Montezuma, and Weaver districts. The estimates given for the production from the sources mentioned as not included in the schedule data furnished by the experts accordingly have a wide margin of uncertainty in comparison with the statements of the yield of localities from which fuller information was received.

TABLE XII.—ARIZONA—*Production of deep mines for the year ending May 31, 1880.*

County.	Ore raised during census year	Average assay value per ton.			Total assay value of ore raised during census year.				
		Gold.	Silver.	Gold and silver.	Gold		Silver.		Total
	Tons	Dolls	Dolls	Dolls	Ounces.	Dolls.	Ounces.	Dollars	Dollars
Maricopa	1,989.00	1 51	114 43	115 94	145.1	3,000	176,039	227,600	230,600
Mohave	2,618 50	10 79	84 30	95 09	1,367 1	28,260	170,729	220,736	248,996
Pima	25,338.00	9 74	76 82	86 56	11,941 4	246,850	1,505,428	1,946,368	2,193,218
Pinal	1,201 00	21 33	31 60	82 93	1,239 3	25,620	29,352	37,950	63,570
Yavapai	6,600 00	4 41	123 70	128 11	*1,408 9	*29,125	631,487	816,450	845,575
Yuma	1,930.00	3 56	35 49	39 05	332 6	6,875	52,973	68,488	75,363
Total, as derived from schedule data	39,676 50	8 56	83 61	92 17	16,434 4	339,730	2,566,008	3,317,592	3,657,322
Additional production, estimated	*8,576 00	*9 30	*114 99	*124 34	*3,877 9	*80,163	*762,745	*986,153	*1,066,316
Total production, estimated	*48,252 50	*8 70	*89 19	*97 89	*20,312.3	*419,893	*3,328,753	*4,303,745	*4,723,638

* Estimated

TABLE XII.—ARIZONA—*Production of deep mines, &c.*—Continued.

County	Ore raised and treated	Average yield per ton			Bullion produced from ore raised and treated during census year.				
		Gold	Silver	Gold and silver	Gold		Silver		Total
	Tons.	Dolls	Dolls	Dolls	Ounces	Dolls	Ounces	Dollars	Dollars
Maricopa	264 00	..	376 44	376 44	. . .	..	76,866	99,381	99,381
Mohave	893 00	10 36	114 49	124 85	447 5	9,250	79,084	102,248	111,498
Pima	12,448 50	9 74	76 82	86 56	4,580 2	96,748	623,499	806,122	902,870
Pinal	119 75	21 09	40 33	61 42	122 2	2,526	3,735	4,829	7,355
Yavapai	3,223 00	3 32	144 79	148 11	517 6	10,700	360,933	466,650	477,350
Yuma	204 00	5 00	...	5 00	49.3	1,020	.....	.....	1,020
Total, as derived from schedule data	17,152 25	7 01	86 24	93 25	5,816 8	120,244	1,144,117	1,479,230	1,599,474
Additional production, estimated	*8,576 00	*7 01	*86 24	*93 25	*2,908 4	*60,122	*572,059	*739,615	*799,737
Total production, estimated	*25,728 25	*7 01	*86 24	*93 25	*8,725 2	*180,366	*1,716,176	*2,218,845	*2,399,211

* Estimated

PLACER MINES.—The schedule data include 798.2 ounces, or $16,500, of gold from the Arizona placers, to which are added 653 ounces, or $13,500, by estimate, bringing the total product from this source up to 1,451.2 ounces, or $30,000. This was chiefly derived from Yavapai County.

IDAHO.

The tabulation of the output of this Territory is based upon reports of the examining expert on 369 deep mines, 14 placer mines, 18 amalgamating mills, 2 arrastras, and 2 smelting works, besides several general reports on whole districts.

From 1876 up to the close of the census year, the product of this Territory has been mainly dependent upon the older mining districts, of which the placer mines of Boise Basin have contributed a large proportion. The panic in the stock market of San Francisco in 1876 led to a suspension of operations in the principal Owyhee mines, which for some years previous to that period had yielded large returns. This crash was due quite as much to mismanagement of the mines themselves as to causes inherent in the speculative market; but whatever the reason, the result was the closing down of many mines which probably would have been still largely productive if properly worked. As the case now stands, the Owyhee district, which formerly yielded by far the greater part of the total output of the Territory, at present furnishes only about one-fifth of the aggregate. It is to be hoped that at no distant time in the future this district may again appear as a large producing center.

Had these statistics been collected for a year ending only a few months later, the new Wood River country would have added largely to the total product. Operations in this district were only seriously begun toward the close of May, 1880; hence the large product from ores shipped to Salt Lake during the fall of the same year does not enter into the tabulation for the census year.

In addition to the developments in the Wood River country, a number of other new localities appear as future important productive sources, prominent among which is the Sawtooth district, which from the absence of local milling facilities was at a standstill pending the erection of reduction works. Another year will witness a considerable bullion production from the mines of this district. The same remark holds good with regard to Smiley's cañon, from which a small amount of ore was shipped at great expense to distant points for reduction. The returns from these shipments were such as to give great hope for a large increase when it becomes possible to treat the ores at greater advantage in mills placed near the mines.

In the Yankee Fork region a decided impulse—the effect of which was not shown until the opening of the season of 1881—was given by the erection of the fine and well-appointed mill of the Custer Company. Previous to the building of this mill the ores of the district had either to be worked in arrastras, with a large percentage of loss, or be freighted at a heavy charge to Salt Lake, or elsewhere, for treatment. In spite of these disadvantages two mines were shipping considerable amounts of $900 ore, while a third was developing an immense body of ore which was expected to yield $300 per ton.

The smelting works recently constructed at Bay Horse and Kinnikinnick will also add largely to the total product.

The period covered by the census year, while one of great promise for the future of the territory, nevertheless showed a comparatively small yield. The probabilities are that within two years the output of Idaho will at least have doubled.

The deposits of Idaho bullion (so far as it is possible to segregate them, a very large portion having passed through private refineries and thus losing their identity) up to the close of the fiscal year ending June 30, 1880, are stated by the Director of the Mint to have been $24,137,417 gold, $727,296 silver, and $24,864,713 total. This amount is far less than the actual output up to that date, vague unofficial estimates placing the total yield as high as $60,000,000.

Of the gold product for the census year, 59.42 per cent. is from placers, and 40.58 per cent. from the deep mines. Idaho furnishes 7.32 per cent. of the placer output of the United States, 2.81 per cent. of the deep mine gold, and 4.43 per cent. of the total gold; 1.13 per cent. of the silver, and 2.60 per cent. of the entire product of the precious metals in the whole country. As a gold-producer the territory ranks sixth, and in silver, seventh. The average yield per square mile is $17.45 gold, $5.30 silver, and $22.75 total. In this respect Idaho stands fifth in point of gold, seventh in silver, and sixth in developed richness in gold and silver. The average yield per capita is $45.38 gold, $13.78 silver, and $59.16 in both precious metals, placing the rank as regards product in reference to population third as to gold, sixth as to silver, and fifth altogether. The comparison with regard to population is probably the most reliable test of the relative prosperity of a mining region.

TABLE XIII.—IDAHO—*Production of deep mines for the year ending May 31, 1880.*

County	Ore raised during census year	Average assay value per ton			Total assay value of ore raised during census year.				
		Gold	Silver.	Gold and silver	Gold		Silver		Total
	Tons	Dollars	Dollars	Dollars	Ounces.	Dollars	Ounces	Dollars.	Dollars
Alturas	4,077 75	36 43	46 12	82 55	7,185 4	148,536	145,477	188,088	336,624
Boise	16,605	16 92	6 51	23 43	13,594 3	281,020	83,684	108,195	389,215
Idaho	*500	*25 00	....	*25 00	*604 7	*12,500	....	....	*12,500
Lemhi	5,000	60 00	60 00	120 00	14,512.5	300,000	232,036	300,000	600,000
Nez Percés	300	20 00	....	20 00	290 3	6,000	....	....	6,000
Oneida	500	25 00	....	25 00	604 7	12,500	....	....	12,500
Owyhee	8,342 75	32 35	33 81	66 16	13,057 7	269,927	218,190	282,097	552,024
Washington	500	15 00	....	15 00	362 8	7,500	....	....	7,500
Total	35,825.50	28 97	24 52	53 49	50,212 4	1,037,983	679,387	878,380	1,916,363

County	Ore raised and treated	Average yield per ton.			Bullion produced from ore raised and treated during census year				
		Gold.	Silver.	Gold and silver.	Gold		Silver		Total
	Tons	Dollars	Dollars	Dollars	Ounces.	Dollars.	Ounces.	Dollars.	Dollars
Alturas	908	53 13	65 45	118 58	2,333 7	48,242	45,971	59,436	107,678
Boise	15,645	13 44	5 39	18 83	10,169 9	210,231	65,330	84,465	294,696
Idaho	*500	*20 00	....	*20 00	*483 7	*10,000	....	....	*10,000
Lemhi	2,500	50 00	50 00	100 00	6,046 9	125,000	96,683	125,000	250,000
Nez Percés	*300	*15 00	....	*15 00	*217 7	*4,500	....	....	*4,500
Oneida	500	20 00	....	20 00	483 7	10,000	....	....	10,000
Owyhee	7,176 75	25 09	24 68	49 77	8,712 4	180,101	136,985	177,109	357,210
Washington	500	10 00	....	10 00	241 9	5,000	....	....	5,000
Total	28,029 75	21 16	15 91	37 07	28,689 9	593,074	344,969	446,010	1,039,084

County.	Ore raised but not treated	Assay value of ore raised during census year and remaining on hand at close of year					Bullion produced during census year from ore previously raised.				
		Gold		Silver		Total	Gold		Silver		Total
	Tons	Ounces.	Dollars	Ounces	Dollars	Dollars	Ozs	Dolls.	Ozs	Dolls	Dolls
Alturas	3,169 75	4,396.7	90,887	95,653	123,670	214,557	169 3	3,500	2,707	3,500	7,000
Boise	960 00	1,867 0	38,595	13,388	17,310	55,905	166 2	3,436	....	....	3,436
Lemhi	2,500 00	7,256 2	150,000	116,018	150,000	300,000	....	....	....	....	....
Owyhee	1,166 00	2,891 7	59,776	58,563	75,715	135,491	....	....	....	....	....
Total	7,795 75	16,411 6	339,258	283,622	366,695	705,953	335 5	6,936	2,707	3,500	10,436

* Estimated.

TABLE XIV.—IDAHO—*Production of placer mines for the year ending May* 31, 1880

County	Gold	
	Ounces	Dollars.
Ada	241 9	5,000
Alturas	1,693 1	35,000
Boise	30,120 4	622,645
Cassia	967 5	20,000
Idaho	2,902 5	60,000
Lemhi	967 5	20,000
Nez Percés	483 8	10,000
Oneida	1,451 2	30,000
Owyhee	2,515 5	52,000
Shoshone	483 8	10,000
Washington	725 6	15,000
Total	42,552 8	870,645

OREGON.

Oregon is one of the o'dest of the western mining States, the discovery of gold within its limits having followed closely upon that in California. Its output has never been very large in comparison with the yield of its neighbor State, but although the mines have become secondary to its agricultural resources in point of importance, they still furnish occupation and profit to many of its inhabitants. The quartz veins of Baker County, in the eastern portion of the State, adjoining Idaho Territory, continue to yield the larger portion of the total deep-mine product of this State. The prevailing type of the Oregon ores is a free gold quartz, though rebellious gold ores, requiring special treatment, are found in some localities, and a small amount of silver is produced in Grant County.

The latter county takes the lead in surface mining, while Baker, Jackson, and Josephine Counties are also productive of a considerable amount of placer gold.

Oregon now ranks seventh on the roll of the mining States in production of gold, eleventh in output of silver, and ninth in its yield of both metals. Its quota toward the total production of the United States is 7.75 per cent. of the placer gold, .80 per cent. of the deep-mine gold, 3.29 per cent. of the total gold, and only .07 per cent. of the total silver. The percentage of the total combined gold and silver product is 1.49 per cent. The average yield per square mile is $11.43 gold, $0.20 silver, and $11.63 total. The product per capita is $6.28 gold, $0.11 silver, and $6.39 total, giving Oregon a rank of seventh in gold, tenth in silver, and ninth in total bullion output, in point of production as relative to population. The small proportion per capita shows how completely mining has been overshadowed by other industries in this State.

TABLE XV.—OREGON—*Production of deep mines for the year ending May* 31, 1880.

County	Ore raised during census year.	Average assay value per ton			Total assay value of ore raised during census year.				
		Gold.	Silver	Gold and silver.	Gold.		Silver.		Total.
	Tons	Dollars	Dollars	Dollars	Ounces	Dollars	Ounces	Dollars	Dollars.
Baker	12,737	11 00	1 59	12 59	6,776 9	140,091	15,713	20,316	160,407
Grant	1,200	76 87	45 88	122 75	4,462 1	92,240	42,579	55,050	147,290
Josephine	150	*34 83	.. ..	*34 83	*252 7	*5,225	. . .	.. . .	*5,225
Total	14,087	16 86	5 35	22 21	11,491 7	237,556	58,292	75,366	312,922

County	Ore raised and treated	Average yield per ton.			Bullion produced from ore raised and treated during census year.				
		Gold	Silver	Gold and silver	Gold		Silver		Total
	Tons.	Dollars	Dollars	Dollars	Ounces	Dollars	Ounces	Dollars	Dollars.
Baker	12,607	7 80	34	8 14	4,755 5	98,305	3,331	4,307	102,612
Grant	1,015	67 21	13 43	80 64	3,300 2	68,221	10,549	13,639	81,860
Josephine	150	31 66	.. ...	31 66	229 8	4,750	.	.. ...	4,750
Total	13,772	12 44	1 30	13 74	8,285 5	171,276	13,880	17,946	189,222

County.	Ore raised but not treated.	Assay value of ore raised during census year and remaining on hand at close of year.					Bullion produced during census year from ore previously raised.				
		Gold		Silver.		Total	Gold.		Silver		Total.
	Tons.	Ounces	Dollars	Ounces	Dollars	Dollars	Ozs	Dolls	Ounces	Dollars	Dollars.
Baker	130	188 7	3,900	3,017	3,900	7,800	4 3	88	1,285	1,661	1,749
Grant	185	894 9	18,500	28,617	37,000	55,500	-----	-----	--- --	---- --	-------
Total	315	1,083 6	22,400	31,634	40,900	63,300	4 3	88	1,285	1,661	1,749

* Estimated

TABLE XVI.—OREGON—*Production of placer mines for the year ending May* 31, 1880.

County.	Gold.	
	Ounces	Dollars
Baker	7,262 8	150,136
Coos	3 6	75
Curry	453 5	9,375
Douglas	620 5	12,826
Grant	14,096 5	291,400
Jackson	9,132 7	188,790
Josephine	9,503 4	196,454
Umatilla	3,680 4	76,080
Wasco	58 1	1,200
Total	44,811 5	926,336

WASHINGTON.

Of the small product reported from the deep mines of Washington Territory, nearly the whole comes from Peshaston district, in Yakima County, where gold quartz mining is conducted on a small scale.

The Upper Columbia placers furnish over one-half of the total placer yield of the Territory. The Skagit mines, in Whatcom County, about which, from time to time, reports glittering with golden promise have been spread, are not yet to be numbered among the important productive deposits of the country. They have attracted much attention from the press, and have been the scene of several incipient "rushes," but the shortness of the season, inaccessibility, and other natural disadvantages have combined to retard operations, and the yield is still very scanty.

TABLE XVII.—WASHINGTON—*Production of deep mines for the year ending May* 31, 1880.

County	Ore raised during census year.	Average assay value per ton.			Total assay value of ore raised during census year				
		Gold.	Silver	Gold and silver	Gold		Silver.		Total.
	Tons	Dollars	Dollars	Dollars.	Ounces	Dollars	Ounces	Dollars	Dollars.
Yakima	437	*41 85	Trace	*41 85	*884 6	*18,287	.. ..	.. ...	*18,287
Scattered	100	37 50	Trace	37 50	181.4	3,750	....	....	3,750
Total	537	41 04	Trace.	41 04	1,066.0	22,037	... .	......	22,037

County.	Ore raised and treated.	Average yield per ton			Bullion produced from ore raised and treated during census year.				
		Gold	Silver.	Gold and silver	Gold		Silver.		Total.
	Tons	Dollars.	Dollars	Dollars	Ounces	Dollars	Ounces	Dollars	Dollars
Yakima	437	31 59	Trace	31 59	667 6	13,800	....	....	13,800
Scattered	100	30 00	Trace	30 00	145 1	3,000	....	... ..	3,000
Total	537	31 28	Trace	31 28	812 7	16,800	......	... ...	16,800

* Estimated

TABLE XVIII.—WASHINGTON—*Production of placer mines for the year ending May* 31, 1880.

Locality	Gold	
	Ounces	Dollars.
Whatcom County, Skagit mines	193.5	4,000
Yakima County, Swauk mines	483 7	10,000
Upper Columbia placers	2,902.5	60,000
All other placers	2,176 9	45,000
Total	5,756.6	119,000

ALASKA.

This vast territory, occupying an area of over half a million square miles, is for the most part still an unexplored region. The small amount of prospecting which has been done has developed the fact that Alaska contains many gold-bearing localities, none of which, however, have yet yielded any considerable output. The climate and remoteness from communications will always be obstacles in the way of mining, but in spite of the natural disadvantages of the country, it is reasonable to look for an increased product in the future. Recent reports, much exaggerated, of fabulous discoveries of mountains of silver ore have attracted many adventurous miners to Alaska. Thus far only disappointment has resulted. The Takou gold district, which has been explored to some extent, is, however, stated to have yielded $150,000 in the season of 1881.

The small amount of placer gold received at the San Francisco mint from Alaska during the census year, $5,951, does not perhaps represent the whole product for that period, as a portion may have found its way to Victoria, and thus have become identified with the product of British Columbia. No means of tracing this small possible balance are at hand. The total was in any event insignificant.

STATISTICS OF THE DIVISION OF THE ROCKY MOUNTAINS.

[Collected and compiled under the direction of Mr S. F. Emmons, geologist-in-charge and special agent of census]

COLORADO.

From an average annual production of only three or four millions, Colorado has suddenly risen to the first rank as a producer of the precious metals among the States and Territories for gold and silver combined, as well as for silver alone, while for gold it holds the fourth rank. In the relation of production to area it holds the first rank likewise for gold and silver combined and for silver alone, and the third for gold alone. In the relation of production to population, however, it ranks only third for gold and silver together, second for silver alone, and sixth for gold alone. The total value of its product during the census year in gold and silver was, in round numbers, nineteen and a quarter million dollars, and, if we add to this the value of lead and copper in crude metal produced, we have a total value of metallic product of twenty-two and three-quarters million dollars.

The collection of statistics of the precious metals in this State presents certain peculiar difficulties. First, from the fact that there are so many small mines which keep no accurate record of their production; second, because a very large proportion of its ores, being essentially heterogeneous in composition, have to be smelted, and are thus more difficult to trace than milling ores. The smelting ores are sold, it is true, mostly to smelters within the State, but the same mine often sells to different and widely-separated works, and the smelters themselves buy ores in small lots from many mines, of which no separate record is kept. Moreover, the check furnished in the more western States over the total production by the express returns is here wanting, since practically the whole silver product is shipped east in lead bullion, of which the transportation companies keep no record. Nevertheless, owing to the almost uniform willingness which the more important mine-owners, samplers, and smelters have shown to afford the data which they possessed, it is believed that the totals attained represent a very close approximation to the actual product of the State, and that the figures given are, on the average, within 5 per cent. of the true amount, although in districts as yet incompletely developed this percentage may be greater.

TABLE XIX.—COLORADO—*Production of deep mines for the year ending May 31, 1880.*

County.	Ore raised during census year	Average assay value per ton			Total assay value of ore raised during census year				
		Gold	Silver.	Gold and silver.	Gold		Silver.		Total.
	Tons.	Dolls	Dolls.	Dolls.	Ounces	Dollars	Ounces	Dollars.	Dollars
Boulder	7, 868	58 17	49 46	107 63	22, 137 0	457, 613	301, 025	389, 195	846, 808
Chaffee	979	20 58	171 64	192 22	975 0	20, 155	129, 965	168, 032	188, 187
Clear Creek ..	37, 031	10 15	52 79	62 94	18, 191 0	376, 041	1, 511, 754	1, 954, 547	2, 330, 588
Custer	16, 094	91	37 17	38 08	706 0	14, 594	462, 721	598, 252	612, 846
Gilpin	123, 668	16 27	5 46	21 73	97, 337 0	2, 012, 134	521, 871	674, 727	2, 686, 861
Gunnison	252	36 03	721 03	757 06	439 2	9, 079	140, 537	181, 700	190, 779
Hinsdale	2, 695	3 07	69 45	72 52	400 0	8, 269	144, 762	187, 163	195, 432
Huerfano	35	20 69	96 97	117 66	35 0	724	2, 625	3, 394	4, 118
Lake §	152, 451	54	90 04	90 58	4, 000. 0	82, 687	10, 617, 216	13, 726, 998	13, 809, 685
La Plata	12	10 00	246 75	256 75	5 8	120	2, 290	2, 961	3, 081
Ouray	1, 790	41 41	154 81	196 22	3, 585. 5	74, 119	214, 327	277, 103	351, 222
Park	5, 364	1 36	146 21	147 57	352 7	7, 291	606, 585	784, 254	791, 545
Rio Grande.....	550	15 50	....	15 50	412 5	8, 527	....	....	8, 527
San Juan	2, 725	73	121 39	122 12	96 5	1, 995	255, 847	330, 785	332, 780
Summit	4, 846	3 73	85 88	89 61	875 0	18, 088	321, 889	416, 170	434, 258
Total.......	356, 360	8 68	55 26	63 94	149, 548 2	3, 091, 436	15, 233, 414	19, 695, 281	22, 786, 717

TABLE XIX.—COLORADO—*Production of deep mines, &c.*—Continued.

County.	Ore raised and treated.	Average yield per ton			Bullion produced from ore raised and treated during census year				
		Gold	Silver	Gold and silver.	Gold		Silver		Total.
	Tons.	Dolls	Dolls	Dolls	Ounces	Dollars	Ounces	Dollars	Dollars.
Boulder	7,558.0	40 28	46 82	87 10	14,728 3	304,461	273,688	353,851	658,312
Chaffee	161 0	6 33	46 65	52 98	*49 3	*1,019	*5,809	*7,510	*8,529
Clear Creek	†35,821 0	6 11	46 73	52 84	*10,582 3	*218,756	*1,294,774	*1,674,013	*1,892,769
Custer	‡6,784 0	2 12	10 66	12 78	696 2	14,392	55,927	72,308	86,700
Gilpin	123,645 0	13 08	2 61	15 69	*78,263 4	*1,617,848	*250,074	*323,321	*1,941,169
Gunnison	252 0	18 11	100 00	118 11	*220 3	*4,554	19,507	25,221	29,775
Hinsdale	2,695.0	2 61	13 09	15 70	277 8	5,743	99,958	129,236	134,979
Huerfano	5 5	....	57 27	57 27	....	....	244	315	315
Lake §	140,623 0	58	89 34	89 92	3,913 7	80,904	9,717,819	12,564,168	12,645,072
La Plata	12 0	8 58	226 00	234 58	5 0	103	2,098	2,712	2,815
Ouray	1,311 0	12 69	78 55	91 24	*804 5	*16,631	*79,651	*102,981	*119,612
Park	5,364 0	18	95 67	95 85	*46 0	*951	*396,921	*513,179	*514,130
Rio Grande	550 0	9 79	....	9 79	260 5	5,385	....	....	5,385
San Juan	1,353 0	1 29	104 31	105 60	84 0	*1,736	*109,166	*141,141	*142,877
Summit	4,446.0	1 16	79 66	80 82	250 0	*5,168	*273,915	*354,145	*359,313
Total	330,580 5	6 89	49 20	56 09	110,181 3	2,277,651	12,579,551	16,264,101	18,541,752

County	Ore raised but not treated	Assay value of ore raised during census year and remaining on hand at close of year.					Bullion produced during census year from ore previously raised				
		Gold		Silver.		Total	Gold		Silver.		Total
	Tons	Ozs	Dolls	Ounces	Dollars	Dollars.	Ozs	Dolls	Ozs.	Dolls	Dolls.
Boulder	310 0	1,423 0	29,416	21,470	27,759	57,175	....	....	9,487	12,266	12,266
Chaffee	818 0	708 4	14,644	107,706	139,253	153,897	....	....	....	....	....
Clear Creek	1,210 0	2,053 5	42,450	133,254	172,284	214,734	....	....	....	....	....
Custer	9,310 0	....	....	316,350	409,009	409,009	....	....	....	....	....
Gilpin	23 0	18 1	374	97	125	499	11,425 7	236,190	*62,322	*80,576	316,766
Huerfano	29 5	29 5	610	2,212	2,860	3,470	....	....	....	....	....
Lake §	11,828.0	118 3	2,445	823,702	1,064,964	1,067,409	....	....	....	....	....
Ouray	479 0	1,457 1	30,121	87,093	112,603	142,724	....	....	....	....	....
San Juan	1,372 0	....	....	112,960	146,046	146,046	....	....	....	....	....
Summit	400 0	200 0	4,134	26,800	34,650	38,784	....	....	....	....	....
Scattered	....	....	....	....	....	....	4,078 7	84,314	147,707	190,970	275,284
Total	25,779.5	6,007 9	124,194	1,631,644	2,109,553	2,233,747	15,504 4	320,504	219,516	283,812	604,316

* Estimated † 14,384 tons lost by concentration.
‡ 4,684 tons lost by concentration. § Including the Leadville district

In the foregoing tables the following are the more important items of uncertainty or inadequacy of data:

Arapahoe County.—In this county, as well as in Jefferson and Pueblo counties, no mines producing gold and silver are known to exist. In these, however, are located important smelting works, which buy and treat ores from almost every county in the State, as well as from Montana and New Mexico. The bullion production of these counties would therefore be an important fraction of the total bullion yield of the State. It has, however, been considered best to apportion this yield as nearly as possible among the counties in which the ore was raised. This has been done in the following manner: The greater part of the ore treated could be traced back to the county where it was raised, and the total bullion product of each lot of ore was deduced from the average assay value of such lot, of the total amount treated, and of the total amount of bullion produced, in the case of each individual smelter. A portion of ore treated and bullion produced therefrom, which could not be directly traced back to its source, was distributed on estimated proportions, founded mainly on the relative amounts of ore produced, as determined by schedules and previous estimates. In considering the amount of bullion produced and ore treated, there is this element of uncertainty in some of the calculations, that the larger smelters cannot always say that the bullion produced was from the very lots of ore purchased, as they keep a varying stock of ore on hand. It is probable, however, that, considering the whole, the figures obtained are sufficiently near the truth.

Boulder County.—No reliable data could be obtained in regard to the Niwot mine, which is said to produce about 15,000 tons of ore per year. In general the returns from this county were more incomplete and less satisfactory than from most counties in the State. The product, as obtained from smelters, is approximately correct; that from mills less certain and probably incomplete.

Chaffee County contains a number of promising mines, but owing to absence of owners no reliable data of production during census year could be obtained.

Clear Creek County.—One element of uncertainty in this county is the very common practice of leasing the mine to one or more parties, who pay the owner a royalty, or a portion of the gross product. A second is, that the ores are sampled, frequently concentrated, and sometimes treated in Gilpin County. Small lots of rich ore have been also shipped to smelters in the east, of which no record could be obtained. The loss by concentration (14,384 tons) was obtained by actual returns from ore-dressing works; in one case only, of a few hundred tons, an estimate being made of the degree of concentration. The proportionately large loss in treatment is due, doubtless, to defective systems of working, but may be less than shown by the figures given above, since the product of rich ores shipped east does not appear here.

Custer County.—Its production is relatively low, since the Bassick mine did not produce during a great part of the census year. The loss by concentration (4,684 tons) is an estimate, deducting the sum of tons treated and tons remaining on hand from tons raised.

Gilpin County.—Owing to the system pursued by a large proportion of the mines and mills, viz: that the miners send their ore to custom mills to be treated, and receive in return the bullion produced, less charges, without any assay control to determine how much was lost in treatment, or any record being kept by mills of value of bullion returned, it has been necessary to estimate a large proportion of the bullion thus produced. The express returns give for the year ending June 30, 1880, a shipment from Central City of 88,016 ounces gold bullion, of reported value of $1,320,260. The census figures for the year ending May 31, 1880, are somewhat less, viz: For the mill production, 54,361.8 ounces fine gold, having a mint value of $1,123,758.11, showing that this estimate is probably somewhat under the truth, although it is not certain that absolutely all bullion shipped from Central City was produced within Gilpin County. The figures in the column of "Bullion from ore raised prior to census year" are an estimate of the yield of tailings from the mills which were sold to smelters during the year, and which are supposed to come mainly from ore raised during previous years.

Gunnison County.—But few mines were sufficiently developed to be regular producers during the census year, and many small lots shipped out for treatment may have escaped the record.

Hinsdale County.—The principal smelting works of the San Juan region are located here, and its production includes probably some small lots of ore raised in Ouray and San Juan counties, which could not be segregated.

Huerfano County has but few mines. From only a single district were returns made by the expert who had charge of this portion of the State.

Lake County.—Is the largest producer and furnishes the most accurate data, though it has been impossible in every case to actually trace back the bullion produced to the individual mine from which it came. The figures given are known to be under the truth for the following reason: The "American" and "Gage, Hagaman & Co.'s" smelters ran during a portion of the year, but were shut down and changed hands, so that when these statistics were collected no record, or even estimate, could be obtained of the amount of bullion produced by them. A thousand tons of crude bullion, of an average of 300 ounces silver per ton, would probably be an outside figure for the production of the two. This would add 300,000 ounces silver to the total production for the year. No record was obtained of the amount of ore, if any, which was shipped directly from Leadville to the smelting works at Omaha; its influence on the total production would be, at all events, inconsiderable. With these exceptions the figures given present a very accurate estimate of the bullion produced. With regard to the gold production the amount contained in the ores is in general too small to be taken account of, and it is only when concentrated in the lead bullion that it becomes appreciable; moreover a considerable portion of it comes from small lots of auriferous ores purchased by smelters from mines or prospects in outlying districts within the county, and in some cases from Gunnison or Summit counties. The gold contents of ore raised had therefore to be largely determined by estimate.

La Plata County.—From this county reports of only a single district were obtained, as the mines were as yet but little developed in the census year; probably many small lots of ore are unaccounted for.

Ouray County.—Doubtless from this county also the returns are somewhat incomplete, and it is certain that some addition is due to the amount of "bullion produced" which has been credited to it. Unfortunately data are wanting for making an accurate estimate, although it is known that some of this has been credited to Hinsdale County.

Park County.—At the time of collecting these statistics accurate data could be obtained from but few of the producing mines of this county; it has been necessary, therefore, to deduce them largely from information obtained from samplers and smelters, and estimate their proportionate bullion yield.

Rio Grande County.—Here, also, returns were obtained from but a single district.

San Juan County.—To this the same remarks are applicable which were made in regard to Ouray County.

Summit County.—From this county, for various reasons, the returns as regards the census year are rather incomplete, and figures probably below the truth. The bullion produced also had to be largely estimated. The following years will probably show an increased production.

To show the data from which the figures given above have been obtained the number of mines from which full schedules were received is subjoined, and the proportion thereof that have been bullion-producers during the census year, as well as those producers of which data have been obtained otherwise than by schedules and visits of census experts:

Total deep mines scheduled	249
Productive mines scheduled	126
Productive mines reported otherwise	249
Total productive mines reported	375
Total all mines reported on	498

TABLE XX.—COLORADO—*Production of placer mines for the year ending May 31, 1880.*

County.	Gold	
	Ounces.	Dollars
Chaffee	1,275.0	26,357
Clear Creek	410 0	8,476
Lake	835 0	17,261
Park	1,000 0	20,672
Routt	241 9	5,000
Summit	1,160 0	23,979
Total	4,921.9	101,745

The above table gives all the data which were obtained by the experts engaged in this work on placer and hydraulic workings in the State. The inherent difficulty of obtaining complete information with regard to surface mining, in that it is carried on only during a limited portion of the year, and in great part by individuals who keep no accurate account of their gains, renders these returns necessarily incomplete here as elsewhere. In Colorado, moreover, owing to the fact that other gold bullion is produced so largely, it has been impossible to supplement these figures by express or mint returns. While the above figures doubtless very inadequately express the production of placer gold for the State, it is a fact that this production was relatively small during the census year, owing to the unusual activity in prospecting for and working deep mines.

COPPER AND LEAD.—Although these belong rather to the useful than to the precious metals, their importance among the mineral products of Colorado, and their intimate connection with the production of gold and silver, render their consideration here essential. In Table XXI, given below, only the crude metal obtained from ores actually smelted within the State is given, no account being taken of the copper or lead contained in ores which were shipped outside of the State for treatment. This amount is, however, of comparatively little importance, forming probably not over 5 per cent. of the total product. The lead product was all in the form of argentiferous lead bullion, which was shipped to various smelters in the East to be refined.

The copper product was partly as matte, but largely in the form of copper oxide. Of the actual shipments of the latter a portion has been produced from ores raised in Montana; a proportionate amount of the total product has, however, been credited to that Territory in its appropriate place.

In calculating the value of these metals the average market value of either for the year has been assumed as 4½ cents per pound for lead, 20 cents per pound for copper.

TABLE XXI.—COLORADO—*Crude bullion product for the year ending May 31, 1880.*

County.	Gross tons	Lead		Copper.		Gold		Silver		Total
		Tons	Dolls	Tons	Dolls	Ozs	Dolls	Ozs.	Dolls	Dolls
Arapahoe	1, 225	....	....	980	392, 000	....	....	....	....	392, 000
Hinsdale	800	790 00	71, 100	....	....	270 0	5, 581	96, 878	125, 254	201, 935
Jefferson	1, 117	525 75	47, 318	598	239, 200	10, 315 0	213, 231	565, 020	730, 514	1, 230, 263
Lake	28, 383	28, 226 00	2, 540, 340	....	....	3, 830 2	79, 177	8, 053, 946	10, 412, 947	13, 032, 464
Ouray	90	89 00	8, 010	....	....	....	....	24, 103	31, 163	39, 173
Park	57	56 00	5, 040	....	....	....	....	11, 996	15, 510	20, 550
Pueblo	2, 191	2, 126 50	191, 385	....	....	1, 347 0	27, 845	1, 557, 608	2, 013, 831	2, 233, 061
Summit	260	256 00	23, 040	....	....	....	....	10, 400	13, 446	36, 486
Total....	34, 123	32, 069 25	2, 886, 233	1, 578	631, 200	15, 762 2	325, 834	10, 319, 951	13, 342, 665	17, 185, 932

Lead, $90 per ton. Copper, $400 per ton.

In the subjoined table are shown the relative amounts of ore treated by mill process and by smelting, and their average yield per ton. Its principal value is to show the average character of ore in each county in reference to its adaptation to either process of reduction. It would have been extremely interesting, had the data been such as would yield accurate results, to have given the assay value of the ore treated in either case, and thus compare the relative losses in either process, but the number of cases in which it has been necessary to estimate product from assay value, or *vice versâ*, would seriously impair the value of such comparison. This subject will be found treated at length in the final census report.

TABLE XXII.—COLORADO—*Production of smelting works and amalgamating mills for the year ending May* 31, 1880.

County.	Ore raised and smelted	Average yield per ton			Bullion produced from ore smelted during census year				
		Gold	Silver.	Gold and silver	Gold.		Silver.		Total.
	Tons	Dollars	Dollars	Dollars	Ounces	Dollars	Ounces.	Dollars	Dollars.
Boulder	3,412 0	68 52	47 10	115 62	11,309 8	233,794	124,307	160,717	394,511
Chaffee	161 0	*6 33	*46 65	*52 98	*49 3	*1,019	*5,809	*7,510	*8,529
Clear Creek †	9,701.0	11 93	116 26	128 19	*5,599 3	115,748*	872,344	*1,127,854	*1,243,602
Custer ‡	982 0	14 24	64 65	78 89	676 2	13,978	49,107	63,490	77,468
Gilpin	10,218 0	48 36	28 26	76 62	23,901 5	494,088	223,305	288,711	782,799
Gunnison	252 0	18 11	100 00	118 11	*220 3	*4,554	19,507	25,221	29,775
Hinsdale	'2,695 0	2 61	13 09	15 70	277 8	5,743	99,958	129,236	134,979
Huerfano	5 5	......	57 27	57 27	......	......	244	315	315
Lake	140,623 0	58	89 34	89 92	3,913 7	80,903	9,717,819	12,564,168	12,645,071
La Plata	12 0	8 58	226 00	234 58	5.0	103	2,098	2,713	2,816
Ouray	1,015 0	6 66	100 62	107 28	327 0	6,760	78,995	102,133	108,893
Park	5,364 0	*18	*95 67	*95 85	*46.0	*951	*396,921	*513,179	*514,130
Rio Grande	....	....	....	....	....	....	....	......	......
San Juan	1,353 0	*1 29	*104 31	*105 60	*84 0	*1,736	*109,166	*141,141	*142,877
Summit	3,771 0	....	*93 91	*93 91	......	.....	*273,915	*354,145	*354,145
Total.	179,564 5	5 34	86 21	91 55	46,409 9	959,377	11,973,495	15,480,533	16,439,910

County.	Ore raised and milled	Average yield per ton			Bullion produced from ore milled during census year				
		Gold	Silver.	Gold and silver	Gold		Silver.		Total
	Tons	Dollars	Dollars	Dollars	Ounces	Dollars	Ounces.	Dollars.	Dollars
Boulder	4,146	17 05	46 58	63 63	3,418 5	70,667	149,381	193,135	263,802
Chaffee	....	....	....	....	.....	.....	.....	.....	.....
Clear Creek †	11,736	8 78	46 54	55 32	*4,983 0	*103,008	*422,430	*546,160	*649,168
Custer ‡	1,118	38	7 88	8 26	20 0	413	6,820	8,818	9,231
Gilpin	113,427	9 91	30	10 21	54,361 9	1,123,760	26,769	34,610	1,158,370
Gunnison	......	......	......	......	......	......	......	......	......
Hinsdale	......	......	......	......	......	......	......	......	......
Huerfano	......	......	......	......	......	......	......	......	......
Lake	......	......	......	......	......	......	......	......	......
La Plata	......	......	......	......	......	......	......	......	......
Ouray	296	33 35	2 86	36 21	477 5	9,871	656	848	10,719
Park	......	......	......	......	......	......	......	......	......
Rio Grande	550	9 79	.....	9 79	260 5	5,385	......	......	5,385
San Juan	......	......	......	......	......	......	......	......	......
Summit	675	*7 66	......	*7 66	*250 0	*5,168	......	......	*5,168
Total.	131,948	9 99	5 94	15 93	63,771 4	1,318,272	606,056	783,571	2,101,843

* Estimated † 14,384 tons lost by concentration. ‡ 4,684 tons lost by concentration

DAKOTA.

The metallic production of Dakota is derived from the region of the Black Hills, and in greater part from Lawrence County, where free milling gold-quartz ores of low grade are reduced in amalgamating mills of great size. The perfection to which the milling process has been brought is shown by the large percentage of the assay value extracted. Custer and Pennington counties are opening new mines, but had scarcely become producers during the census year.

TABLE XXIII.—DAKOTA—*Production of deep mines for the year ending May 31*, 1880.

County.	Ore raised during census year	Average assay value per ton			Assay value of ore raised during census year				
		Gold	Silver	Gold and silver	Gold.		Silver		Total
	Tons	Dolls	Dolls.	Dolls	Ozs	Dolls	Ozs	Dolls	Dolls
Custer	2,250	13 89	0 07	13 96	1,511 7	31,250	122	158	31,408
Lawrence	526,998	7 65	34	7 99	195,063 3	4,032,316	136,190	176,080	4,208,396
Pennington . ..	7,500	10 31	09	10 40	3,738 9	77,290	541	699	77,989
Total....	536,748	7 71	33	8 04	200,313 9	4,140,856	136,853	176,937	4,317,793

County	Ore raised and treated	Average yield per ton			Bullion produced from ore raised and treated during census year				
		Gold	Silver	Gold and silver	Gold		Silver.		Total
	Tons.	Dolls	Dolls	Dolls	Ozs	Dolls	Ozs	Dolls	Dolls
Lawrence	495,630	6 33	0 15	6 48	151,759 7	3,137,154	54,577	70,563	3,207,717
Pennington	500	3 20	.....	3 20	77.4	1,600	.. ....	.. ....	1,600
Total	496,130	6 33	14	6 47	151,837 1	3,138,754	54,577	70,563	3,209,317

County	Ore raised but not treated	Assay value of ore raised during census year and remaining on hand at close of year					Bullion produced during census year from ore previously raised				
		Gold		Silver		Total	Gold		Silver		Total
	Tons	Ozs.	Dolls	Ozs	Dolls	Dolls	Ozs	Dolls	Ozs	Dolls	Dolls
Custer	2,250	1,511 7	31,250	122	158	31,408	.. ...	. ....	.....	.....	.. ...
Lawrence ..	31,308	12,621 7	260,914	24,741	31,988	292,902	5,622 7	116,233	.....	.. .	116,233
Pennington ..	7,000	3,619 9	74,830	541	699	75,529	.... ..	.... ..	.....	.. ...	.. ....
Total	40,618	17,753 3	366,994	25,404	32,845	399,839	5,622 7	116,233	.....	.....	116,233

Dakota placer mines.—The following table gives the production of placer mines so far as could be ascertained by the expert in charge of this district. The amount seems very small, compared with the supposed value of the surface deposits in this region. This may be in part accounted for by the fact that several important companies were making ditches, and preparing for work on a large scale, but had not become producers during the census year.

TABLE XXIV.—DAKOTA—*Production of placer mines for the year ending May 31, 1880.*

County.	Gold	
	Ounces.	Dollars
Lawrence	2,307 5	47,700
Pennington	152 8	3,159
Total	2,460 3	50,859

MONTANA.

Montana has within its boundaries the elements favorable to a large production of the precious metals—rich and varied ores and abundant fuel, both coal and wood. As yet, however, owing to lack of development and want of sufficient transportation facilities, it has not taken its proper rank as a producer. Owing to the great extent of territory over which its mines are scattered, and the fact that, from circumstances beyond our control, the collection of statistics was not completed until the winter was far advanced and travel rendered thereby very difficult, our data leave something to desire in point of completeness. It was evident that the figures of gold production deduced from the schedules were below the truth, since the mint returns report the gold production of Montana as a little over a million dollars in excess. As the mint figures are certainly below the truth, it was proper that this difference should be added, the only question being to what branch of mining it should be credited. Now, the census returns from placer and hydraulic mines were notoriously incomplete, since, owing to the lateness of the season, but few of their owners could be found; but it is well known that they form the most important element in the gold production of Montana. On the other hand, it was thought that returns had been obtained from practically all the mills and smelting works. Under these circumstances it was judged best to discard the census figures for hydraulic and placer mines altogether, and assume as their production the difference between the amount of gold produced, as determined by mill and smelters' returns, and the total product obtained from mint returns. While, therefore, it is possible that a small amount of the gold credited to hydraulic and placer mines may belong to mill production, it is probably not more than that by which the mint returns fall short of giving the total gold production of the Territory as gold which, for various reasons, had not passed through the hands of its agents.

The following table gives the production of the deep mines of Montana by counties, and the yield of the ore treated, as far as could be ascertained, though some small lots of ore are known to have been shipped east, which could not be traced:

TABLE XXV.—MONTANA—*Production of deep mines for the year ending May* 31, 1880.

County.	Ore raised during census year.	Average assay value per ton			Assay value of ore raised during census year				
		Gold	Silver.	Gold and silver	Gold		Silver		Total.
	Tons.	Dolls	Dolls	Dolls	Ounces	Dolls	Ounces	Dolls	Dolls
Beaver Head ...	10, 936	2 22	96 19	98 41	1, 176 2	24, 314	813, 727	1, 052, 068	1, 076, 382
Deer Lodge ..	81, 256	6 34	45 19	51 53	24, 910 7	514, 950	2, 840, 198	3, 672, 092	4, 187, 042
Jefferson	3, 335	54 66	29 70	84 36	8, 818 6	182, 297	76, 616	99, 057	281, 354
Lewis and Clarke	10, 493	16 18	6 33	22 51	8, 215 0	169, 819	51, 379	66, 428	236, 247
Madison.	8, 838	28 45	1 40	29 85	*12, 166 2	*251, 498	9, 582	12, 389	*263, 887
Total......	114, 858	9 95	42 68	52 63	55, 286 7	1, 142, 878	3, 791, 502	4, 902, 034	6, 044, 912

County	Ore raised and treated	Average yield per ton			Bullion produced from ore raised and treated during census year				
		Gold	Silver	Gold and silver	Gold		Silver		Total.
	Tons	Dolls	Dolls	Dolls	Ounces	Dolls	Ounces	Dolls	Dolls
Beaver Head ...	10, 902 0	1 81	66 90	68 71	955 4	19, 750	564, 110	729, 338	749, 088
Deer Lodge ...	57, 029 0	5 92	34 83	40 75	16, 337 7	337, 729	1, 536, 134	1, 986, 067	2, 323, 796
Jefferson	3, 038 0	18 49	24 54	43 03	2, 717 2	56, 169	57, 670	74, 562	130, 731
Lewis and Clarke	10, 343 0	12 71	2 44	15 15	6, 361 3	131, 499	19, 554	25, 281	156, 780
Madison	5, 264 5	16 49	07	16 56	4, 198 8	86, 798	292	378	87, 176
Total	86, 576 5	7 30	32 52	39 82	30, 570 4	631, 945	2, 177, 760	2, 815, 626	3, 447, 571

County	Ore raised but not treated	Assay value of ore raised during census year and remaining on hand at close of year					Bullion produced from ore raised prior to census year				
		Gold.		Silver		Total	Gold		Silver		Total
	Tons	Ozs	Dolls	Ozs	Dolls	Dolls	Ozs	Dolls	Ozs	Dolls	Dolls
Beaver Head ...	34 0	...	...	4, 208	5, 440	5, 440	.	....	....	....	.....
Deer Lodge	24, 227 0	5, 867 6	121, 294	852, 237	1, 101, 857	1, 223, 151	203 2	4, 200	61, 808	79, 911	84, 111
Jefferson .	297 0	3, 990 9	82, 499	2, 700	3, 491	85, 990	11 3	234	1, 029	1, 330	1, 564
Lewis and Clarke	150 0	119 0	2, 460	600	776	3, 236		....	.....	.....	......
Madison	3, 573 5	2, 883 7	59, 611	558	721	60, 332	313 5	6, 481	.....	...	6, 481
Total	28, 281. 5	12, 861 2	265, 864	860, 303	1, 112, 285	1, 378, 149	528 0	10, 915	62, 837	81, 241	92, 156

* Estimated

In the foregoing table the following possible cause of error should be noted: In Summit Valley district, Deer Lodge County, owing to the incomplete character of some of the returns, and the fact that many mines sell ore to both mills and smelters, there has been a possible duplication in estimating the bullion product. This overestimate, if such it really is, would not, however, amount to more than 500 tons, and is probably more than offset by the insufficiency of the data obtained. Considerable copper ore carrying silver goes out of the county for treatment, some of which could not be traced. Manganese ore, carrying some silver, is used by the smelters as flux, and is not accounted for in the "Tons raised"; but its yield should appear in the "Bullion produced".

The following table shows the relative amounts of ore reduced in stamp mills and by smelting works, with the average yield per ton, and total contents in gold and silver in each case:

TABLE XXVI.—MONTANA—*Ore treated by smelting works and amalgamating mills.*

	Ore treated.	Average yield per ton			Bullion produced				
		Gold.	Silver.	Gold and silver	Gold		Silver		Total.
	Tons.	Dollars	Dollars.	Dollars	Ounces.	Dollars	Ounces.	Dollars	Dollars.
Smelted......	14, 680 0	64	78 36	79 00	454 4	9, 393	889, 362	1, 149, 856	1, 159, 249
Milled	71, 896. 5	8 65	23 18	31 83	30, 116 0	622, 552	1, 288, 398	1, 665, 770	2, 288, 322
Total ..	86, 576 5	7 30	32 52	39 82	30, 570 4	631, 945	2, 177, 760	2, 815, 626	3, 447, 571

HYDRAULIC AND PLACER MINES.—The gravel deposits of Montana form an important source of its wealth, and their product is known to be very considerable. The figures for this product, as explained above, have been assumed, in the absence of more reliable data derived from direct information, and are:

Gold...ounces..	56, 255.6
Value..	$1, 162, 908

The counties from which hydraulic-mine returns were received are Deer Lodge, Meagher, Beaver Head, and Lewis and Clarke, the relative amount of production reported from each standing in the order in which they are named above.

The ores of Montana, like those of Colorado, contain considerable amounts of copper and lead, which cannot be neglected in considering its production of metals. The table below gives the amounts which could be traced, a portion of the copper having been reduced to copper oxide in Colorado. The figures quoted are for crude bullion which was not reduced to the metallic state within the Territory. A certain amount of copper ore was shipped directly east from Montana, but its value or contents could not be ascertained.

TABLE XXVII.—MONTANA—*Crude bullion product for the year ending May* 31, 1880.

County.	Gross tons	Base bullion				Precious metal contents				Total
		Lead		Copper		Gold		Silver		
		Tons	Dolls	Tons	Dolls.	Ozs.	Dolls	Ounces	Dolls.	Dolls.
Beaver Head....	1, 568	1, 132.5	101, 925	186 25	74, 500	. ..	....	562, 574	727, 352	903, 777
Deer Lodge......	525	......	.. ..	420 00	168, 000	343 5	7, 101	160, 300	207, 252	382, 353
Jefferson	83	81 5	7, 335	......	.. ..	332 0	6, 863	30, 378	39, 276	53, 474
Total	2, 176	1, 214 0	109, 260	606 25	242, 500	675 5	13, 964	753, 252	973, 880	1, 339, 604

Lead, $90 per ton Copper, $400 per ton

NEW MEXICO.

Although during the census year the mines of New Mexico were attracting much attention, their practical development was awaiting the completion of the railroads which were about to intersect it. Its mining districts were, many of them, difficult and even dangerous of access, and it was almost impossible to ascertain in advance whether they had actually producing mines. The collection of statistics under these circumstances was peculiarly difficult, and the completeness of the material obtained was seriously impaired by the assassination of Col. Charles Potter, the expert in charge of this Territory. The data presented below do not necessarily give a fair idea of the capabilities of the Territory as a mineral producer. It is believed, however, that the quantity of ore produced during the census year, and not accounted for below, is not of very great amount.

The subjoined table gives the production of the deep mines by counties:

TABLE XXVIII.—NEW MEXICO—*Production of deep mines for the year ending May 31, 1880.*

County.	Ore raised during census year	Average assay value per ton			Total assay value of ore raised during census year				
		Gold	Silver.	Gold and silver.	Gold.		Silver		Total.
	Tons.	Dolls	Dolls	Dolls	Ozs.	Dolls	Ozs.	Dolls	Dolls.
Doña Aña	718 5	82 65	......	82 65	2,872 8	59,386	......	......	59,386
Grant	9,668.0	2 62	79 78	82 40	1,225 0	25,323	596,567	771,301	796,624
Santa Fé	100 0	20 67	32 32	52 99	100 0	2,067	2,500	3,232	5,299
Total	10,486 5	8 28	73 86	82 14	4,197 8	86,776	599,067	774,533	861,309

County.	Ore raised and treated.	Average yield per ton			Bullion produced from ore raised during census year.				
		Gold.	Silver.	Gold and silver	Gold		Silver		Total.
	Tons.	Dolls	Dolls	Dolls	Ounces	Dollars.	Ounces	Dollars	Dollars
Doña Aña	718 5	49 59	......	49 59	1,723 7	35,632	......	......	35,632
Grant	6,734 0	2 04	58 26	60 30	663 8	13,722	303,455	392,337	406,059
Total	7,452 5	6 62	52 65	59 27	2,387 5	49,354	303,455	392,337	441,691

County.	Ore raised but not treated.	Assay value of ore raised during census year and remaining on hand at close of year				
		Gold.		Silver		Total
	Tons.	Ounces.	Dollars.	Ounces	Dollars	Dollars
Grant	2,934	....	....	178,288	230,509	230,509
Santa Fé	100	100	2,067	2,500	3,232	5,299
Total	3,034	100	2,067	180,788	233,741	235,808

PLACER MINES.—Considerable rich placer ground is known to exist in New Mexico, but as yet but little gold has been obtained from it, owing to want of water. No record could be obtained of any product from such workings during the census year.

WYOMING.

Wyoming is surrounded on three sides by important mining regions, but has as yet developed but few mines within its borders. During the census year, as far as could be ascertained, the actual production of gold and silver has been confined to Sweetwater County, of which the production is given below:

TABLE XXIX.—WYOMING—*Production of deep mines for the year ending May* 31, 1880.

County	Ore raised during census year	Average assay value per ton			Total assay value of ore raised during census year.				
		Gold	Silver	Gold and silver	Gold		Silver		Total.
	Tons	Dolls	Dolls	Dolls.	Ounces	Dollars	Ounces	Dollars	Dollars
Sweetwater	843	*27 42	- ...	*27 42	*1,118 1	*23,113	....	....	*23,113
Total	843	*27 42	......	*27 42	*1,118 1	*23,113	....	....	*23,113

County	Ore raised and treated.	Average yield per ton			Bullion produced from ore raised and treated during census year				
		Gold	Silver.	Gold and silver.	Gold		Silver.		Total
	Tons	Dolls	Dolls.	Dolls	Ounces	Dollars	Ounces	Dollars	Dollars
Sweetwater	843	20 55	.....	20 55	837 9	17,321	....	....	17,321
Total	843	20 55	.....	20 55	837.9	17,321	....	....	17,321

* Estimated.

STATISTICS OF THE EASTERN DIVISION.

The following tables, which are grouped together without comment, are compiled from schedule data furnished by Prof. Raphael Pumpelly, together with such information as could be gathered from other sources than the direct census investigation. Some unavoidable gaps occur in the tables, arising chiefly from the uncertainty regarding assay values to be expected where mining is conducted on a small scale. The estimates for Michigan and for Tennessee are not included in this exhibit, as they are derived exclusively from material other than that collected directly by the experts.

TABLE XXX.—ALABAMA—*Production of deep mines for the year ending May* 31, 1880.

County.	Ore raised and treated	Average yield per ton—gold	Gold bullion produced from ore raised and treated during census year.	
	Tons	Dollars	Ounces	Dollars
Cleburn	100	10 00	48 4	1,000
Talladega	24	12 50	14 5	300
Total	124	10 50	62.9	1,300

TABLE XXXI.—GEORGIA—*Production of deep mines for the year ending May* 31, 1880.

County.	Ore raised during census year.	Average assay value per ton—gold	Assay value of ore raised during census year		Ore raised and treated during census year	Average yield per ton—gold.	Gold bullion produced from ore raised and treated during census year.		Ore raised but not treated	Assay value of ore raised during census year and remaining on hand at close of year.	
	Tons	Dolls	Ozs	Dolls.	Tons.	Dolls.	Ozs.	Dolls	Tons	Ozs.	Dolls.
Cherokee	262	22 00	151 1	3,124	205	11 22	111 3	2,300	57	60 7	1,255
Cobb *a*	100	......	......	......	100	4 00	19 3	400	......	......	......
Forsyth *a*	40	......	......	......	40	5 08	9 8	203	......	......	......
Hall *a*	150	......	......	......	150	10 00	72 6	1,500	......	......	......
Lincoln *a*	550	......	......	......	550	10 88	289 5	5,984	......	......	......
McDuffie *a*	100	......	......	......	100	6 00	29 0	600	......	......	......
Meriwether *a*	1,590	......	......	......	1,590	2 00	153.8	3,180	......	......	......
Total	2,792	......	151 1	3,124	2,735	5 18	685 3	14,167	57	60.7	1,255

a Assay values not given.

TABLE XXXII.—GEORGIA—*Production of placer-mines for the year ending May* 31, 1880.

County.	Gold.	
	Ounces	Dollars.
Cherokee	10.9	225
Hall	183 2	3,788
Lumpkin	2,838.3	58,673
Union	72.6	1,500
White	129.5	2,677
Total	3,234.5	66,863

TABLE XXXIII.—MAINE—*Production of deep mines for the year ending May 31, 1880.*

County.	Ore raised during census year	Average assay value per ton.			Assay value of ore raised during census year.				
		Gold.	Silver.	Gold and silver	Gold.		Silver.		Total
	Tons.	Dolls	Dolls	Dolls.	Ounces	Dollars.	Ounces.	Dollars	Dollars.
Hancock	1,800	......	30 00	30 00	....	....	39,446	51,000	51,000
Penobscot	400	26 87	5 17	32 04	519 9	10,748	1,599	2,068	12,816
York	50	6 75	32 30	39 05	16 3	337	1,249	1,615	1,952
Total	2,250	4 93	24 30	29 23	536.2	11,085	42,294	54,683	65,768

County	Ore raised and treated	Average yield per ton			Bullion produced from ore raised and treated during census year.				
		Gold.	Silver.	Gold and silver	Gold.		Silver		Total
	Tons	Dolls.	Dolls	Dolls	Ounces	Dollars	Ounces	Dollars	Dollars
Hancock	400	7 50	18 00	25 50	145 1	3,000	5,569	7,200	10,200
Total	400	7 50	18 00	25 50	145 1	3,000	5,569	7,200	10,200

County.	Ore raised but not treated	Assay value of ore raised during census year and remaining on hand at close of year.				
		Gold.		Silver.		Total.
	Tons.	Ounces	Dollars	Ounces	Dollars.	Dollars
Hancock	1,400	....	....	32,486	42,000	42,000
Penobscot	400	519 9	10,748	1,599	2,068	12,816
York	50	16 3	337	1,249	1,615	1,952
Total	1,850	536.2	11,085	35,334	45,683	56,768

TABLE XXXIV.—NEW HAMPSHIRE—*Production of deep mines for the year ending May 31, 1880.*

County.	Ore raised and treated	Average yield per ton.			Bullion produced from ore raised and treated during census year.				
		Gold.	Silver	Gold and silver.	Gold.		Silver.		Total
	Tons.	Dolls.	Dolls	Dolls	Ounces	Dollars	Ounces	Dollars.	Dollars
Grafton	2,183	5 04	7 32	12 36	532 1	11,000	12,375	16,000	27,000
Total	2,183	5 04	7 32	12 36	532 1	11,000	12,375	16,000	27,000

TABLE XXXV.—NORTH CAROLINA—*Production of deep mines for the year ending May 31, 1880.*

County	Ore raised during census year	Average assay value per ton			Assay value of ore raised during census year.				
		Gold	Silver	Gold and silver	Gold		Silver		Total
	Tons	Dolls	Dolls	Dolls	Ounces	Dollars.	Ounces	Dollars	Dollars.
Davidson	20,200	17 50	2 50	20 00	16,931 2	*350,000	38,673	*50,000	*400,000
Gaston	1,821	.....	.....	.....	.....	.....	.....	.....	.....
Guilford	10	.....	.....	.....	.....	.....	.....	.....	.....
Mecklenburg	11,370	.....	.....	.....	.....	.....	.....	.....	.....
Moore	625	.....	.....	.....	.....	.....	.....	.....	.....
Nash	60	.....	.....	.....	.....	.....	.....	.....	.....
Rowan	1,200	9 00	3 00	12 00	522 4	10,800	2,784	3,600	14,400
Stanley	500	.....	.....	.....	.....	.....	.....	.....	.....
Total	35,786	.....	.....	.....	17,453.6	360,800	41,457	53,599	414,400

County.	Ore raised and treated.	Average yield per ton			Bullion produced from ore raised and treated during census year.				
		Gold	Silver	Gold and silver.	Gold		Silver.		Total
	Tons.	Dolls	Dolls	Dolls.	Ozs	Dolls	Ozs.	Dolls.	Dolls
Davidson	206	10 00	.....	10 00	96.8	2,000	.....	.....	2,000
Gaston	1,821	5 00	.....	5 00	440 5	9,107	.....	.....	9,107
Guilford	10	28 70	.....	28 70	13 9	287	.....	.....	287
Mecklenburg	11,370	8 33	.....	8 33	4,584 5	94,770	.....	.....	94,770
Moore	625	7 84	0 16	8 00	237 0	4,900	77	100	5,000
Nash	60	20 07	.....	20 07	58 2	1,204	.....	.....	1,204
Stanley	500	4 00	.....	4 00	96 8	2,000	.....	.....	2,000
Total	14,586	7 83	.....	7 83	5,527 7	114,268	77	100	114,368

County.	Ore raised but not treated.	Assay value of ore raised during census year and remaining on hand at close of year.				
		Gold		Silver		Total.
	Tons	Ozs.	Dolls	Ozs	Dolls	Dolls
Davidson	20,000	*16,931 2	*350,000	*38,673	*50,000	*400,000
Rowan	1,200	522 4	10,800	2,784	3,600	14,400
Total	21,200	*17,453.6	*360,800	*41,457	*53,600	414,400

* Estimated.

TABLE XXXVI.—NORTH CAROLINA—*Production of placer mines for the year ending May* 31, 1880.

County.	Gold	
	Ounces.	Dollars.
Montgomery	207 6	4,291
Pope	19 1	396
Total	226.7	4,687

TABLE XXXVII.—SOUTH CAROLINA—*Production of deep mines for the year ending May 31, 1880.*

County.	Gold bullion produced from ore raised and treated during census year	
	Ounces	Dollars
Abbeville	24 2	500
Colleton	290 2	6,000
Total	314 4	6,500

TABLE XXXVIII.—SOUTH CAROLINA—*Production of placer mines for the year ending May 31, 1880.*

County	Gold	
	Ounces.	Dollars
Chesterfield	316 4	6,541
Total	316 4	6,541

TABLE XXXIX.—VIRGINIA—*Production of deep mines for the year ending May 31, 1880.*

County.	Ore raised during census year	Average assay value per ton			Assay value of ore raised during census year.				
		Gold	Silver	Gold and silver	Gold		Silver		Total.
	Tons	Dolls	Dolls	Dolls	Ozs	Dolls	Ozs	Dolls	Dolls.
Buckingham	74	......	.. ..	......	......	......	......	......	..
Culpeper	90	40 09	1 40	41 49	174 5	3,608	97	126	3,734
Total	164	.. ...	.. ..	.. ...	174 5	3,608	97	126	3,734

County	Ore raised and treated	Average assay value per ton—gold	Gold bullion produced from ore raised and treated during census year		Ore raised but not treated	Assay value of ore raised during census year and remaining on hand at close of year.				
						Gold		Silver.		Total.
	Tons.	Dollars	Ounces	Dollars	Tons.	Ozs	Dolls	Ozs	Dolls	Dollars.
Buckingham	74	5 00	17 9	371	......	......	......	......	......	.. ...
Culpeper	5	35 80	8 7	179	85	164 8	3,408	94	122	3,530
Total from schedule data	79	6 96	26 6	550	85	164 8	3,408	94	122	3,530
Additional production shown by mint receipts	......	... ...	424.3	8,772	......	......	......	......	......	....
Total	......	....	450.9	9,322	85	164.8	3,408	94	122	3,530

SILVER CONTAINED IN PLACER GOLD.

No account is taken by the miners of the silver alloyed with placer gold, unless in the exceptional cases where the value of the former is allowed for in the sale of the product, as in direct sales to the mints or United States assay offices. In the aggregate this silver forms a considerable item, which should be included in the total product, but which has usually been disregarded by statisticians.

The schedules of the experts contain data for a close estimate as to the average tenor of the placer product. A statement of the fineness in gold of samples from various localities is appended.

TABLE XL.—*Specimen examples of placer gold.*

CALIFORNIA

County and locality	Fineness in gold	Remarks.
BUTTE		
Centerville	0 900	
Cherokee Flat	0 970	
Magalia	0 900	
Morris Ravine	0.905—0 908	
Oroville	0 942	
CALAVERAS.		
Mokelumne Hill	0 850—0 960	
DEL NORTE		
Bunker Hill Mine	0 887—0 925	
China Creek	0 900	
Happy Camp	0 875—0 935	
Indian Creek	0 900	
Wingate Mine	0 944—0 950	
EL DORADO		
Placerville	0 980	
HUMBOLDT.		
Gold Bluffs	0 940	
Orleans Bar	0.726	Sold for $13 to $17 per ounce.
PLACER		
Bath	0 850	
Dutch Flat	0 900—0 910	
Gold Run	0 900	
Iowa Hill	0 784—0 814	
Michigan Bluffs	0 925—0 960	
PLUMAS.		
Black Hawk Mine	0 924	
Cook's Cañon	0 885	
Gopher Hill	0 936	
Hungarian Hill	0 924	
Seneca	0.846	
SHASTA.		
Igo	0.885	
SISKIYOU.		
Callahan's Ranch	0 859	Sold for $17 75 per ounce.
Cottonwood	0.860	
Coyote Gulch	0 900—0 950	
Galena Hill	0 880—0.930	
Greenhorn	0 850	
Humbug Creek	0 809—0 865	
Indian Creek	0.835—0 900	Sold for $17 per ounce.
McAdams Creek	0 750—0 900	
Oro Fino	0 762	

TABLE XL.—*Specimen examples of placer gold*—Continued.

CALIFORNIA—Continued.

County and locality.	Fineness in gold	Remarks
Rattlesnake Creek	0. 827	Sold for $16.50 per ounce
Sawyer's Bar	0 850	
Sciad Valley	0 887—0. 912	
Scott Valley	0 805	Sold for $16 to $16.25 per ounce.
South Fork Salmon	0 835	Sold for $16.75 per ounce.
Yreka	0. 749—0 863	Sold for $15 to $17.12 per ounce
STANISLAUS.		
La Grange	0. 920	
TRINITY.		
Buckeye	0 890—0 900	
Cañon Creek	0 894—0 896	
Chapman's and Fisher's Mines	0 914—0 917	
Douglas	0 912	
Indian Creek	0 920	
Junction City	0 875—0 915	Sold for $18 per ounce.
Red Hill	0 910—0. 917	
Trinity Center	0. 900	
Trinity Mine	0 887—0 903	
Weaver	0. 906—0. 927	

COLORADO.

CHAFFEE		
Hope	0 850	
CLEAR CREEK.		
Jackson	0. 880	
LAKE.		
California	0. 850—0. 875	
PARK		
Alma township	0. 819	
ROUTT		
Hahn's Peak	0. 666	
SUMMIT		
Bevan	0 750—0 820	
Spalding	0. 850—0. 900	

DAKOTA.

LAWRENCE		
Bear Gulch	0 940	
Cape Horn	0. 870	
PENNINGTON.		
Cañon	0 925	
Confederate	0 925—0. 940	
Jenny and Strawberry	0 940	

GEORGIA.

CHEROKEE.		
Fifteenth district	0. 927	Sold for $19 20 per ounce.
HALL.		
810 G. M. 9th and 12th districts	0. 900—0 916	

TABLE XL.—*Specimen examples of placer gold*—Continued.

GEORGIA—Continued.

County and locality	Fineness in gold.	Remarks.
LUMPKIN		
Twelfth district	0.875—0.995	
Thirteenth district	0.962—0.992	
WHITE		
Fourth district	0.945	
UNION.		
Tenth district	0.981	

IDAHO

BOISÉ		
Boisé Basin and vicinity	0.7806	Average of 413 lots.

MONTANA.

BEAVER HEAD.		
Bannock	0.935	
DEER LODGE		
Gold Hill	0.950—0.956	
Henderson Gulch	0.925—0.957	
Independence	0.725—0.730	
McClellan's Gulch	0.860—0.930	Sold for $17.50 per ounce
Nelson	0.935—0.940	
Summit Valley	0.700	
LEWIS AND CLARKE		
Last Chance	0.910	
MEAGHER		
German	0.830—0.835	
Thompson's Gulch	0.945—0.980	

OREGON

BAKER		
Amelia	0.810—0.900	
Blue Cañon	0.840—0.853	Sold for $16.50 per ounce
Chicken Creek	0.725	Sold for $15 per ounce
Humboldt Basin	0.789—0.866	Do Do
Mormon Basin	0.750	Sold for $16 per ounce
Pocahontas	0.782—0.851	Sold for $15.50 to $17 per ounce.
Rye Valley	0.756	
Shasta	0.850—0.860	Sold for $16.50 per ounce
Willow Creek	0.825	
CURRY		
Sixes River	0.825	Sold for $17 per ounce
DOUGLAS		
Big Bend	0.925—0.950	Sold for $17 per ounce
Cañonville	0.900—0.956	
Green Mountain	0.825—0.830	
GRANT.		
Cañon City	0.850—0.900	Sold for $17.60 per ounce.
Granite	0.750—0.761	
Marysville	0.805—0.887	Sold for $16.25 to $17.60 per ounce
Rock Creek	0.857	Sold for $16.50 to $16.75 per ounce.
Trail Creek	0.850	

TABLE XL.—*Specimen examples of placer gold*—Continued.

OREGON—Continued.

County and locality.	Fineness in gold.	Remarks
JACKSON.		
Applegate	0.850	
Ashland	0.846	
Coyote Creek	0.895—0.930	
Dry Diggings	0.975	
Fort Lane	0.870	Sold for $16.25 per ounce
Forty-nine	0.837	Sold for $16.50 per ounce
Grass Creek	0.875—0.900	
Jackass Creek	0.950	
Jacksonville	0.860	
Sam's Valley	0.825	
Sardine Creek	0.810—0.900	Sold for $16.75 per ounce
Sterling	0.826—0.908	
Uniontown	0.804—0.820	Sold for $16.75 per ounce.
Wolf Creek	0.925	
JOSEPHINE.		
Althouse	0.865—0.875	Sold for $16.50 per ounce.
Cañon Creek	0.900	Sold for $17 per ounce.
Grass Creek	0.909—0.930	
Illinois	0.900	
Josephine	0.900	
Murphy	0.900	
Silver Creek	0.900	
Waldo	0.910—0.927	
Yank	0.967	
UMATILLA.		
Columbia River	0.740	Sold for $15.30 per ounce.
WASCO.		
Ochoco	0.711	

From the same sources the following condensed abstract has been prepared, showing the average fineness in gold and silver of the placer yield of several States and Territories, with the number of specimen examples from which these averages are derived. The amount of base metal contained in the crude bullion varies from nothing to 0.020.

TABLE XLI.—*Average tenor of placer gold.*

State or Territory.	Number of examples	Average fineness	
		Gold	Silver.
California	80	0.8836	0.1124
Colorado	9	0.8205	0.1755
Dakota	7	0.9235	0.0725
Georgia	10	0.9228	0.0732
Idaho	413	0.7806	0.2134
Montana	14	0.8951	0.1009
Oregon	77	0.8727	0.1233
Total	610	......	......

From eighty examples of California placer dust and bullion an average fineness of 0.8836 is derived, a proportion slightly in excess of that stated in Dana's "Mineralogy," where the fineness is quoted at 0.875 to 0.885, or an average of 0.880. It is possible that the census average is a trifle too high, owing to the natural tendency of producers to overestimate the fineness of their gold; but the slight difference between it and the figures given by Dana would not materially affect the general result.

The average for Idaho is of 413 lots of placer gold from Boisé basin, a district producing three-fourths of the total for the Territory. This gold is of less fineness than that obtained in several other localities in Idaho, but the average stated will hold as a close approximation for the total.

There are three methods of obtaining from these data an average for the United States—neither of which is quite free from defects.

If the sum of the figures representing the average gold fineness for the several States and Territories be divided by seven, the number of the States and Territories from which reliable data as to fineness are obtainable, the quotient is 0.871257, which may be described as an average of geographical distribution. This, however, does not represent the average fineness of the whole actual amount produced, for by this method each State and Territory is taken as an equal member in the calculation, without regard to the large difference in their several products. Thus, Georgia, with a product of $66,863, has as much weight in influencing the general average as California with a placer yield of $8,580,989, or 128 times as large.

Another mode is to give each individual example equal weight, disregarding territorial limits. Dividing the sum of fineness in gold of 610 specimen examples, 495,887, by 610, an average of 0.8129 is obtained. This gives a true average for the number of cases in which the fineness is definitely given in the schedules, but represents neither the average according to geographical distribution nor that of the whole product. In this way California, with a placer product nine and three-fourths times greater than that of Idaho, is largely overweighted by the latter, owing to the preponderance of examples furnished by Idaho in the census returns. The result is evidently too low.

The third and preferable method is to multiply the average fineness for each State and Territory by the coefficient of the several yields, and then divide the sum of the products so obtained by the sum of the coefficients. This gives each not an equal but a just weight. The result is the average fineness of the total product without reference to the producing source. This principle is thus applied:

State or Territory	Average fineness in gold		Yield of placer gold in millions of dollars		Resultants.
California	0 8836	×	8.581	=	7.5821716
Colorado	0.8205	×	0.102	=	0.0836910
Dakota	0.9235	×	0.051	=	0.0470985
Georgia	0.9228	×	0.067	=	0.0618276
Idaho	0 7806	×	0.880	=	0 6869280
Montana	0.8951	×	1.163	=	1.0410013
Oregon	0.8727	×	0.926	=	0.8081202
			11 770		10.3108382

$$\text{Total average gold fineness} = \frac{10.3108382}{11\ 770} = 0\ 87602$$

The proportionate contents in silver and in base metal are similarly ascertained. By using the figures representing the average tenor of the placer gold for each of the States and Territories for which reliable data are obtainable, and assuming the general average deduced from them for the cases in which the returns are defective, the probable total silver contents may readily be calculated. It is found that the 580,766.6 ounces of fine gold were associated with 80,177.3 ounces of fine silver and 2,753.2 ounces of base metal, making the total weight of the crude placer gold 663,697.1 ounces. In mint value the silver contents were worth only $103,661 as against $12,005,524 for the gold. Thus while the ratio of silver to gold products was 1 : 7.2437 in weight, it was only 1 : 115 8153 in assay value. At the market rates the value of this placer silver, if any account were taken of it, would be considerably less, or a ratio of about 1 : 131. The loss to the miners in the price paid for the actual gold contents of the placer dust, when sold in small quantities to local dealers, is so much greater than the whole value of the silver contents, that the latter does not appear to them a matter of any consequence. The amount of silver alloyed with the placer gold of the several States and Territories is shown in the accompanying table:

TABLE XLII.—*Contents and mint value of crude placer gold.*

State or Territory	Contents of placer gold.				Mint value		
	Fine gold	Fine silver	Base metal	Total crude metal	Gold	Silver.	Total
	Ounces	Ounces.	Ounces.	Ounces.	Dollars	Dollars	Dollars
Alaska	287 9	*39 4	1 3	328 6	5, 951	*51	6, 002
Arizona	*1, 451 2	*198 8	*6 6	*1, 656 6	*30, 000	*257	*30, 257
California	415, 105 0	52, 804 2	1, 879 1	469, 788 3	8, 580, 989	68, 271	8, 649, 260
Colorado	4, 921 9	1, 052. 8	24 0	5, 998 6	101, 745	1, 361	103, 106
Dakota	2, 460 3	193 1	0 2	2, 653 6	50, 859	250	51, 109
Georgia	3, 234 5	256 6	14 0	3, 505 1	66, 863	332	67, 195
Idaho	42, 552 8	11, 633 1	327 1	54, 512 9	879, 645	15, 040	894, 685
Montana	56, 255 6	6, 341 4	251 4	62, 848 4	1, 162, 908	8, 199	1, 171, 107
Nevada	*2, 418 7	*331 3	*11 0	*2, 761 1	*50, 000	*428	*50, 428
North Carolina	*226 7	*31 0	*1 0	*258 8	*4, 687	*40	*4, 727
Oregon	44, 811 5	6, 331 2	205 4	51, 348 1	926, 336	8, 186	934, 522
South Carolina	316 4	*43. 3	*1. 4	*361 2	6, 541	*56	*6, 597
Utah	967 5	*132 5	*4 4	*1, 104 4	20, 000	*171	*20, 171
Washington	5, 756 6	*788. 6	*26 3	*6, 571 4	119, 000	*1, 019	*120, 019
Total	580, 766 6	80, 177. 3	2, 753. 2	663, 697 1	12, 005, 524	103, 661	12, 109, 185

* Estimated

RÉSUMÉ OF PRODUCTION STATISTICS.

The total product of each State and Territory, including the yield of the deep mines from ore which was raised prior to, but reduced during, the census year, and also the silver contents of placer gold, appears in the complete exhibit contained in the following table, which shows the aggregate bullion output of the United States for the year ending May 31, 1880:

TABLE XLIII.—*Production by geographical divisions.*

PACIFIC DIVISION

State or Territory.	Product.		
	Gold.	Silver	Total
Alaska	$5,951	$51	$6,002
Arizona	211,966	2,325,826	2,537,792
California	17,150,954	1,150,886	18,301,840
Idaho	1,479,655	464,550	1,944,205
Nevada	4,888,247	12,430,666	17,318,913
Oregon	1,097,700	27,793	1,125,493
Utah	291,555	4,743,090	5,034,645
Washington	135,800	1,019	136,819
Total	25,261,828	21,143,881	46,405,709

DIVISION OF THE ROCKY MOUNTAINS

State or Territory.	Gold.	Silver	Total
Colorado	$2,699,900	$16,549,274	$19,249,174
Dakota	3,305,846	70,813	3,376,659
Montana	1,805,768	2,905,066	4,710,834
New Mexico	49,354	392,337	441,691
Wyoming	17,321	....	17,321
Total	7,878,189	19,917,490	27,795,679

EASTERN DIVISION.

State or Territory.	Gold.	Silver	Total
Alabama	$1,300	....	$1,300
Georgia	81,030	$332	81,362
Maine	3,000	7,200	10,200
Michigan	....	25,858	25,858
New Hampshire	11,000	16,000	27,000
North Carolina	118,955	140	119,095
South Carolina	13,041	56	13,097
Tennessee	1,998	....	1,998
Virginia	9,322	....	9,322
Total	239,646	49,586	289,232

SUMMARY

Division	Gold.	Silver	Total
Pacific Division	$25,261,828	$21,143,881	$46,405,709
Division of the Rocky Mountains	7,878,189	19,917,490	27,795,679
Eastern Division	239,646	49,586	289,232
Total	33,379,663	41,110,957	74,490,620

The relative quota contributed by each of the three great arbitrary divisions into which the country has been apportioned is indicated in the foregoing abstract, from which it will be seen that the Pacific division furnished 75.68 per cent. of the gold, 51.43 per cent. of the silver, and 62.43 per cent. of the total. The division of the Rocky Mountains yields 23.60 per cent. of the gold, 48.45 per cent. of the silver, and 37.18 per cent. of the total. The product of the Eastern division represents 0.72 per cent. of the gold, 0.12 per cent. of the silver, and 0.39 per cent. of the total.

The bullion product of the deep mines of the United States for the year under review amounted to 35 tons 900 pounds avoirdupois (1,033,973.1 ounces troy) of fine gold, and 1,087 tons 900 pounds avoirdupois (31,717,299 ounces troy) of fine silver. That of the placer mines weighed 19 tons 1,824 pounds avoirdupois (580,766.6 ounces troy) in fine gold, with which were alloyed 2 tons 1,498 pounds avoirdupois (80,177 ounces troy) of silver. The total weight of fine bullion was no less than 55 tons 724 pounds avoirdupois (1,614,739.7 ounces troy) of gold, and 1,090 tons 398 pounds avoirdupois (31,797,476 ounces troy) of silver. These huge figures may be better grasped, perhaps, by considering that the gold represents five ordinary car-loads, while a train of 109 freight cars of the usual capacity would be required to transport the silver. Historians have stated that during the early Spanish occupation whole galleons were freighted exclusively with silver from the mines of Mexico and Peru. This would hardly seem to be an exaggeration, in view of the fact that the present annual product of the United States would suffice to form the full cargo of a large modern vessel.

COMPARISONS.

The relative proportion of placer gold to that produced by the deep mines; the percentage in each class of product of the precious metals from the several mining regions of the United States; the average yield per square mile and per capita in different localities, and the rank of the States and Territories in productiveness, are indicated in the following exhibits:

TABLE XLIV.—*Percentage of placer gold and gold from deep mines in total gold product.*

State or Territory	Placer mines	Deep mines
Alabama		100 00
Alaska	100 00	
Arizona	14 16	85 84
California	50 03	49 97
Colorado	3 77	96 23
Dakota	1 54	98 46
Georgia	82 51	17 49
Idaho	59 42	40 58
Maine		100 00
Montana	64 40	35 60
Nevada	1 02	98 98
New Hampshire		100 00
New Mexico		100 00
North Carolina	3 94	96 06
Oregon	84 39	15 61
South Carolina	50 16	49 84
Tennessee		100 00
Utah	6 86	93 14
Virginia		100 00
Washington	87 63	12 37
Wyoming		100 00
United States (including Alaska)	35 97	64 03

TABLE XLV.—*Relative production of the States and Territories.*

State or Territory.	Gold.			Silver.	Total.
	Placer mines	Deep mines.	Total gold		
	Per cent.	Per cent	Per cent.	Per cent	Per cent.
Alabama		0 01	0 01		
Alaska	0.05		0 02		
Arizona	0 25	0 85	0 63	5 66	3 40
California	71 47	40 09	51 38	2 80	24 70
Colorado	0 85	12 16	8 09	40 25	25 85
Dakota	0 42	15.23	9 90	0.17	4.52
Georgia	0 56	0 07	0 24		0 10
Idaho	7 32	2 81	4 43	1 13	2 60
Maine		0 01	0 01	0 02	0 01
Michigan				0 06	0 03
Montana	9 68	3 01	5 41	7 07	6 32
Nevada	0 41	22 64	14.64	30 24	23 24
New Hampshire		0 05	0 03	0 04	0 03
New Mexico		0 23	0 15	0.95	0 59
North Carolina	0 04	0 53	0 36		0 15
Oregon	7 75	0 80	3 29	0 07	1 49
South Carolina	0 05	0 03	0.04		0.01
Tennessee		0 01	0 01		
Utah	0 16	1 27	0 87	11 54	6 75
Virginia		0 04	0 03		0 01
Washington	0 99	0 08	0 41		0 18
Wyoming		0 08	0 05		0 02
Total	100.00	100 00	100 00	100 00	100.00

TABLE XLVI.—*Average product per square mile for the year ending May* 31, 1880.

States and Territories	Gold.	Silver.	Total.
Alabama	$0 02		$0.02
Alaska	.01		01
Arizona	1 87	$20 58	22 45
California	108 80	6 84	115 14
Colorado	25 98	159 22	185 20
Dakota	22 17	48	22 65
Georgia	1 36		1 36
Idaho	17 45	5 30	22 75
Maine	.09	.22	31
Michigan		44	.44
Montana	12 36	19 83	32 19
Nevada	44 16	112 29	156 45
New Hampshire	1 18	1 72	2 90
New Mexico	.40	3 20	3 60
North Carolina	2 28	002	2 282
Oregon	11.43	.20	11 63
South Carolina	43		.43
Tennessee	05		.05
Utah	3 43	55 82	59 25
Virginia	22		22
Washington	1 96		1 96
Wyoming	18		18
United States (including Alaska)	9 31	11 44	20 75
United States (not including Alaska)	11.03	13 55	24 58
United States (including only the States and Territories producing gold and silver, with Alaska)	14 68	18 02	32 70
United States (including only the States and Territories producing gold and silver, and not including Alaska)	19 44	23 88	43 32
Average for Colorado, California, Nevada, Utah, Montana, Dakota, Arizona, and Idaho	33 47	42.64	76 11

TABLE XLVII.—*Average product per capita for the year ending May 31, 1880.*

States and Territories	Gold	Silver.	Total
Alabama	$0.001	......	$0 001
Alaska	20	......	20
Arizona	5 24	$57 51	62 75
California	19 84	1 25	21 09
Colorado	13 89	85 16	99 05
Dakota	24 46	.52	24 98
Georgia	.05	......	05
Idaho	45 38	13.78	59 16
Maine	005	011	016
Michigan	......	.02	.02
Montana	46 11	73 98	120 09
Nevada	78 51	199 63	278.14
New Hampshire	03	05	08
New Mexico	.41	3 28	3 69
North Carolina	08	00007	08
Oregon	6 28	.11	6 39
South Carolina	.01	......	01
Tennessee	.001	......	001
Utah	2 03	32 94	34 97
Virginia	.006	......	006
Washington	1 81	......	1 81
Wyoming	83	......	.83
United States (including Alaska)	.66	82	1 48
United States (not including Alaska)	66	.82	1 48
United States (including only the States and Territories producing gold and silver, with Alaska)	2 60	3 20	5 80
United States (including only the States and Territories producing gold and silver, and not including Alaska)	2 61	3 21	5 82
Average for Colorado, California, Nevada, Utah, Montana, Dakota, Arizona, and Idaho	21 05	26 80	47 85

TABLE XLVIII.—*Rank of the States and Territories in actual product, for the year ending May 31, 1880.*

Gold.	Silver.	Total
1. California	1. Colorado	1. Colorado
2 Nevada	2 Nevada	2 California.
3. Dakota	3 Utah	3. Nevada.
4 Colorado	4. Montana	4 Utah
5 Montana	5 Arizona	5. Montana
6. Idaho	6 California	6 Dakota
7. Oregon	7 Idaho	7 Arizona.
8 Utah	8. New Mexico	8 Idaho
9 Arizona	9 Dakota	9 Oregon
10. Washington	10. Michigan	10 New Mexico
11 North Carolina	11 Oregon	11 Washington
12. Georgia	12 New Hampshire	12 North Carolina
13 New Mexico	13 Maine	13. Georgia
14 Wyoming		14 New Hampshire
15 South Carolina		15 Michigan
16 New Hampshire		16 Wyoming
17 Virginia		17 South Carolina
18 Alaska		18 Maine
19. Maine		19. Virginia.
20. Tennessee		20 Alaska
21. Alabama		21. Tennessee.
		22. Alabama

TABLE XLIX.—*Rank of the States and Territories in product per square mile, for the year ending May 31, 1880.*

Gold.	Silver.	Total.
1. California	1. Colorado	1. Colorado.
2. Nevada	2. Nevada	2. Nevada.
3. Colorado	3. Utah	3. California.
4. Dakota	4. Arizona	4. Utah.
5. Idaho	5. Montana	5. Montana.
6. Montana	6. California	6. Idaho.
7. Oregon	7. Idaho	7. Dakota.
8. Utah	8. New Mexico	8. Arizona.
9. North Carolina	9. Dakota	9. Oregon.
10. Washington	10. Michigan	10. New Mexico.
11. Arizona	11. Maine	11. New Hampshire.
12. Georgia	12. Oregon	12. North Carolina.
13. New Hampshire	13. North Carolina	13. Washington.
14. South Carolina		14. Georgia.
15. New Mexico		15. Michigan.
16. Virginia		16. South Carolina.
17. Wyoming		17. Maine.
18. Maine		18. Virginia.
19. Tennessee		19. Wyoming.
20. Alabama		20. Tennessee.
21. Alaska		21. Alabama.
		22. Alaska.

TABLE L.—*Rank of the States and Territories in product per capita, for the year ending May 31, 1880.*

Gold.	Silver.	Total.
1. Nevada	1. Nevada	1. Nevada.
2. Montana	2. Colorado	2. Montana.
3. Idaho	3. Montana	3. Colorado.
4. Dakota	4. Arizona	4. Arizona.
5. California	5. Utah	5. Idaho.
6. Colorado	6. Idaho	6. Utah.
7. Oregon	7. New Mexico	7. Dakota.
8. Arizona	8. California	8. California.
9. Utah	9. Dakota	9. Oregon.
10. Washington	10. Oregon	10. New Mexico.
11. Wyoming	11. New Hampshire	11. Washington.
12. New Mexico	12. Michigan	12. Wyoming.
13. Alaska	13. Maine	13. Alaska.
14. North Carolina		14. North Carolina.
15. Georgia		15. New Hampshire.
16. New Hampshire		16. Georgia.
17. South Carolina		17. Michigan.
18. Virginia		18. Maine.
19. Maine		19. South Carolina.
20. Tennessee		20. Tennessee.
21. Alabama		21. Virginia.
		22. Alabama.

PRODUCTION UNACCOUNTED FOR IN THE PRECEDING TABLES.

In addition to the returns received directly from the mines, there are several minor points to be included in the total yield. A larger item than it is usually considered to be is the annual hoarding of rich specimens. This is not accounted for in the mine production as reported. While it is impossible to state the actual amount thus absorbed with any degree of precision, a careful estimate would place the value of the gold nuggets and ore annually added to the cabinets of collectors at not less than $150,000, and that of the silver ore at about $50,000. This, in view of the great number of mineral collections maintained throughout the mining territory, is certainly not an overestimate.

There is also quite an extensive manufacture of gold quartz into jewelry and souvenirs, particularly in San Francisco. The value so absorbed does not probably fall short of $50,000 annually. In 1870 the United States mining commissioner estimated the amount of gold hoarded as specimens or worked up by local jewelers at $400,000. The same authority, at that period, estimated the annual loss of gold-dust in handling as currency at $100,000. As the practice of using dust for money has almost disappeared, the amount so lost is now very small.

Another indefinite quantity is the value of precious metal lost in melting, in assay grains, etc. Summing up the estimates for these additional items, the following result is reached:

TABLE LI.—*Production unaccounted for in tabulation.*

	Gold	Silver.	Total
Bullion product shown in preceding tables	$33,379,663	$41,110,957	$74,490,620
Estimated value of specimens hoarded	150,000	50,000	200,000
Estimated value of gold quartz made into jewelry and souvenirs	50,000	....	50,000
Estimated value of gold-dust lost in handling as currency	10,000	....	10,000
Estimated loss in melting and assaying, assay grains, etc	20,000	10,000	30,000
Total	33,609,663	41,170,957	74,780,620

ASSAY VALUE OF FINE BULLION.

For convenience in referring to the dual series of troy weights of fine bullion and their equivalent assay values, the following conversion tables, which were prepared for use in tabulating the census statistics of production, are here appended:

TABLE LII.—*Conversion of Troy ounces of fine metal into United States money*

GOLD

1 ounce Troy = $20.671834 1 dollar = 0 048374957925 ounce Troy.

Ounces	Dollars	Ounces	Dollars	Ounces	Dollars	Ounces	Dollars
1	20 671834	51	1,054 263534	100	2,067 1834	5,100	105,426 3534
2	41 343668	52	1,074 935368	200	4,134 3668	5,200	107,493 5368
3	62 015502	53	1,095 607202	300	6,201 5502	5,300	109,560 7202
4	82 687336	54	1,116 279036	400	8,268 7336	5,400	111,627 9036
5	103 359170	55	1,136 950870	500	10,335 9170	5,500	113,695 0870
6	124 031004	56	1,157 622704	600	12,403 1004	5,600	115,762 2704
7	144 702838	57	1,178 294538	700	14,470 2838	5,700	117,829 4538
8	165 374672	58	1,198 966372	800	16,537 4672	5,800	119,896 6372
9	186 046506	59	1,219 638206	900	18,604 6506	5,900	121,963 8206
10	206 718340	60	1,240 310040	1,000	20,671.8340	6,000	124,031 0040
11	227 390174	61	1,260.981874	1,100	22,739 0174	6,100	126,098 1874
12	248 062008	62	1,281 653708	1,200	24,806 2008	6,200	128,165 3708
13	268 733842	63	1,302 325542	1,300	26,873 3842	6,300	130,232 5542
14	289 405676	64	1,322 997376	1,400	28,940 5676	6,400	132,299 7376
15	310 077510	65	1,343 669210	1,500	31,007 7510	6,500	134,366 9210
16	330 749344	66	1,364 341044	1,600	33,074 9344	6,600	136,434 1044
17	351 421178	67	1,385 012878	1,700	35,142 1178	6,700	138,501 2878
18	372 093012	68	1,405 684712	1,800	37,209 3012	6,800	140,568 4712
19	392 764846	69	1,426 356546	1,900	39,276 4846	6,900	142,635 6546
20	413 436680	70	1,447 028380	2,000	41,343 6680	7,000	144,702 8380
21	434 108514	71	1,467 700214	2,100	43,410 8514	7,100	146,770 0214
22	454 780348	72	1,488 372048	2 200	45,478 0348	7,200	148,837 2048
23	475 452182	73	1,509 043882	2,300	47,545.2182	7,300	150,904 3882
24	496.124016	74	1,529 715716	2,400	49,612 4016	7,400	152,971 5716
25	516 795850	75	1,550 387550	2,500	51,679 5850	7,500	155,038 7550
26	537 467684	76	1,571 059384	2,600	53,746 7684	7,600	157,105 9384
27	558 139518	77	1,591 731218	2,700	55,813 9518	7,700	159,173 1218
28	578 811352	78	1,612 403052	2,800	57,881 1352	7,800	161,240 3052
29	599 483186	79	1,633 074886	2,900	59,948 3186	7,900	163,307 4886
30	620 155020	80	1,653 746720	3,000	62,015 5020	8,000	165,374 6720
31	640 826854	81	1,674 418554	3,100	64,082 6854	8,100	167,441 8554
32	661 498688	82	1,695 090388	3,200	66,149 8688	8,200	169,509 0388
33	682 170522	83	1,715 762222	3,300	68,217 0522	8,300	171,576 2222
34	702 842356	84	1,736 434056	3,400	70,284 2356	8,400	173,643 4056
35	723 514190	85	1,757.105890	3,500	72,351 4190	8,500	175,710 5890
36	744 186024	86	1,777 777724	3,600	74,418 6024	8,600	177,777 7724
37	764 857858	87	1,798 449558	3,700	76,485 7858	8,700	179 844 9558
38	785 529692	88	1,819 121392	3,800	78,552 9692	8,800	181 912 1392
39	806 201526	89	1,839 793226	3,900	80,620 1526	8,900	183,979 3226
40	826 873360	90	1,860 465060	4,000	82,687 3360	9,000	186,046 5060
41	847 545194	91	1,881 136894	4,100	84,754 5194	9,100	188,113 6894
42	868 217028	92	1,901 808728	4,200	86,821 7028	9,200	190,180 8728
43	888 888862	93	1,922 480562	4,300	88,888 8862	9,300	192,248 0562
44	909 560696	94	1,943 152396	4,400	90,956 0696	9,400	194,315 2396
45	930 232530	95	1,963 824230	4,500	93,023 2530	9,500	196,382 4230
46	950 904364	96	1,984 496064	4,600	95,090 4364	9,600	198,449 6064
47	971 576198	97	2,005 ·167898	4,700	97,157 6198	9,700	200,516 7898
48	992 248032	98	2,025.839732	4,800	99,224 8032	9,800	202,583 9732
49	1,012 919866	99	2,046 511566	4,900	101,291 9866	9,900	204,651 1566
50	1,033 591700	100	2,067 183400	5,000	103,359 1700	10,000	206,718 3400

TABLE LII.—*Conversion of Troy ounces of fine metal into United States money*—Continued.

SILVER.

1 ounce Troy=$1.2929 1 dollar=0 773455023513 ounce Troy.

Ounces	Dollars	Ounces	Dollars	Ounces.	Dollars	Ounces.	Dollars.
1	1 2929	51	65 9379	100	129 29	5,100	6,593 79
2	2 5858	52	67 2308	200	258 58	5,200	6,723 08
3	3 8787	53	68 5237	300	387 87	5,300	6,852 37
4	5 1716	54	69 8166	400	517 16	5,400	6,981 66
5	6.4645	55	71.1095	500	646 45	5,500	7,110 95
6	7.7574	56	72.4024	600	775 74	5,600	7,240 24
7	9 0503	57	73.6953	700	905 03	5,700	7,369 53
8	10 3432	58	74 9882	800	1,034 32	5,800	7,498 82
9	11 6361	59	76 2811	900	1,163 61	5,900	7,628.11
10	12 9290	60	77 5740	1,000	1,292 90	6,000	7,757 40
11	14 2219	61	78 8669	1,100	1,422 19	6,100	7,886 69
12	15 5148	62	80.1598	1,200	1,551 48	6,200	8,015 98
13	16 8077	63	81 4527	1,300	1,680 77	6,300	8,145 27
14	18 1006	64	82 7456	1,400	1,810 06	6,400	8,274 56
15	19.3935	65	84.0385	1,500	1,939 35	6,500	8,403 85
16	20 6864	66	85 3314	1,600	2,068 64	6,600	8,533 14
17	21.9793	67	86 6243	1,700	2,197.93	6,700	8,662 43
18	23 2722	68	87 9172	1,800	2,327 22	6,800	8,791 72
19	24 5651	69	89 2101	1,900	2,456 51	6,900	8,921 01
20	25 8580	70	90 5030	2,000	2,585 80	7,000	9,050 30
21	27.1509	71	91 7959	2,100	2,715 09	7,100	9,179 59
22	28 4438	72	93 0888	2,200	2,844 38	7,200	9,308 88
23	29.7367	73	94 3817	2,300	2,973 67	7,300	9,438 17
24	31 0296	74	95 6746	2,400	3,102 96	7,400	9,567 46
25	32 3225	75	96.9675	2,500	3,232 25	7,500	9,696 75
26	33 6154	76	98 2604	2,600	3,361 54	7,600	9,826 04
27	34.9083	77	99 5533	2,700	3,490 83	7,700	9,955 33
28	36 2012	78	100 8462	2,800	3,620 12	7,800	10,084 62
29	37.4941	79	102 1391	2,900	3,749 41	7,900	10,213 91
30	38.7870	80	103 4320	3,000	3,878.70	8,000	10,343 20
31	40.0799	81	104 7249	3,100	4,007 99	8,100	10,472.49
32	41 3728	82	106 0178	3,200	4,137 28	8,200	10,601 78
33	42.6657	83	107.3107	3,300	4,266 57	8,300	10,731.07
34	43 9586	84	108 6036	3,400	4,395.86	8,400	10,860 36
35	45 2515	85	109.8965	3,550	4,525.15	8,500	10,989.65
36	46 5444	86	111.1894	3,600	4,654 44	8,600	11,118 94
37	47 8373	87	112.4823	3,700	4,783 73	8,700	11,248 23
38	49.1302	88	113 7752	3,800	4,913.02	8,800	11,377 52
39	50 4231	89	115.0681	3,900	5,042 31	8,900	11,506 81
40	51.7160	90	116 3610	4,000	5,171 60	9,000	11,636 10
41	53 0089	91	117.6539	4,100	5,300 89	9,100	11,765 39
42	54 3018	92	118 9468	4,200	5,430.18	9,200	11,894 68
43	55 5947	93	120 2397	4,300	5,559 47	9,300	12,023.97
44	56.8876	94	121 5326	4,400	5,688 76	9,400	12,153 26
45	58 1805	95	122 8255	4,500	5,818 05	9,500	12,282 55
46	59 4734	96	124 1184	4,600	5,947 34	9,600	12,411.84
47	60 7663	97	125.4113	4,700	6,076 63	9,700	12,541.13
48	62.0592	98	126 7042	4,800	6,205.92	9,800	12,670 42
49	63 3521	99	127.9971	4,900	6,335.21	9,900	12,799 71
50	64.6450	100	129.2900	5,000	6,464.50	10,000	12,929 00

TABLE LIII.—*Conversion of United States money into Troy ounces of fine metal.*

GOLD.

1 dollar = 0 048374957925 ounce Troy. 1 ounce Troy = $20 671834

Dollars.	Ounces	Dollars	Ounces	Dollars	Ounces	Dollars	Ounces
1	0 048375	51	2 467123	100	4 837496	5,100	246 712285
2	0 096750	52	2 515498	200	9 674992	5,200	251 549781
3	0 145125	53	2 563873	300	14 512487	5,300	256 387277
4	0 193500	54	2 612248	400	19 349983	5,400	261 224773
5	0 241875	55	2 660623	500	24 187479	5,500	266.062269
6	0 290250	56	2 708998	600	29 024975	5,600	270 899764
7	0 338625	57	2 757373	700	33 862471	5,700	275 737260
8	0 387000	58	2 805748	800	38 699966	5,800	280 574756
9	0 435375	59	2 854123	900	43 537462	5,900	285 412252
10	0.483750	60	2 902497	1,000	48 374958	6,000	290 249748
11	0 532125	61	2.950872	1,100	53 212454	6,100	295 087243
12	0 580499	62	2 999247	1,200	58 049950	6,200	299 924739
13	0 628874	63	3 047622	1,300	62 887445	6,300	304 762235
14	0 677249	64	3 095997	1,400	67 724941	6,400	309 599731
15	0 725624	65	3 144372	1,500	72 562437	6,500	314 437227
16	0 773999	66	3 192747	1,600	77 399933	6,600	319 274722
17	0 822374	67	3 241122	1,700	82 237428	6,700	324 112218
18	0 870749	68	3 289497	1,800	87 074924	6,800	328 949714
19	0 919124	69	3 337872	1,900	91 912420	6,900	333 787210
20	0 967499	70	3 386247	2,000	96 749916	7,000	338 624705
21	1 015874	71	3 434622	2,100	101 587412	7,100	343 462201
22	1 064249	72	3 482997	2,200	106 424907	7,200	348 299697
23	1.112624	73	3 531372	2,300	111 262403	7,300	353 137193
24	1.160999	74	3 579747	2,400	116 099899	7,400	357.974689
25	1 209374	75	3 628122	2,500	120.937395	7,500	362 812184
26	1 257749	76	3 676497	2,600	125 774891	7,600	367 649680
27	1 306124	77	3 724872	2,700	130 612386	7,700	372 487176
28	1 354499	78	3 773247	2,800	135 449882	7,800	377 324672
29	1 402874	79	3 821622	2,900	140 287378	7,900	382 162168
30	1 451249	80	3 869997	3,000	145 124874	8,000	387.999663
31	1 499624	81	3 918372	3,100	149 962370	8,100	391 837159
32	1 547999	82	3 966747	3,200	154 799865	8,200	396 674655
33	1.596374	83	4 015122	3,300	159 637361	8,300	401 512151
34	1.644749	84	4 063496	3,400	164 474857	8,400	406 349647
35	1 693124	85	4 111871	3,500	169.312353	8,500	411 187142
36	1 741498	86	4 160246	3,600	174 149849	8,600	416 024638
37	1.789873	87	4 208621	3,700	178 987344	8,700	420 862134
38	1 838248	88	4 256996	3,800	183 824840	8,800	425.699630
39	1 886623	89	4 305371	3,900	188 662336	8,900	430 537126
40	1 934998	90	4 353746	4,000	193 499832	9,000	435 374621
41	1 983373	91	4 402121	4,100	198 337327	9,100	440 212117
42	2 031748	92	4 450496	4,200	203 174823	9,200	445 049613
43	2 080123	93	4 498871	4,300	208 012319	9,300	449 887109
44	2.128498	94	4 547246	4,400	212.849815	9,400	454 724604
45	2.176873	95	4.595621	4,500	217.687311	9,500	459 562100
46	2 225248	96	4 643996	4,600	222 524806	9,600	464 399596
47	2 273623	97	4 692371	4,700	227.362302	9,700	469 237092
48	2.321998	98	4.740746	4,800	232 199798	9,800	474 074588
49	2.370373	99	4.789121	4,900	237 037294	9,900	478 912083
50	2.418748	100	4.837496	5,000	241 874790	10,000	483 749579

TABLE LIII.—*Conversion of United States money into Troy ounces of fine metal*—Cont'd.

SILVER

1 dollar = 0 773455023513 Troy ounce 1 ounce Troy = $1 2929

Dollars.	Ounces	Dollars	Ounces	Dollars	Ounces	Dollars	Ounces
1	0 77346	51	39 44621	100	77 34550	5,100	3,944 62062
2	1 54691	52	40 21966	200	154 69100	5,200	4,021 96612
3	2 32037	53	40 99312	300	232 03651	5,300	4,099 31162
4	3 09382	54	41 76657	400	309 38201	5,400	4,176 65713
5	3 86728	55	42 54003	500	386 72751	5,500	4,254 00263
6	4 64073	56	43 31348	600	464 07301	5,600	4,331 34813
7	5 41419	57	44 08694	700	541 41852	5,700	4,408 69363
8	6 18764	58	44 86039	800	618 76402	5,800	4,486 03914
9	6 96110	59	45 63385	900	696 10952	5,900	4,563 38464
10	7 73455	60	46 40730	1,000	773 45502	6,000	4,640 73014
11	8 50801	61	47 18076	1,100	850 80053	6,100	4,718 07564
12	9 28146	62	47 95421	1,200	928 14603	6,200	4,795 42115
13	10 05492	63	48 72767	1,300	1,005 49153	6,300	4,872 76665
14	10 82837	64	49 50112	1,400	1,082 83703	6,400	4,950 11215
15	11 60183	65	50 27458	1,500	1,160 18254	6,500	5,027 45765
16	12 37528	66	51 04803	1,600	1,237. 52804	6,600	5,104 80316
17	13 14874	67	51 82149	1,700	1,314 87354	6,700	5,182 14866
18	13 92219	68	52 59494	1,800	1,392 21904	6,800	5,259 49416
19	14 69565	69	53 36840	1,900	1,469 56454	6,900	5,336 83966
20	15 46910	70	54 14185	2,000	1,546 91005	7,000	5,414 18516
21	16 24256	71	54 91531	2,100	1,624 25555	7,100	5,491 53067
22	17 01601	72	55 68876	2,200	1,701 60105	7,200	5,568 87617
23	17 78947	73	56 46222	2,300	1,778 94655	7,300	5,646 22167
24	18 56292	74	57 23567	2,400	1,856 29206	7,400	5,723 56717
25	19 33638	75	58 00913	2,500	1,933 63756	7,500	5,800 91268
26	20 10983	76	58 78258	2,600	2,010. 98306	7,600	5,878 25818
27	20 88329	77	59 55604	2,700	2,088 32856	7,700	5,955 60368
28	21 65674	78	60 32949	2,800	2,165 67407	7,800	6,032 94918
29	22 43020	79	61 10295	2,900	2,243 01957	7,900	6,110 29469
30	23 20365	80	61 87640	3,000	2,320 36507	8,000	6 187 64019
31	23 97711	81	62 64986	3,100	2,397 71057	8,100	6,264 98569
32	24 75056	82	63 42331	3,200	2,475 05608	8,200	6,342 33119
33	25 52402	83	64 19677	3,300	2,552 40158	8,300	6,419 67670
34	26 29747	84	64 97022	3,400	2,629 74708	8,400	6,497 02220
35	27 07093	85	65 74368	3,500	2,707 09258	8,500	6,574 36770
36	27 84438	86	66 51713	3,600	2,784 43808	8,600	6,651 71320
37	28 61784	87	67 29059	3,700	2,861 78359	8,700	6,729 05870
38	29 39129	88	68 06404	3,800	2,939 12909	8,800	6,806 40421
39	30 16475	89	68 83750	3,900	3,016 47459	8,900	6,883 74971
40	30 93820	90	69 61095	4,000	3,093 82009	9,000	6,961 09521
41	31. 71166	91	70 38441	4,100	3,171 16560	9,100	7,038 44071
42	32 48511	92	71 15786	4,200	3,248 51110	9,200	7,115 78622
43	33 25857	93	71 93132	4,300	3,325 85660	9,300	7,193 13172
44	34. 03202	94	72 70477	4,400	3,403 20210	9,400	7,270 47722
45	34 80548	95	73 47823	4,500	3,480 54761	9,500	7,347 82272
46	35 57893	96	74 25168	4,600	3,557 89311	9,600	7,425 16823
47	36 35239	97	75 02514	4,700	3,635 23861	9,700	7,502 51373
48	37 12584	98	75 79859	4,800	3,712 58411	9,800	7,579 85923
49	37 89930	99	76 57205	4,900	3,789 92962	9,900	7,657 20173
50	38 67275	100	77 34550	5,000	3,867 27512	10,000	7,734 55024

DISCOUNT AND MARKET VALUE.

The figures given in the production tables are of assay values, and are therefore considerably higher than the actual market value. Disregarding express charges, commissions, and cost of refining and coining, there is still a large deduction to be made for this discount, in estimating the cash value of the bullion to the producers. Assuming the gold to have brought on the average $20 per troy ounce, and the silver $1.12½ per troy ounce, the cash received would have been $32,394,794 for the gold, $35,772,160 for the silver, and $68,166,954 total. The loss to the miners, as compared with the full assay value, would therefore have been $984,869 on the gold, $5,338,797 on the silver, and $6,323,666 altogether, or about one thirty-fourth of the full gold coining value, over one-eighth of the nominal silver value, and over one-twelfth in all, during the single census year. While there is no regular discount on gold, the large amount of placer gold sold at an undervaluation renders the average price assumed a probable one. The price for the silver is an estimate of average local rates for the year.

THE OUTLOOK.

The immediate outlook for the precious metal mines, as a whole, is very encouraging. The great Leadville (Colorado), Eureka (Nevada), Tombstone (Arizona), and Bodie (California), districts are maintaining a steady output, while the new Wood River and other districts in Idaho, and a number of recent discoveries in Arizona, hold forth great promise for the future. In fact, estimates of the yield subsequent to the census period indicate an actual and considerable gain.*

FINAL DISPOSITION OF THE PRECIOUS METALS—COINAGE.

The receipts of bullion of domestic production at the United States assay offices, as previously explained, do not indicate the absolute amount of the mine output, but they serve as a useful check in many instances. The following tables are abstracts from the carefully collected statistics of the Treasury Department, selected with reference to their bearing upon the question of production:

TABLE LIV.—*Receipts of gold and silver of domestic production at the mints and United States assay offices during the fiscal year ending June* 30, 1880

State or Territory	Gold	Silver	Total
	Dollars.	Dollars	Dollars
Alabama	752 79	...	752 79
Alaska	5,950 90	...	5,950 90
Arizona	158,919 75	991,323 38	1,150,243 13
California	7,118,816 42	303,846 91	7,422,663 33
Colorado	2,244,069 74	1,257,790 41	3,501,860 15
Dakota	2,750,022 09	21,104 54	2,771,126 63
Georgia	89,831 08	48 73	89,879 81
Idaho	510,546 73	102,999 86	613,546 59
Michigan (Lake Superior)	...	129,686 94	129,686 94
Montana	1,805,768 00	1,262,982 32	3,068,750 32
Nevada	518,261 85	5,087,242 18	5,605,504 03
New Mexico	91,037 28	424,967 31	516,004 59
North Carolina	85,659 57	379 18	86,038 75
Oregon	583,365 34	1,174 26	584,539 60
South Carolina	11,861 70	15 52	11,877 22

* While this report was going through the press, Wells, Fargo & Co. reported the yield of the mines of the Western States and Territories, together with that from British Columbia, to have been $31,869,686 gold, $45,077,829 silver, and $76,947,515 total, for the calendar year 1881.

TABLE LIV.—*Receipts of gold and silver of domestic production, &c.*—Continued.

State or Territory	Gold	Silver.	Total.
	Dollars.	Dollars	Dollars
Tennessee	1,998 30		1,998 30
Utah	27,029 19	627,703 85	654,733 04
Virginia	9,322 07		9,322 07
Washington	34,529 24		34,529 24
Wyoming	17,320 70		17,320 70
Refined bullion (gold)	18,161,943 52		18,161,943 52
Refined bullion (silver)		2,970,757 92	2,970,757 92
Parted from silver	1,449,524 54		1,449,524 54
Parted from gold		219,387 26	219,387 26
Contained in silver	1,161 47		1,161 47
Contained in gold		2,978 23	2,978 23
Other sources (gold)	144,013 13		144,013 13
Other sources (silver)		18,728,368 15	18,728,368 15
Total	35,821,705 40	32,132,756 95	67,954,462 35

The following tables show the amount of coinage executed during the fiscal year ending June 30, 1880, and the total coinage of the United States up to that date:

TABLE LV.—*Coinage by the United States mints for the fiscal year ending June* 30, 1880.

Metal.	Coinage executed.
Gold	$56,157,735 00
Silver	27,942,437 50
Total gold and silver coinage	84,100,172 50
Minor coinage	269,971 50
Total coinage	84,370,141 00

TABLE LVI.—*Total coinage by the United States mints from* 1793 *to close of fiscal year ending June* 30, 1880.

Metal.	Coinage executed
Gold	$1,133,103,322 00
Silver	292,333,436 90
Total gold and silver coinage	1,425,436,758 90
Minor coinage	13,283,167 05
Total coinage	1,438,719,925 95

CONSUMPTION OF THE PRECIOUS METALS IN THE ARTS.

Besides the demand for coinage and export, the precious metals are subjected to a further and constant drain in the large annual consumption in the arts. Until quite recently it was impossible to ascertain the amount so absorbed with any degree of accuracy, though many attempts were made to this end by officials and statisticians. In 1870, estimates furnished by the large gold-refining houses and manufacturing jewelers showed that probably not less than $9,000,000, and possibly over

$13,000,000, of gold were used in the arts during that year. Out of this indefinite sum it was impossible to segregate the proportion of bullion of domestic production so consumed from the United States coin, foreign coin and bullion, and old articles remelted for manufacturing purposes.

Latterly fuller and more reliable data are available. A systematic investigation, conducted by the Director of the Mint, Hon. Horatio C. Burchard, has resulted in tracing this consumption with great accuracy. Records are now kept at the several mints and United States assay offices of the value of bars made and delivered by them for use in the arts and manufacturing. From these returns, supplemented by individual reports from a large proportion of the manufacturing establishments collected with much care, it is estimated that the amount of gold thus consumed in the United States in the fiscal year ending June 30, 1880, was $10,000,000, and of silver $5,000,000, or $15,000,000 in all. Of this, $5,500,000 gold and $4,000,000 silver were of domestic bullion produced during the year, together with $2,500,000 gold and $600,000 silver United States coin. The remainder consisted of old manufactured articles and foreign coin remelted.

This large amount is absorbed mainly in the following principal industries: The manufacture of jewelry, plate, and plated ware, and articles of *vertu;* watch-case, gold pen, instrument, and spectacle making; dentistry; gilding; photography; and to a less extent in glass staining and in various chemical processes. In addition to the leading uses enumerated, there are many others, insignificant individually, but in the aggregate demanding a considerable supply of the precious metals.

OTHER ESTIMATES OF THE BULLION PRODUCT.

As a means of comparison, several independent estimates, derived from different sources of information and compiled upon widely diverse systems, are appended. They are:

1. Estimates of Dr. Adolf Soetbeer (as published in *Petermann's Mittheilungen*, Erganzungsheft No. 57) of the product of the United States up to the close of 1875; kilograms being converted into troy ounces and German marks into United States money. The conclusions reached by Dr. Soetbeer were based upon an analytical study and comparison of the literature of the subject, and are generally accepted with confidence.

2. Estimates of Hon. Horatio C. Burchard, Director of the Mint, founded upon the "consumption and export" system, supplemented by circular inquiries among the producers. The Director, in his annual report for 1880, states the gross product for that fiscal year in round numbers as $36,000,000 gold, $37,700,000 silver (coinage value), and $73,700,000 total.

3. Estimates of Dr. Rossiter W. Raymond, formerly United States Mining Commissioner, for the period covered by his official term.

4. Estimates of Prof. J. D. Whitney.

TABLE LVII.—*Dr. Soetbeer's estimate of the production of the precious metals in the United States to the close of* 1875.

Periods.	Number of years	Gold product.			Silver product		
		Total.	Yearly average	Value	Total	Yearly average	Value.
		Ounces.	Ounces	Dollars	Ounces	Ounces	Dollars
1804–'20	17	1,929	113	39,876	....	....	....
1821–'30	10	35,368	3,537	731,121	....	....	....
1831–'40	10	273,295	27,329	5,649,509	....	....	....
1841–'50	10	5,658,825	565,883	116,978,291	....	....	....
1851–'55	5	14,275,673	2,855,135	295,104,343	1,334,325	266,865	1,725,149
1856–'60	5	12,394,757	2,478,951	256,222,359	996,725	199,345	1,288,666
1861–'65	5	10,722,832	2,144,566	221,660,603	27,972,602	5,594,520	36,165,777
1866–'70	5	12,217,918	2,443,584	252,566,773	48,389,387	9,677,877	62,562,638
1871–'75	5	9,565,344	1,913,069	197,733,203	90,798,425	18,159,685	117,393,284
Total	72	65,145,941	12,432,167	1,346,678,078	169,491,464	33,898,292	219,135,514

TABLE LVIII.—*Estimate of the production of the precious metals in the United States from* 1848 *to* 1880, *by fiscal years.*

[From reports of Hon. Horatio C. Burchard, Director of the Mint.]

Year.	Gold	Silver.	Total gold and silver.
	Dollars	Dollars	Dollars
1848	10,000,000	....	10,000,000
1849	40,000,000	50,000	40,050,000
1850	50,000,000	50,000	50,050,000
1851	55,000,000	50,000	55,050,000
1852	60,000,000	50,000	60,050,000
1853	65,000,000	50,000	65,050,000
1854	60,000,000	50,000	60,050,000
1855	55,000,000	50,000	55,050,000
1856	55,000,000	50,000	55,050,000
1857	55,000,000	50,000	55,050,000
1858	50,000,000	50,000	50,050,000
1859	50,000,000	100,000	50,100,000
1860	46,000,000	150,000	46,150,000
1861	43,000,000	2,000,000	45,000,000
1862	39,200,000	4,500,000	43,700,000
1863	40,000,000	8,500,000	48,500,000
1864	46,000,000	11,000,000	57,000,000
1865	53,225,000	11,250,000	64,475,000
1866	53,500,000	10,000,000	63,500,000
1867	51,725,000	13,500,000	65,225,000
1868	48,000,000	12,000,000	60,000,000
1869	49,500,000	12,000,000	61,500,000
1870	50,000,000	16,000,000	66,000,000
1871	43,000,000	23,000,000	66,000,000
1872	36,000,000	28,750,000	64,750,000
1873	36,000,000	35,750,000	71,750,000
1874	33,490,902	37,324,594	70,815,496
1875	33,467,856	31,727,560	65,195,416
1876	39,929,166	38,783,016	78,712,182
1877	46,897,390	39,793,573	86,690,963
1878	51,206,360	45,281,385	96,487,745
1879	38,899,858	40,812,132	79,711,990
1880	36,000,000	37,700,000	73,700,000
Total	1,520,041,532	460,422,260	1,980,463,792

TABLE LIX.—*Bullion production of the United States from* 1868 *to* 1875.

[Estimated by Dr. Rossiter W. Raymond, United States Mining Commissioner.]

State or Territory	1868.	1869	1870	1871.
	Dollars	Dollars	Dollars	Dollars
California	22,000,000	22,500,000	25,000,000	20,000,000
Nevada	14,000,000	14,000,000	16,000,000	22,500,000
Montana	15,000,000	9,000,000	9,100,000	8,050,000
Idaho	7,000,000	7,000,000	6,000,000	5,000,000
Oregon and Washington	4,000,000	3,000,000	3,000,000	2,500,000
Arizona	500,000	1,000,000	800,000	800,000
New Mexico	250,000	500,000	500,000	500,000
Colorado and Wyoming	3,250,000	4,000,000	3,775,000	4,763,000
Utah			1,300,000	2,300,000
From other parts	1,000,000	500,000	525,000	250,000
Total	67,000,000	61,500,000	66,000,000	66,663,000

State or Territory.	1872	1873	1874	1875
	Dollars	Dollars	Dollars	Dollars
California	19,049,098	18,025,722	20,300,531	17,753,151
Nevada	25,548,801	35,254,507	35,452,233	40,478,369
Montana	6,068,339	5,187,047	3,844,722	3,573,600
Idaho	2,695,870	2,500,000	1,880,004	1,750,000
Oregon and Washington	2,000,000	1,585,784	763,605	1,246,978
Arizona	625,000	500,000	487,000	750,000
New Mexico	500,000	500,000	500,000	325,000
Colorado and Wyoming	4,761,465	4,070,263	5,188,510	5,302,810
Utah	2,445,284	3,778,200	3,911,601	3,137,688
From other parts	250,000	250,000	100,000	500,000
Total	63,943,857	71,651,523	72,428,206	74,817,596

TABLE LX.—*Gold production of the Southern States from* 1804 *to* 1850.

[Estimates of Professor J. D. Whitney.]

Value of gold production by States.		Value of gold production in the respective divisions of time	
Georgia	$6,048,900	1804–'23	$47,000
North Carolina	6,842,900	1824–'30	715,000
South Carolina	818,100	1831–'40	6,695,000
Tennessee and Alabama	263,800	1841–'50	7,715,300
Virginia	1,198,600		
Total	15,172,300	Total	15,172,300

BULLION PRODUCT OF THE WORLD.

The world's annual output, so far as ascertainable, is shown in the following tables, which state the sources according to political divisions, and also by continents. The data are for calendar years except for the United States, British Columbia, and Japan. Accurate statistics of the small production of gold and silver in Central America, that of silver in Canada, and gold in Nova Scotia are not available. The totals given are probably slightly under the actual amount. A comparison of the individual figures shows that the United States produce 33.13 per cent. of the gold yield of the whole world, 50.54 per cent. of the silver, and 40.91 per cent. of the total. Of the aggregate supply of the precious metals, North America (including the United States, Mexico, and British Columbia) furnishes 55.78 per cent.

TABLE LXI.—*Annual bullion product of the world—political distribution.*

Country.	Gold	Silver	Total.
	Dollars.	Dollars.	Dollars
United States*	33, 379, 663	41, 110, 957	74, 490, 620
Mexico	989, 161	25, 167, 763	26, 156, 924
British Columbia†	910, 804		910, 804
Africa‡	1, 993, 800		1, 993, 800
Argentine Republic	78, 546	420, 225	498, 771
Colombia	4, 000, 000	1, 000, 000	5, 000, 000
Rest of South America‡	1, 993, 800	1, 039, 190	3, 032, 990
Australia§	29, 018, 223		29, 018, 223
Austria	1, 062, 031	2, 002, 727	3, 064, 758
Germany§	205, 361	6, 938, 073	7, 143, 434
Norway		166, 270	166, 270
Italy§	72, 375	17, 919	90, 324
Russia§	26, 584, 000	415, 676	26, 999, 676
Sweden	1, 994	62, 435	64, 429
Rest of Europe		2, 078, 380	2, 078, 380
Japan	466, 548	916, 400	1, 382, 948
Total	100, 756, 306	81, 336, 045	182, 092, 351

*Census of 1880 †Actual export ‡From Dr Soetbeer's estimate in 1875. §Estimated from production of other years.

TABLE LXII.—*Annual bullion product of the world—continental distribution.*

Continent.	Total bullion product	Percentage of total product
	Dollars.	Per cent
North America	101, 558, 348	55 78
Africa	1, 993, 800	1 10
Australia	29, 018, 223	15 93
Europe, including Russia in Asia	39, 607, 271	21 75
Japan	1, 382, 948	0 76
South America	8, 531, 761	4 68
Total	182, 092, 351	100. 00

EXPLANATION OF CHARTS.

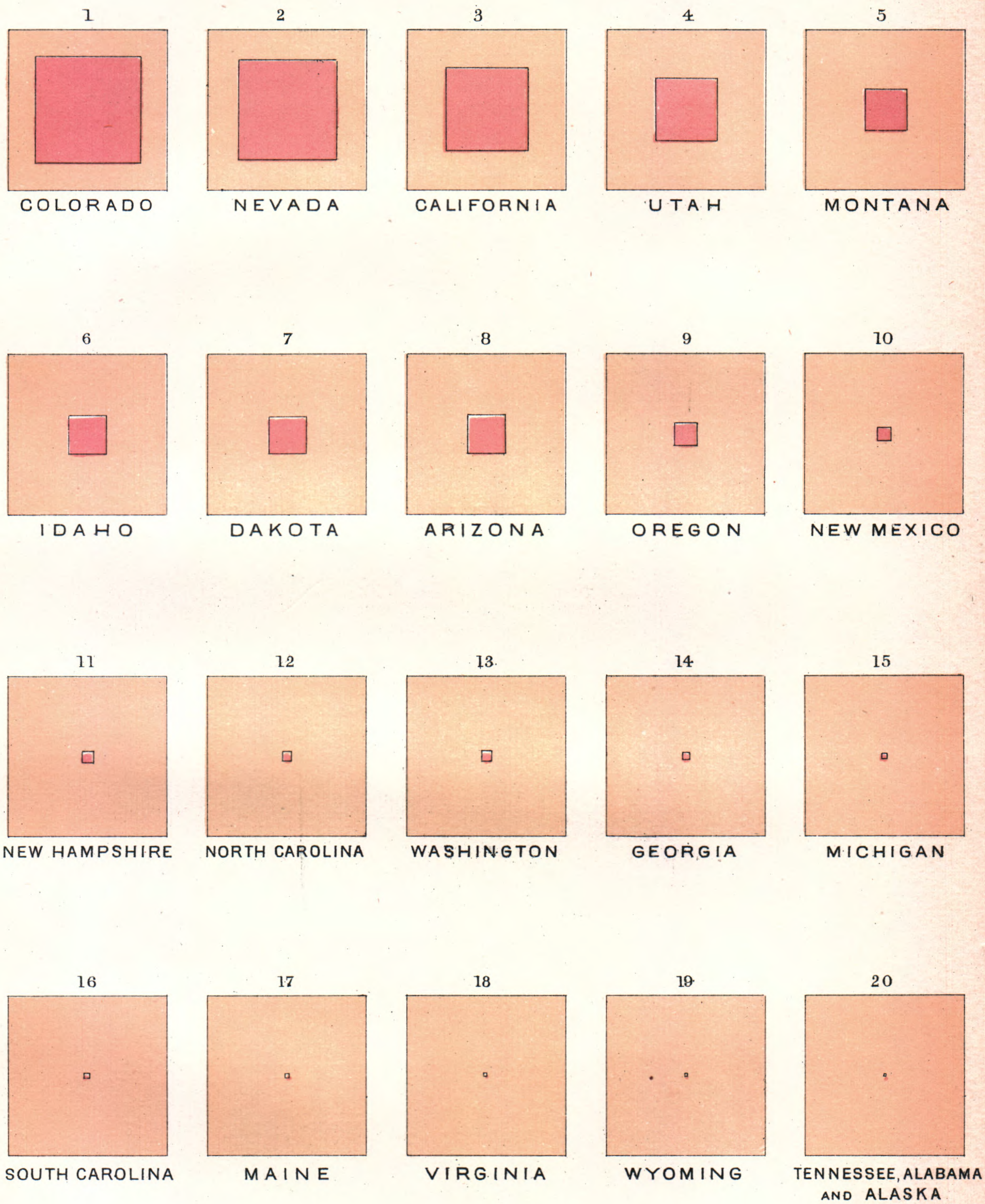
The construction of the diagrams in the following charts is based upon the figures reached in the preceding compilation, which the plates are designed to exhibit graphically.

The plates illustrating the bullion product of the several States and Territories per square mile and per capita are founded upon the averages given by Tables XLVI and XLVII, in connection with the official measurements of areas by Mr. Henry Gannett, geographer of the Tenth Census, and the latest count of the population. The inner squares, printed in mauve, in each case denote the relative averages of bullion product (gold and silver combined), while the outer gray squares are of an arbitrary, uniform size, and represent in one chart the unit of area, and in the other, the unit of population—that is, the square mile and the single individual. The length of the sides of the inner squares is given by the respective square roots of the averages.

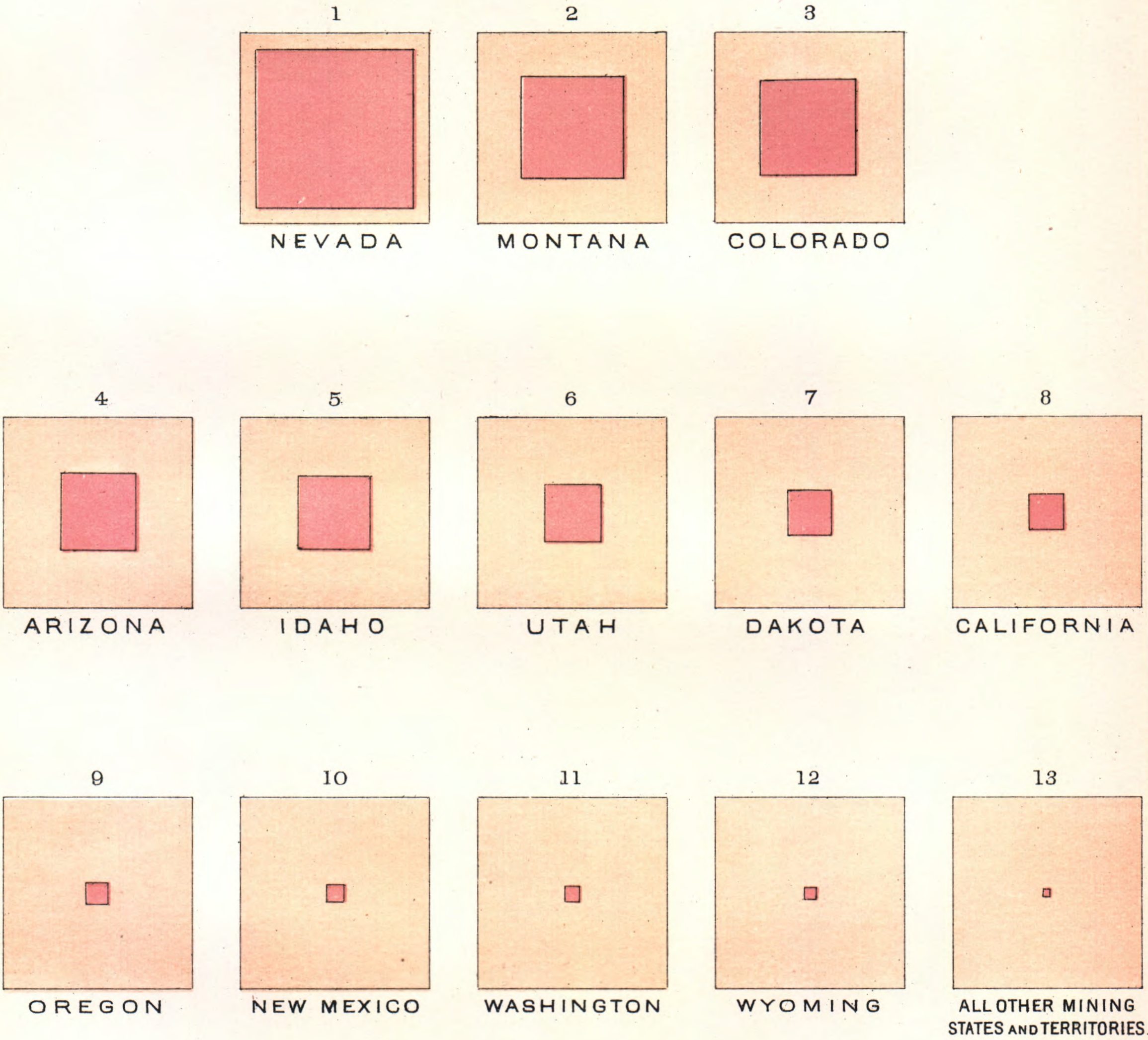
The plate showing the absolute bullion product of the States and Territories, without reference to their size or population, is a repetition in a graphic form of the figures given in Table XLIII, which is the summary of the bullion product of the United States for the census year. It exhibits at a glance three distinct comparisons: that of the gold product, that of the silver, and that of both precious metals. The natural arrangement of the series, according to the totals, is observed. The extreme height of each column is in each case equal to the sum of the height indicating gold plus that representing the silver. Two essential features are in this manner presented to the eye: first, the wide difference between the product of the three leading mining States, Colorado, California, and Nevada, and that of the remainder of the country; and second, the remarkable diversity in the proportions of gold and silver in different localities. Colorado and California appear to be anti-types; the one showing a large predominance in the silver yield, the other in that of gold. A similar contrast is shown by another pair, Utah and Dakota.

The chart exhibiting the annual fluctuations in the yield of the precious metals since 1848 is in itself a history of the mining industry. The rapid increase in the product following the discovery of the gold fields in California, which reached its highest point in 1853, from which year, owing to the gradual exhaustion of the more accessible and richer deposits, the yield for a time gradually dwindled; the impulse given by the finding of the great Comstock lode, and the addition of the Idaho placers to the productive sources; the effect of the Crown Point and Belcher ore-body upon the total product; and, finally, the sudden and vast increase consequent upon the opening of the famous bonanza in the Consolidated Virginia and California mines—these are all pictured. The annals of the silver production, a comparatively recent addition to the national resources, are thus recorded in full. If the chart be carried forward beyond the limits of the census year, the rising curves would tell of Leadville and of Tombstone. The figures assumed in this chart are the annual estimates of the Director of the Mint for fiscal years up to the census year, for which the results reached in this compilation are quoted. It should be remarked that as the fiscal year embraces only the first half of the calendar year of the same designation, the curves in some cases are projected one space to the right of what their position would be were the calendar year to be taken.

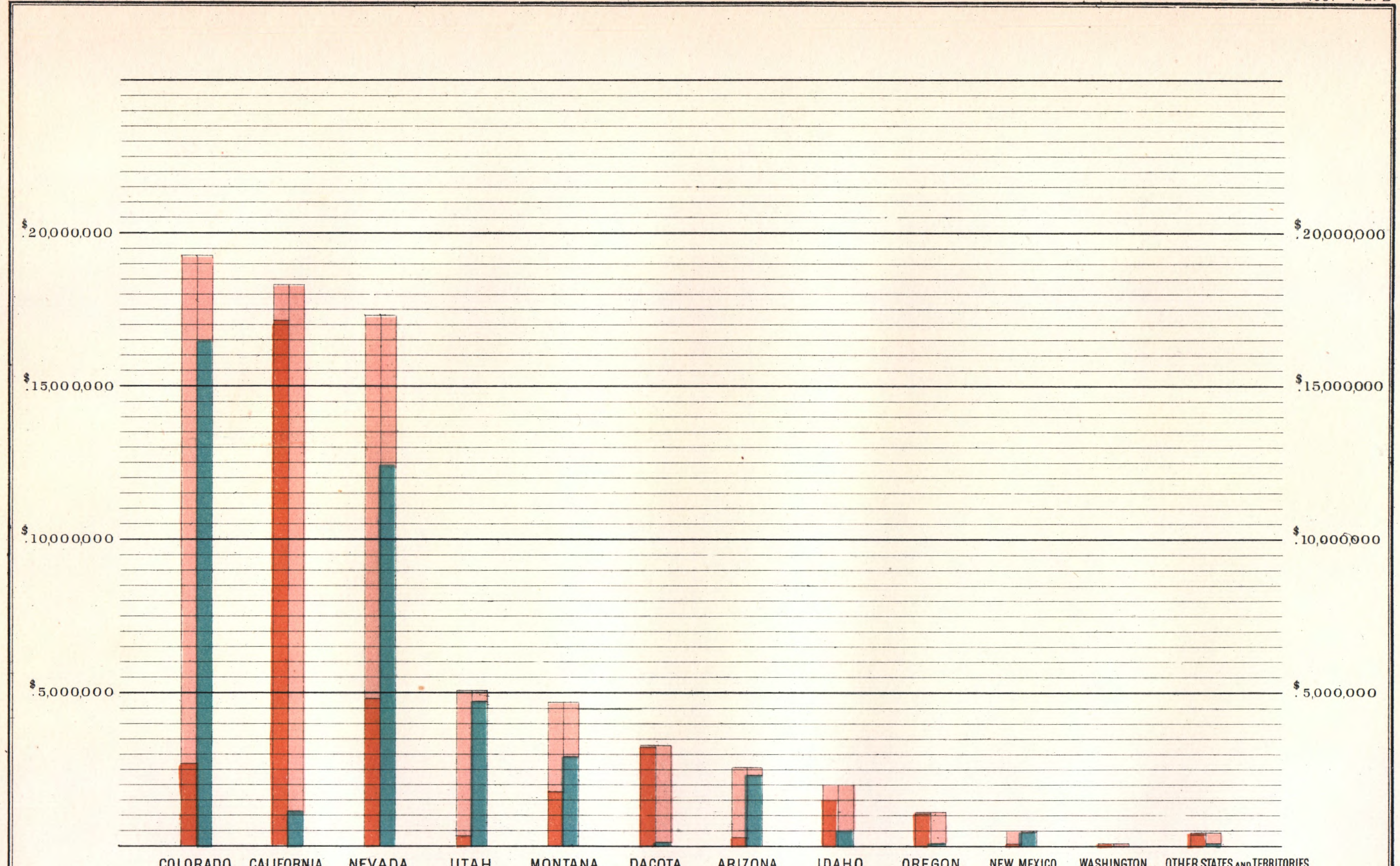
The two plates illustrating the world's annual product are based on the figures of Tables LXI and LXII. In one the yield is segregated, so far as possible, according to the political divisions; in the other, according to its continental distribution. The preponderance of the United States as a bullion-producing nation, and of North America as a bullion-producing continent, is in this manner, perhaps, more clearly indicated than by the tabular exhibit.



BULLION PRODUCT PER SQUARE MILE.



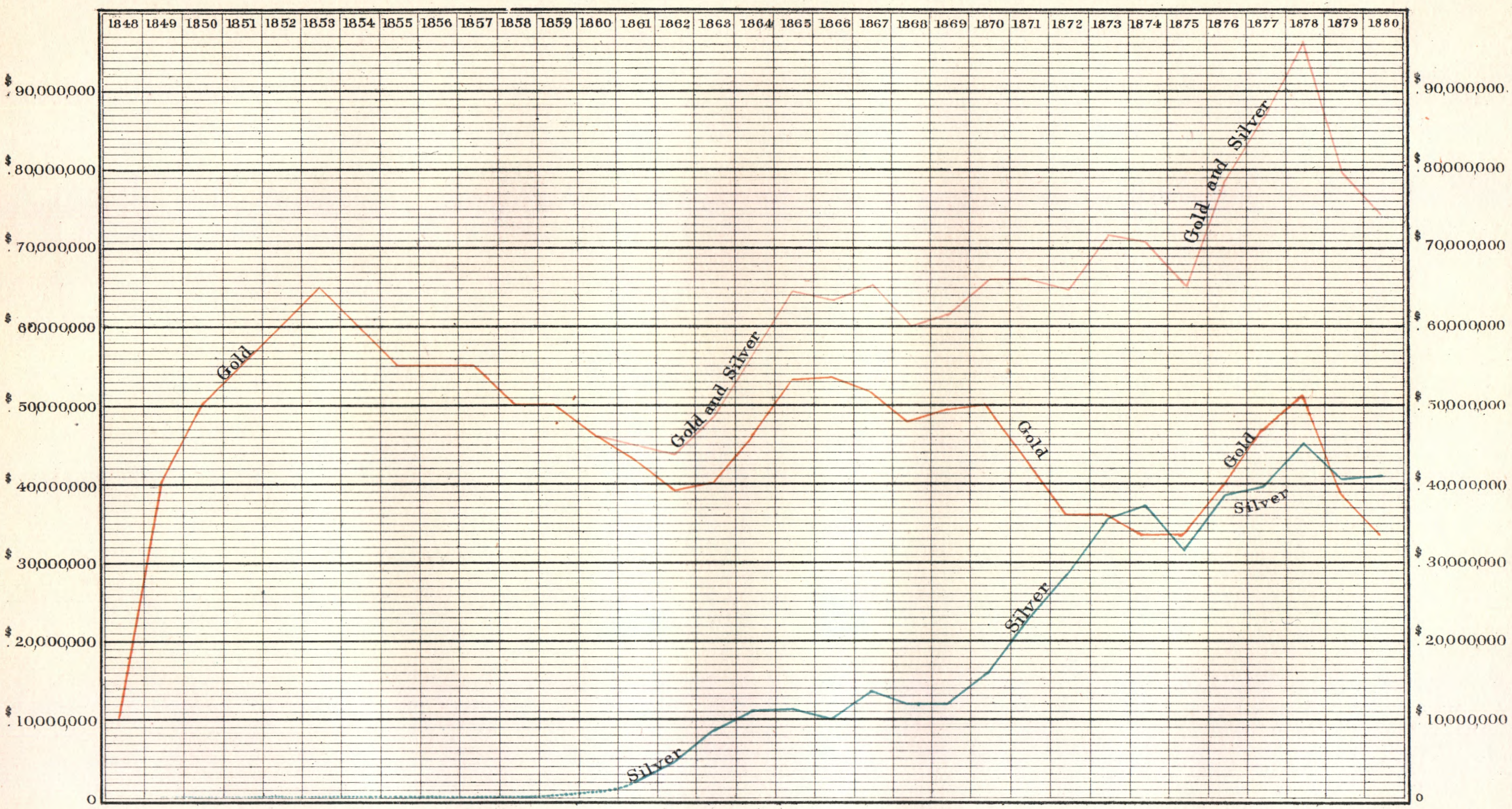
BULLION PRODUCT PER CAPITA.



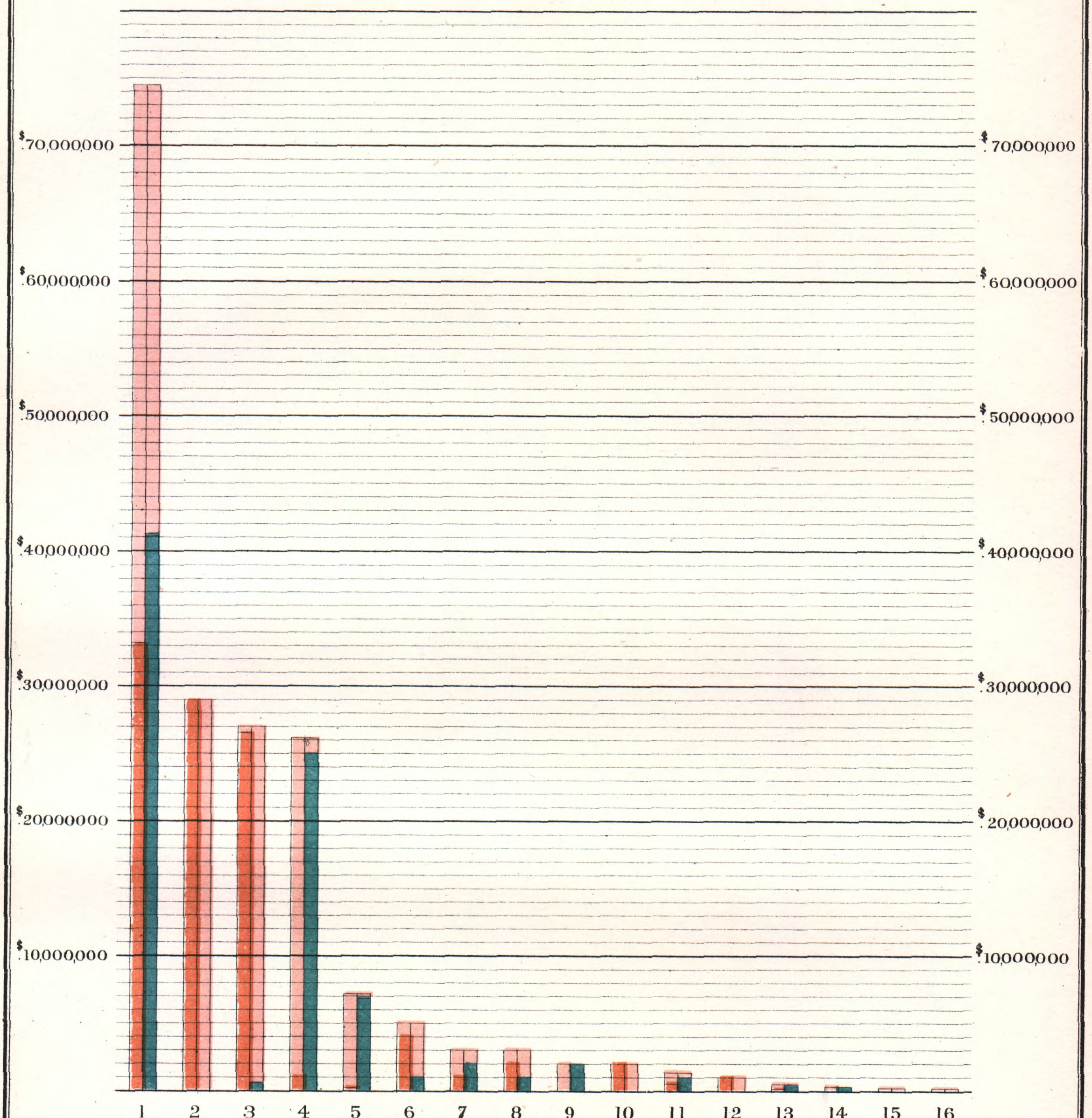
The areas in old gold indicate gold, those in light blue, silver; the relative totals being shown by the extreme height of each column.

RELATIVE BULLION PRODUCT OF THE STATES AND TERRITORIES.

For Fiscal years ending June 30, except 1880, for which the Census period is given.
If the curve for calendar years were given, points in 1875, 1876, 1877, and 1878 would appear one space to the left, respectively.



ANNUAL BULLION PRODUCT OF THE UNITED STATES.

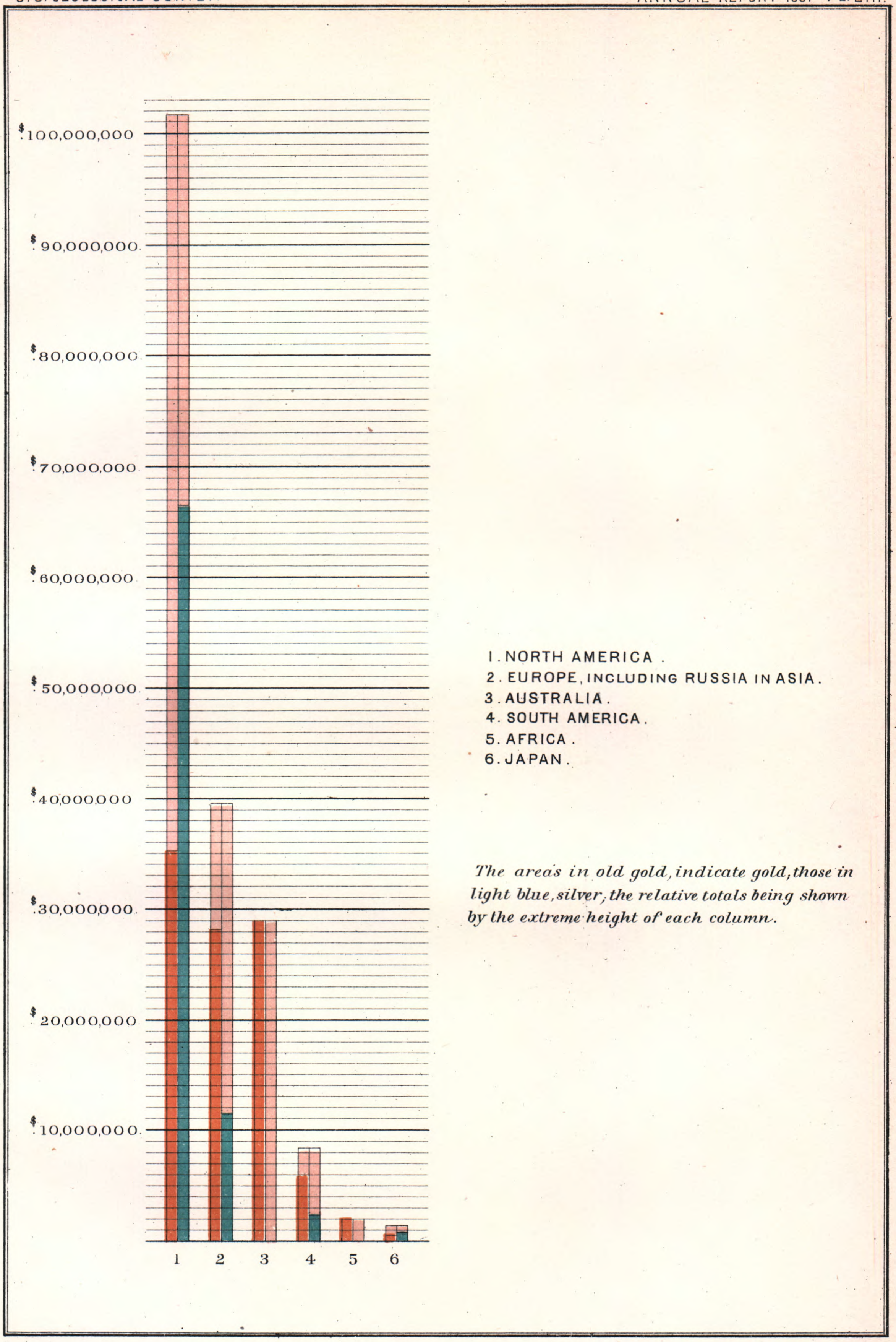


1. UNITED STATES. 2. AUSTRALIA. 3. RUSSIA. 4. MEXICO. 5. GERMANY. 6. COLOMBIA. 7. AUSTRIA 8. SOUTH AMERICA, EXCEPTING COLOMBIA AND THE ARGENTINE REPUBLIC. 9. EUROPE, EXCEPTING RUSSIA, GERMANY, AUSTRIA, NORWAY, ITALY AND SWEDEN. 10. AFRICA. 11. JAPAN. 12. BRITISH COLUMBIA. 13. ARGENTINE REPUBLIC. 14. NORWAY. 15. ITALY. 16. SWEDEN.

The areas in old gold, indicate gold, those in light blue, silver; the relative totals being shown by the extreme height of each column.

ANNUAL BULLION PRODUCT OF THE WORLD.

(POLITICAL DISTRIBUTION.)



ANNUAL BULLION PRODUCT OF THE WORLD.
(CONTINENTAL DISTRIBUTION.)

A NEW METHOD OF MEASURING HEIGHTS BY MEANS OF THE BAROMETER.

BY

G. K. GILBERT.

A NEW METHOD OF MEASURING HEIGHTS BY MEANS OF THE BAROMETER.

By G. K. Gilbert.

CHAPTER I.

THE PROBLEM STATED.

The change proposed in this paper is of a radical nature. Since the time of Laplace the hypsometric formula he developed has formed the groundwork of all investigation and practice. Later writers have made formal modification of some of its terms and have added a term of some importance, and modern physical research has made slight corrections to the values of several of the constants he employed, but the essential features of the formula have not been changed. It is here proposed to abandon it entirely for the greater part of hypsometric work and to substitute a new formula involving none of his constants and having but a single element in common.

For more than a century the thermometer has been the constant companion of the barometer, and in nearly all the best work of recent times the psychrometer also has been called in play. The new method abandons both psychrometer and thermometer and employs the barometer alone.

Departing thus widely from the beaten path, the writer has of necessity reverted to the elementary principles upon which all barometric measurements depend, and he may therefore be permitted, if indeed he is not compelled, to preface the presentation of his method by a review of the purposes and conditions of barometric hypsometry in general.

The opening chapter is devoted to that purpose. It is believed to contain nothing either new or original, and is intended less for the practical meteorologist or hypsometer than for the general reader, to whom it is hoped it will render the succeeding chapters comprehensible. The fourth chapter, on the other hand, and those following it are addressed more especially to the student of hypsometry.

THE FUNDAMENTAL PRINCIPLE.

The principle which underlies the measurement of heights by means of the barometer is an exceedingly simple one, but its application is fraught with difficulty.

The pressure of the atmosphere upon the surface of the earth at the level of the sea is about fifteen pounds to the square inch. If one rises in a balloon or ascends a mountain he passes above successive strata of air and is relieved of their weight. The pressure he sustains at any height is that due to the weight of the air which is above him, and is progressively less and less the higher he goes. The pressure is therefore an indication of the altitude, and it is possible to acquire knowledge of the heights of different parts of the earth's surface by simply measuring the local pressures of the atmosphere. Thus, if one finds that the air imposes a pressure of 10¾ pounds to the inch of surface at the city of Quito, and a pressure of 9¼ pounds on the summit of Pike's Peak, he at once knows that there is less air above Pike's Peak than above Quito, and therefore that it is higher.

A moment's reflection will show that the diminution of pressure from the sea level upward is not simply proportional to the altitude but has a somewhat different law. The density of a gas is proportioned to the pressure to which it is subject, and since the lowest stratum of air is compressed by the weight of the whole atmosphere, while each higher stratum is compressed only by that part of the atmosphere which lies above it, the lowest is denser than any other, and there is a progressive decrease in density from the sea level upward. A A layer of air 1,000 feet deep resting on the ocean contains more matter and weighs more than a layer of similar depth at any higher altitude, and the aeronaut or mountain climber experiences a greater diminution of atmospheric pressure in ascending from the sea level to an altitude of 1,000 feet than he does in continuing his ascent from 1,000 to 2,000 feet, or through an equal space at a greater height. The loss of pressure in the first mile of ascent is 2.6 pounds to the square inch, while in the second it is only 2.2 pounds, and in the third 1.9 pounds.

The law of the relation of altitude to atmospheric pressure is therefore a logical consequent of the law of the compressibility of gases. In its simplest form it is as follows:

The difference in height of any two localities is equal to a certain constant distance multiplied by the difference between the logarithms of the air pressures at the two localities.

If the lower locality is the shore of the sea, then the difference in height deducible under the law is the altitude above sea level of the upper locality.

This relation is the foundation of all barometric hypsometry, and although its discovery was attained only by the cumulative efforts of many illustrious physicists, it is exceedingly simple. But there are a number of modifying conditions of which account must be taken in its application, and it is with these that we are chiefly concerned in this paper. Their consideration will be deferred, however, until a brief outline has been given of the means employed for the measurement of atmospheric pressures.

BAROMETERS.

The pressure on any spot of the earth's surface is equivalent to the weight of the prism of air extending upward from the spot to the confines of the atmosphere, and for convenience of discussion the pressure is conceived as being actually given by this ideal prism of air, which is called the atmospheric column.

Four distinct devices have been employed to weigh the atmospheric column. The *mercurial barometer* counterpoises against it a column of mercury, and is analogous in principle to the common scales. The *aneroid barometer* receives the pressure of the air on a metallic spring, and is strictly analogous to the spring balance. The *boiling-point apparatus* does not directly weigh the air, but merely determines the temperature at which water boils, depending for its result upon the principle that the boiling point of water is raised by increase of pressure and lowered by its diminution. The *density apparatus* is a device by which a small quantity of air is imprisoned in a tube and then compressed to a certain definite fraction of its former volume by means of a column of mercury. The height of the column of mercury necessary to do this is proportional to the original density of the air, and therefore to the atmospheric pressure by which that density is produced.

Of these instruments the mercurial barometer is both the oldest and the most accurate, and its use would be universal were it not somewhat cumbrous and easily broken. The aneroid commends itself by its convenient size and its facility of observation, and has a wide use both in reconnaissances and as an adjunct to the mercurial barometer in geographic surveys, but it is too delicate a piece of mechanism to be entirely trustworthy. The boiling-point apparatus is in many cases preferable to the aneroid barometer for independent use, but is nearly superseded by the mercurial. The density apparatus is probably not in use.

The construction of the mercurial barometer is essentially as follows: A glass tube about three feet in length and closed at one end is filled with mercury and then inverted with the open end immersed in a cup of mercury. A portion of the mercury flows from the tube to the cup, and a space is left in the upper (closed) end of the tube. This space is a vacuum, air having no access. The mercurial surface in the tube, having mere vacuity above it, receives no pressure, while the surface in the cup bears the full pressure of the atmosphere, and as a consequence the mercury stands higher in the tube than in the cup. The difference in level between the two surfaces is the height of the column of mercury necessary to counterpoise the weight of the superincumbent air. A column of mercury two inches in height imparts a pressure of about one pound to the square inch, and a column of about thirty inches is accordingly necessary to counterbalance the fifteen pounds of atmospheric pressure at sea level. When, therefore, the barometer is placed near the sea level, the height of the mercury in its tube is about thirty inches above the surface of the mercury in its cup, or, in familiar parlance, the "height of the barometer" is thirty inches. The use of the mercurial barometer is so general that the pressure of the air is ordinarily described by means of the linear measures of its scale instead of by weights—the Englishman and American speaking of inches of pressure and the continental European of millimeters of pressure.

The many forms which have been given to the barometer need not be described here. The cup in which the tube is inverted is ordinarily called a "cistern," and is permanently attached to the tube. A graduated scale, usually of brass, is fastened in close juxtaposition to the tube and the height of the column is ascertained by comparing it with this scale.

A thermometer is also attached, so that the temperature of the mercury of the column and of the brass of the scale may be known. This is rendered necessary by the different expansibility of the two substances under the influence of heat. On a warm day the mercury rises higher along the scale than on a cold one, the air pressure remaining the same.

An observation of the barometer consists, therefore, of two parts: first, a reading of the height of the mercury; and, second, a reading of the temperature of the instrument. A correction is then applied to the mercurial height, so as to give it the value it would have at the standard temperature.

A second correction takes account of the difference in the force of gravity at different places, and becomes necessary because the heaviness of mercury is proportional to the local force of gravity, so that the same absolute air pressure is at different places recorded by mercurial columns of different heights.

The essential part of an aneroid barometer is a thin drum or elastic metal from which the air has been exhausted. The heads of the drum are bent inward by the pressure of the air, the pressure being counterpoised by the elasticity of the metal. With augmentation of pressure the inbending is increased, and by relief from pressure it is diminished; while by a system of levers the movements of the flexed heads are (in most instruments) communicated to an index traversing a dial. The amount of motion imparted to the index by the addition of a unit of pressure depends not only on the arrangement of the levers, but on the form, thickness, and elasticity of the drum-heads, and cannot be precisely foretold for any individual instrument. In order to ascertain it, the movements of the index are compared with those of the column of a mercurial barometer exposed to the same pressures, and the dial is graduated accordingly. The spaces on the dial are given the same name as the units of the mercurial scale, although they have not the same linear dimensions.

The aneroid barometer is thus adjusted in the process of its construction so that its indications accord with those of the mercurial, and it theoretically accomplishes the same results with great economy of time and care; but it is usually found in practice that aneroids subjected to the vicissitudes of travel, and especially of mountain climbing, do not maintain their adjustment. It has therefore become the custom in most surveys to use the instrument only in a dependent way, comparing it at short intervals with a mercurial barometer so as to keep account of the amount and variation of its error. Thus checked it renders important service.

MODIFYING CONDITIONS.

Returning now to the consideration of the relation between local pressures of the atmosphere and local altitudes, we will give attention to the conditions which modify the application of the general law.

The most important of these is temperature, for the density of air varies through a wide range in response to changes of temperature. If the pressure of the air be measured by a barometer in the car of a balloon, and at the same time by another barometer on the ground beneath it, the difference between the two quantities denotes the pressure imposed on the ground by that portion of the atmosphere beneath the balloon, or, as more commonly expressed, it denotes the weight of the column of air between the balloon and the ground. The weight of that column depends on its height and its density. Its density depends primarily on the pressure of the superincumbent air, as indicated by the barometer in the balloon, but it depends also on the temperature of the column itself, being greater if the air is cold than if it is warm. In order, therefore, to compute accurately the altitude of the balloon above the ground, it is necessary to know the temperature of the intervening air column as well as the pressure above and below, and it is of course necessary to know the law which governs the expansion of air in response to the acquisition of heat. In the various formulas which have been employed for the computation of altitude a term has been written to express the influence of the temperature of the air upon the result, and this has been conjoined to the principal term which expresses the relation of heights to pressures. The pressure term is adjusted to the supposition that the temperature of the air is that of freezing water, and the temperature term appears as a correction proportioned to the difference between the actual air temperature and the freezing temperature. For each thousand feet of altitude the correction amounts to two feet (approximately) for every degree of the Fahrenheit scale.

The factor of next importance depends on the humidity of the air column. The atmosphere is essentially a mixture of oxygen, nitrogen, carbonic acid, and aqueous vapor. The proportions of oxygen and nitrogen are practically constant; the quantity of carbonic acid is more variable, but is too small to be considered here; the amount of aqueous vapor is both large and variable. We may, for the present purpose, regard the whole as consisting of two parts, dry air and aqueous vapor, the dry air being a constant homogeneous gas mixture and the aqueous vapor a variable accessory.

Dry air retains permanently the gaseous form but aqueous vapor does not, and upon this difference depends the variability of their mixture. The tension or expansive force of dry air increases in a definite way when its volume is diminished by extraneous pressure, and also when its temperature is raised; its tension is diminished by increase of volume and fall of temperature; and these properties subsist under all pressures and at all temperatures to which the atmosphere is subject. Aqueous vapor follows the same law, but only within a certain range of conditions. For each temperature there is a certain tension which cannot be exceeded, and for each tension there is a certain limiting temperature; and when these limits are passed a portion of the vapor is condensed. The circulation of the air continually varies the conditions to which its aqueous vapor is subject, now causing a part to be precipitated, and again permitting an additional quantity to be absorbed from the ocean or from moist surfaces of land.

If the densities of dry air and aqueous vapor were identical for the same tension—*i. e.*, if the two gases were equally heavy—the ratio of their mixture would not affect the measurement of heights; but aqueous vapor is only five-eighths as dense as dry air, and the density of the air column weighed by the barometer depends therefore in part on the ratio of its contained vapor.

Accurate hypsometry accordingly demands that some account shall be taken of the aqueous contents of the air, and a humidity term has been given place in many formulas for the computation of altitudes.

There are other small factors dependent on the inequality of the force of gravity at different latitudes and at different altitudes, and the consequent inequality in the weight of air, which need not be specified here. For the purpose of the present discussion the difference in altitude of two barometric stations may be regarded as depending on the air pressures at the two stations and the temperature and humidity of the intervening air column.

With the outlines of the subject now before us, the difficulties which bar the way to the attainment of results of the highest accuracy may be stated. They arise from the fact that the air is never in a state of static equilibrium but is perpetually undergoing local changes of pressure, temperature, and humidity. If those changes were uniform, or uniformly periodic, it would not be a hopeless task to take full account of them and eliminate their influence from the hypsometric problem; but they are irregular in a high degree and they spring from causes so complex that their thorough analysis appears impossible.

Consider for a moment how many things conspire to give diversity to meteoric changes. In the first place, the sun, which is the ultimate source of all disturbance, shines only by day. While it shines, a certain amount of heat is imparted to the whole atmosphere, but a much higher temperature is given to the ground and is communicated to the contiguous layer of air. At night the atmosphere loses heat by radiation to space, but the ground loses it still more rapidly and imparts its low temperature to the lowest stratum of air. The lower strata, therefore, have exceptional warmth by day and exceptional coolness by night. If the air is moist it intercepts a greater quantity of solar heat than if it is dry, so that a less quantity reaches the ground; while at night atmospheric moisture checks radiation from the ground. The power of the earth's surface to receive or store or part with heat varies with its character. Naked rocks and cultivated fields, bare earth and grass, forest and snow, are affected very differently by the heat rays of the sun and exert equally diverse influences on the adjacent air, so that one tract of land is often in a condition to heat the air while an adjacent tract is cooling it. Then, too, the sun's heat is unequally distributed through the year; outside the tropics there is a progressive accumulation of heat through summer and a progressive loss through winter. The circle of the seasons thus produced reacts on the surface of the land, causing verdure, barrenness, and snow in alternation; and these in turn have their influence on the local meteoric changes.

The ocean undergoes less change of temperature than the land and its rate of change is slower, so that there is frequent, and indeed almost continuous, contrast of condition between it and the contiguous land.

In many places this contrast is heightened by oceanic currents (born, like air currents, of the sun's rays), which perpetually convey warm water to cold regions and cold water to warm regions.

As a result of all these influences, together with others that might be enumerated, the equilibrium of the air is constantly overthrown and the winds, which tend to readjust it, are set in motion. If a condition of static equilibrium were possible, we may suppose that the whole atmosphere would become a uniform mixture or else one varying according to a simple law, and that it would be arranged in a system of horizontal layers, each one of which would be denser than the one above and rarer than the one below and would have a uniform temperature throughout. But in reality its temperature is continually modified by external influences; the static order of densities is broken and currents are set in motion; and the circulation and the inequalities of temperature conspire to produce inequalities of moisture. Every element of equilibrium is thus set aside and the air is rendered heterogeneous in composition, temperature, and density. Moreover, the disturbing factors are so multifarious and complex that there is infinite variety of combination and infinite variety of result. Nothing can be more fickle than the weather, and the weather is merely the totality of atmospheric states and changes viewed in relation to human activities.

The complete solution of the problem of barometric hypsometry is thus rendered impossible, or if not impossible at least impracticable, since, if our knowledge is ever equal to the task, the expense of the solution in any individual case cannot fail to be greater than that of determining the desired altitude by means of the engineer's level. Approximate solutions only are expected, and ever since the development of the general theory the ingenuity of investigators has been directed to the restriction and limitation rather than to the abolition of errors.

Although the disturbing factors all spring from the same remote source, and although they react upon each other in the most intricate way, it is nevertheless possible, when series of observations are compared, to discriminate many of them, and it has been found that every added refinement of analysis has led to new devices for the elimination of error. A discussion of hypsometric methods should therefore be prefaced by a classification of disturbing factors.

GRADIENT.

Designate by A and B two stations at the same altitude. With the air in a state of static equilibrium each receives the same atmospheric pressure; but when the equilibrium is disturbed one may receive more than the other. If A has a greater pressure than B there is a tendency of the air to move in the direction from A to B until equality of pressure is attained. Add now a third station, C, forming with the others a horizontal triangle, and conceive verticals to be erected at each of the three, proportioned in height to the local pressures. A plane passing through the summits of the verticals will evidently be inclined in some direction (unless the pressures are equal) and this inclination is called *barometric gradient.* The direction toward which the plane inclines is called the direction of the gradient. In other language, the direction of the barometric gradient at any point is the direction toward which there is the most rapid decrease of pressure.

The contour lines drawn on the weather maps published by the United States Signal Service are lines of equal pressure (*isobars*). If lines of gradient were also drawn on one of these maps, each gradient line would pass from an area of high pressure to a center of low pressure in such way as to make a right angle with each pressure contour at the point of intersection.

There is another point of view which will perhaps help to a clearer understanding of the matter. Suppose that of a large number of stations on a plain, A is the one with the lowest pressure at a given time. At any other station, B, the pressure is somewhat greater, but by ascending in mid-air we can find a point, directly above B, where the pressure is precisely the same as at A. So above every point of the plain we can find a corresponding point with the standard pressure, and the combination of all these points constitutes an ideal surface of equal pressure. With the atmosphere in equilibrium such a surface would be level, but in point of fact it is ever undulating. Its inclination at any point is the barometric gradient, its direction of inclination is the direction of gradient, and its degree of inclination measures the amount of gradient.

The standard of pressure assumed in the preceding paragraph is entirely arbitrary, and it is evident that any atmospheric pressure whatever could have been assumed. We can in imagination project through the air a surface containing all points which have a pressure of 30 barometric inches, and another surface containing all points with a pressure of 29 inches, and indeed any number of similar surfaces. In the hypothetic case of atmospheric equilibrium all such surfaces would be both level and parallel, but in the actual case of disturbance and motion none are level and no two are precisely parallel. When widely separated surfaces are compared the variations from parallelism are often so great that their inclinations above the same locality have opposite directions. The atmospheric gradient at the surface of the ground may therefore differ greatly in amount and direction from the simultaneous gradient at a considerable altitude above the same spot.

The importance of the hypsometric difficulties introduced by gradients will be readily understood. It almost never happens that two points to be compared in altitude are in the same vertical line, and whenever they are not their barometric relation involves a factor of gradient. Suppose that barometers have been read simultaneously at *A* and *B*, (Fig. 27) and it is desired to ascertain their difference of altitude. *B C* is a horizontal line, and we will suppose *B D* to give the local profile of

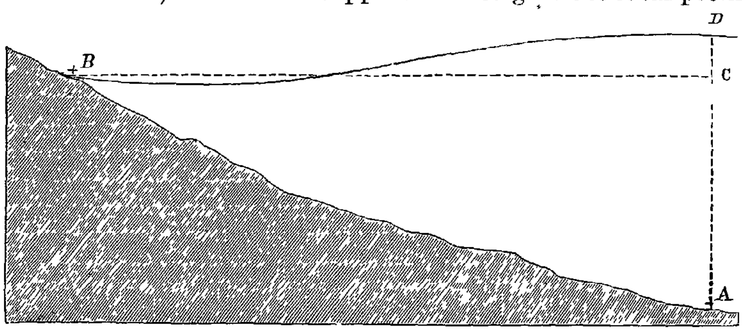


FIG 27.—Diagram to illustrate atmospheric gradient

the surface of equal pressure passing through *B*. If we know the density of the air column above *A*, we can compute from the barometric readings the height (above *A*) of a point (*D*) having the same pressure as the point *B*; but what we really desire is the altitude of the point *C* on a level with *B*, and in order to pass from one to the other we must know the gradient.

Variations of gradient are for the most part the result of conditions so complicated that in the present state of meteorologic science they have to be classed as irregular, but there are two elements of variation which are strictly periodic and have been the subject of much research; one has a daily period, the other a yearly. Changes of gradient may therefore be classed as diurnal, annual, and non-periodic.

Diurnal gradient.—It is a fact familiar to meteorologists that the pressure of the air everywhere undergoes a daily oscillation, being at a maximum soon after sunrise, and at a minimum some hours before sunset, besides exhibiting other maxima and minima. The amount of change is relatively great at the equator and diminishes toward the poles. It is greater in summer than in winter, and it is usually greater in valleys and on plains than on mountain peaks. It is subject, moreover, to variations in character as well as variations in magnitude, and changes of altitude are often accompanied by conspicuous variations in character. The differences which pertain to latitude and to season do not affect the ordinary hypsometric problem, but differences depending on the altitude have a notable influence. The geographer frequently undertakes to determine the height of a mountain by comparing the pressure at its summit with the pressure at its base, and since the diurnal oscillation of pressure is not the same at base and summit an error is introduced into his result. Usually his result is rendered too large in the forenoon and too small in the afternoon, but to this rule there are exceptions; and it is probable that the error cannot be thoroughly eliminated without a knowledge of the nature of the diurnal change at each station.

Annual gradient.—The annual oscillations are variations of what may be called the perennial system of gradients. Since the atmosphere if undisturbed would have no gradients, and since every disturbance produces them, it is easy to understand that any continuous disturbance will be accompanied by permanent gradients. The excess of solar heat received in the tropics, as compared with the polar regions, is of the nature of a continuous disturbance, and sets in motion the great currents of the atmosphere. Warm ocean currents flowing toward the poles, and cold ocean currents flowing toward the equator, are other disturbing elements of a continuous nature, which modify the great air currents in a uniform manner. Under the joint action of these causes the great system of the winds is instituted, and coincident with it a great system of permanent gradients. The annual progress of the sun from tropic to tropic throws a preponderance of heat first on one side of the equator and then on the other and produces an annual cycle of changes both in the great winds and in the permanent gradients.

Non-periodic gradients are caused by the multifarious local agencies and accidents which give rise to variable winds and to storms. They are ordinarily so great and their variations are so rapid that they completely mask, so far as hypsometry is concerned, the perennial and annual gradients—at least in the temperate zones. They do not, however, obscure the diurnal changes to the same extent.

It is necessary, therefore, for accurate determination of altitude by the barometer to take account of the non-periodic gradient and of that gradient which has a daily period. The former is involved in the general air movements of the region at the time of observation; the latter bears some relation to the topographic characters of the points of observation as well as to the hour of observation and the time of year.

DEVICES FOR THE ELIMINATION OF ERRORS DUE TO GRADIENT.

The most important of all the devices which go to make up the barometric method in use consists in the employment of a base station. If the pressure at the shore of the sea were uniform it would be necessary for hypsometric purposes to measure the atmospheric pressure only at the point whose altitude is desired, for that measurement would afford at once the differential pressure and, consequently, the weight of the differential air column. In fact, however, it is not uniform, but fluctuates greatly from week to week, and even from hour to hour, and it is therefore important that we know its amount at the time when the pressure at the higher point is measured. Moreover, since gradients of the non-periodic order often slope continuously in the same direction for hundreds of miles, it follows that we shall diminish the probability of error if we use as the standard for each comparison that point of the coast nearest to the point to be determined.

It is not essential, however, that the point used as a standard—*the base station*—be either at or near the shore, provided only its altitude is known; and if it can be established in close proximity to the point to be measured the effect of non-periodic gradient is nearly avoided.

The intelligent geographer who uses the barometer for the determination of altitudes pursues the following plan: He selects some point either within or near his field of survey for a barometric base station. The height of this point is determined with great care, either by means of the surveyor's level or by means of a series of barometric observations made coincidently with a similar series at some point of known altitude and continued for a long time. Having placed a barometer and observer at the base station he carries another barometer to the points to be determined—called *new stations*—and makes synchronous readings; that is to say, he so arranges the time of observing the barometers that each reading at a new station shall be simultaneous with a reading at the base station. In the subsequent computations only the pairs of synchronous observations are used. By establishing the base station in close proximity to the new stations, the error arising from non-periodic gradient is in great part avoided. By synchrony of observation the results are protected from such errors as might arise from progressive increase or decrease of pressure in the district during the time elapsing between observations not synchronous.

It is evident that the use of the base station excludes from the observations a portion only of the gradient which would otherwise enter, and affords no means of eliminating from the results the error wrought by the remainder. It is often impracticable to place it so near the new station as to render the included gradient insignificant in amount, and it is therefore important to have corrective means at hand.

Two corrective methods are known, although up to the present time one only has been widely employed, namely, the method by long series. Since the non-periodic gradient is produced by a variety of discontinuous causes, it is assumed that it will in the long run favor one direction no more than another, so that the sum total of its influence through a long period will be approximately zero. An extended series of observations, therefore, covering several weeks or months, affords a mean result superior in accuracy to the result from a single pair of observations. The gain in accuracy, however, is usually incommensurate with the attendant expense, and the method is practically resorted to only when some other purpose is at the same time subserved by the observations.

The second method involves the actual determination of the included gradient and demands the employment of at least three base stations. These should be established at approximately the same altitude and in such relative position that the lines joining them shall include the principal portion of the district of new stations. The pressures at the three stations at any point of time afford the means of computing the coincident direction and amount of the gradient on the assumption that the surface of equal pressure, to which reference has already been made, is an inclined *plane*, without curvature. This assumption is never strictly warranted, but if the district is small as compared with the amplitude of the pressure waves which cross it no serious error is involved. The general direction and rate of gradient having been computed, a similar calculation shows how much exists between the new station and that base to which it is referred for the computation of altitude. Its amount is then applied as a correction to the reading at that station.

The same result may be attained more easily and with a sufficient degree of accuracy by applying a graphic method to the same data. The new station, the base stations, and the simultaneous pressures at the base stations being marked on a map, it is a simple matter to draw across it, by eye estimate, contour lines of equal pressure (isobars), and so soon as this has been done the amount of the correction appears by inspection.

The expense of maintaining a number of base stations is a serious objection to this method; but if the accessory stations have other functions, so that the hypsometric work does not have to incur their cost, their practical utility can hardly be doubted. In any country furnished with weather maps such as the thrice-daily series of the United States Signal Service the hypsometer is provided with gradient corrections graphically presented and without expense.

There is one class of non-periodic gradients to which the preceding method will not apply—namely, the gradients accompanying thunder storms and other restricted vortical movements. The assumption that the surface of equal pressure is plane, even for a small district, is in this case so erroneous that isobars cannot be used. If the local effect of the disturbances upon the barometer is indicated by a continuous series of observations made at short intervals, it is sometimes thought best to plot the observations on section paper in such way as to represent the rise and fall of the barometric column by an ascending and descending curve and then graphically replace it by a smoother curve assumed to express the movement which would have taken place but for the exceptional disturbances. In the illustrative diagram the vertical lines represent hours and the horizontal lines hundredths of an inch of pressure. The curved line shows the oscillations of pressure on a day characterized by thunder storms, and the broken line shows the pressure curve as arbitrarily amended. The amended pressure is substituted for the observed in the computations of altitudes. When such disturbances are known to have occurred at the new station or base station and the observations are not sufficiently full to permit their elimination, the best practice is to discard the observations and base no determinations upon them.

The method by plotted isobars has a theoretic advantage over that by long series, in that it takes account of the perennial gradient as well as the non-periodic. It affords a correction for the actual gradient at the moment of observation, without reference to the elements of which that gradient is composed; while the method by long series eliminates errors only by balancing those with a positive sign against those with a negative, and necessarily fails to expunge constant errors. In order, however, to render practical this advantage in the use of isobars it is essential that the altitudes of all the base stations shall have been measured by the spirit level, for if measured barometrically, no matter with what precautions, they will themselves be liable to an unknown correction for perennial gradient.

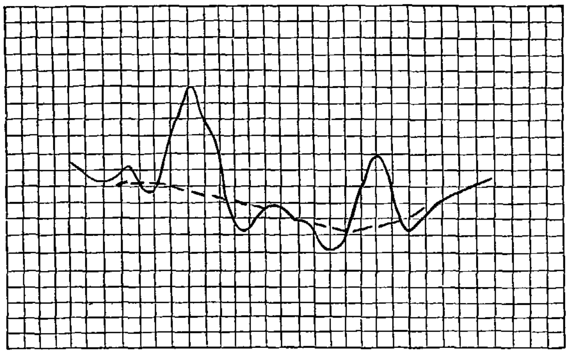


FIG 28 Diagram to illustrate the Graphic Method of Correcting Barometer Readings made during a Thunder Storm

On the other hand, the method by long series has a theoretic advantage over that by plotted isobars, in that it takes account not only of gradients but of the non-parallelism of gradient planes. When the new station is several thousand feet higher than the base stations from which isobars are plotted, it not unfrequently happens that the surface of equal pressure passing through it has a very different form and inclination from the surface of equal pressure passing through the lower stations, and the hypsometric error due to this want of parallelism entirely escapes the method by plotted isobars.

Circumstances sometimes arise in which, while it is impossible to apply corrections for non-periodic gradient, it is nevertheless practicable to enhance the value of the result by discriminating among the individual observations of a short series—giving little influence to some or rejecting them altogether. Nearly all non-periodic gradients are associated with broad cyclonic movements of the air, and whenever this is true their relation to the local wind is somewhat definite; the steeper gradient accompanies the stronger wind, and observations made during a strong wind have therefore a relatively low value. To this rule, however, there are exceptions; in all ordinary cases the direction of the isobaric contour passing through a station can be inferred from the direction of the wind, and whenever it appears that the base and new stations fall under the same isobar, non-periodic gradient need not be feared.

Turning now to the diurnal variation of gradient, we find four methods in use which serve to diminish its influence. It has already been explained that the pressure of the atmosphere everywhere undergoes a daily cycle of change in addition to its other changes, and that the daily cycles of different localities are different. It is especially true that the changes occurring in valleys differ from those on peaks or even on hills. If the cycle at the base station is the same as at the new station, no gradient arises, because the *relative* pressure is unchanged; but if the cycles are unlike, differences of relative pressure occur, and such differences are gradients affecting the hypsometric result. A gradient of this sort varies from hour to hour and is inclined alternately toward the base station and the new. At the instant of changing its direction it ceases altogether, and if that instant can be selected for the observation the error is avoided. One method of escape from the difficulty consists, therefore, in the selection of the most favorable hours for reading the barometers. A great deal of attention has been given to the selection of favorable hours, not indeed with reference to the particular error arising from diurnal gradient, but with reference to the sum total of errors affecting barometric measurement of altitude. There are two serious objections to the employment of hour selection as a corrective for this particular error. The first is that the propitious moment is earlier on some days than on others, even in the same locality and in the same season of the year, while the change of gradient is usually most rapid just as it passes its zero. A small deviation in time would therefore frequently occur and would result in the introduction of a considerable element of gradient. The second is that the favorable moments are not the same for different pairs of stations; so that without a more thorough understanding than has heretofore been attained of the dependence of particular types of diurnal oscillation on the peculiar ities of locality, it must be impracticable to lay down any general and useful rule for the selection of times of observation—at least as applied to the elimination of errors of this class.

The second and most obvious method is to ascertain the diurnal cycle of each station and apply to each observation a correction reducing it to the value it would have if there were no diurnal pressure change.

Suppose, for example, that we wish to compute the relative altitude of Ogden, Utah, and Pioche, Nevada, and have among our data the pressures at the two stations at 1 p. m. on the 1st of October.

Pressure at Ogden=25.502 inches.
Pressure at Pioche=24.221 inches.

Curves exhibiting the pressure cycles (diurnal barometric curves) for those stations at that season of the year have been published by Marshall,* and from them we learn that at one o'clock the pressure at Ogden is .019 in. greater than its mean for the day, while at Pioche it is .004 in. less than the mean. The observed pressure at Ogden is therefore diminished by way of correction, and that at Pioche is increased, and the corrected pressures—

$$25.502-.019=25.483, \text{ and}$$
$$24.221+.004=24\,225,$$

are used in the computation of the desired altitude.

It is an objection to this method that its application to a single station is expensive. Except at maritime stations near the equator, the daily cycle of pressure is so combined with non-periodic changes that it is necessary to make a series of observations extending through several days in order to obtain data to separate it,—an outlay of time ill compensated by the advantage gained. It may be said also that while the observations to determine the pressure curve must extend through several days, a series comprising only a single day will afford a mean value of the pressure for that day which can be used directly in the computation with superior advantage. This consideration is so obvious that in practice observations for the diurnal curve at a station are never made for the purpose merely of aiding in the computations of altitude for that station. There is a general belief, however, that the diurnal pressure cycles of all stations in the same district which have approximately the same altitude are so nearly identical that one may be substituted for another, and that it is therefore possible to ascertain the character of the oscillation at one station of such a group and assume it for the others. In this way an obvious economy is effected where many new stations are to be determined, and if the belief is well founded it is possible, by classifying all the new stations of a survey in groups and determining the diurnal oscillations for each group, to prepare a system of corrections which will practically rid the observations of diurnal gradient. It is to be feared, however, that the belief is not warranted, for recent investigations tend to show that the local peculiarities of diurnal cycles depend as much upon the topographic peculiarities as upon the altitudes of their localities, so that any grouping based purely upon altitude would be fallacious and misleading.

The third method consists in selecting a base station within each group of new stations and referring all stations of that group to it in

* U. S. Geog. Surveys W. of the 100th Mer., vol II, pp 544, 545, and Plate IX

the computation. The diurnal curves of new and base station being hypothetically identical, no diurnal gradient exists and no correction is needed. Being based upon the same assumption as the last method it is open to the same objection, and the great expense of using a base station for each similar group of new stations would effectually prevent its use if no object were to be attained aside from the elimination of diurnal gradients. There are, however, other and more important advantages to be gained by such a multiplication and vertical distribution of stations, as will presently appear.

In the fourth method series of observations are made at the base and new stations for twenty-four hours, and the means of these series are employed in the computation instead of the individual observations. It is probable that the effect of diurnal oscillation is completely eliminated by this procedure,—it is at least impossible to distinguish from non-periodic gradient any residual gradient which may exist. The sole objection to the method is its expense, but this so far outweighs the object to be attained that it is rarely resorted to.

It is easy to conceive that other means of dealing with diurnal gradient might be devised which would be at the same time effective and economically practicable if only we were possessed of a satisfactory theory of the proximate cause of the diurnal pressure change. The subject has long occupied the attention of meteorologists and hypsometers, and a number of tentative theories have been advanced, but while it may be possible that some of these contain the essence of the true explanation it must be admitted that no one of them has commanded general assent and recognition. Like every other change affected by a daily period, it finds its remote cause in the heat of the sun, but the explanation of its immediate genesis as a result of the daily movements of the atmosphere has proved a baffling problem in atmospheric dynamics. It is to be feared that even after its general theory has been established there will remain great difficulty in the determination of the influence of local geographic conditions.

TEMPERATURE.

It has been explained in a preceding section that gradients are caused initially by inequalities of temperature, and it is equally true that fluctuations of humidity are more or less remotely dependent on changes of temperature; so that the temperature factor is indirectly responsible for a large share of the difficulties which encompass the barometrician. Unfortunately it is directly responsible for the remainder, and the errors of which it is the immediate cause are, on the whole, the most serious of all. They arise from the heterogeneity of air with respect to warmth, and from the practical difficulty of ascertaining the thermic condition of the column of air which is weighed by the barometer. Not only is the greater part of the column inaccessible to us, but that portion to which our observations are restricted is the portion least representative of all.

Having recourse once more to a diagram, let *A* and *B* be two stations at which barometric and thermometric observations have been made and of which it is desired to ascertain the difference in altitude. Let us assume that the difficulties dependent upon gradient have been overcome, so that the atmospheric pressure is known not merely at *B* but at the point *C*, having the same altitude as *B* but situated vertically above *A*. In order to complete the computation it is necessary to know the temperature of the column *A C*. If the atmosphere were in a condition of static equilibrium there would be a uniform gradation of temperature from *C* to *A*, and the mean temperature of the column would be expressed by the half sum of the temperatures at *B* and *A*. In the "hypsometric formula," as it is called,—the formula which expresses the general relations between heights, pressures, temperatures, and moistures, and

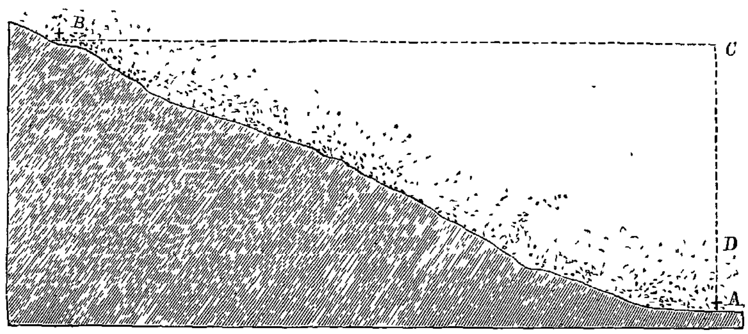


FIG. 29.—Diagram to illustrate the Thermic Inequality of the Atmosphere. The Dots indicate the Region of Most Rapid Change.

which forms the groundwork of all hypsometric computation,—a static condition of the atmosphere is postulated, and this half sum is assumed to give the temperature of the included air column.

How inadmissible this assumption is will appear at once when the manner in which the air acquires and loses heat is recalled. The body of the atmosphere is heated directly by the sun and gives off its heat by radiation to space. The surface of the earth is heated and cooled in the same manner, but many times more rapidly, so that by day it is always much warmer than the body of the air, and by night it is much cooler. A layer of air next the earth receives its warmth from the earth, and is thereby caused to differ widely in temperature from the remainder of the atmosphere.

In middle latitudes the average range of the daily temperature oscillation of the body of the air is about 4°F.*, while for the superficial

*The daily range of the temperature of the body of the atmosphere is not known by direct observation, but indirectly through computations of altitude. When a long series of observations at two stations are combined so as to show the mean pressure, mean temperature, and mean humidity at each station for every hour of the day, and layer it is from 10° to 20° near the sea-shore, and from 20° to 35° in the interior of continents. Usually therefore there are but two moments in the twenty-four hours when the temperature of the air near the ground bears a normal relation to that of the mass of the atmosphere above; in the night it is many degrees too cool, and in the heat of the day it is many degrees too warm.

Unfortunately for the art of barometric hypsometry, the general temperature is the one most important to know, while it is practicable to measure by thermometers only the superficial.

Reverting to the diagram (Figure 29), we may regard the air column *A C* as consisting of two parts, of which the lower, *A D*, is controlled in temperature by the contiguous ground and oscillates daily through a wide thermic range, while the upper and greater, *C D*, is influenced only by radiant heat and is relatively constant The same layer of thermally variable air includes the upper barometric station as well as the lower, so that the thermometer reading at *B* affords no indication of the temperature at *C*, and the temperatures observed at *A* and *B* absolutely fail to give the temperature of the air column *A C*. They therefore fail to afford the data demanded for the computation of the altitude.

The trouble does not end here, although its chief element has been outlined. It would perhaps not be a matter of great difficulty to acquire information about the upper air mass if its relation to the ground layer were simple, but such is never the case. Whenever the ground layer is cooler than the air above, it is of course heavier, and, like any other heavy fluid, it flows down hill and accumulates in valleys, forming lakes of cold air. The nightly layer of abnormally cool air is therefore thinner on eminences than in valleys, and the contrast increases as the night advances. When the conditions are reversed, so that the ground layer is warmer than the air above it, it has a tendency to rise, but accomplishes the change in an irregular manner, breaking through the immediately superior layer here and there and rising in streams, which spread out in sheets wherever the conditions of equilibrium are reached. The conditions of equilibrium are greatly affected by the amount of moisture in the rising streams, and it results that the stratification of the air is notably irregular with regard to temperature. Observers in balloons, as they ascend or descend, rarely find an orderly succession of temperatures. If, therefore, we could in some way determine the temperature of

when from these hourly means separate computations are made of the difference in altitude of the two stations, the results are found too great for certain hours and too small for others. The element of the computation which varies most greatly from hour to hour is the temperature, and the differences in result are therefore ascribed to errors in the determination of the temperature It is a simple matter to reverse the process and ascertain what temperature at each hour will give a uniform determination of altitude, and this has been done by Plantamour, Ruhlmann, and others The general result of their investigations is that the general temperature of the atmosphere undergoes a daily change which is exceedingly small, amounting in the Alps to only 4° Fahr. in summer, and less than 2° in winter some point of the upper hypsometric column, $C D$, we should still be unable to deduce the mean temperature of the column with a high degree of accuracy.

DEVICES FOR THE ELIMINATION OF ERRORS DUE TO TEMPERATURE.

At least six different methods have been either employed or recommended for avoiding or eliminating the errors which arise from the imperfection of our means of ascertaining the temperature of the air column weighed by the barometers.

Since the error inheres primarily in the temperatures observed at the two stations whose difference of altitude is to be ascertained, the most obvious way to eradicate it is to apply a correction to the thermometer readings before using them in the computations. Wherever long series of observations of the thermometer and barometer have been made at corresponding stations, high and low, it is practicable, by discussing the means of the series, to ascertain what correction should on the average be made to the thermometer readings at different hours of the day and at different seasons of the year in order to obtain accurate determinations of height; and this work has been performed by various investigators for several different pairs of stations, the results being embodied in tables of corrections.

When these tables come to be applied, however, a high degree of accuracy is not attained, and for this there are two reasons:

In the first place, there is a great dissimilarity in the observed temperature oscillations of consecutive days. The correction which would be appropriate to a certain hour of the average July day, for example, will apply closely to very few individual July days, being too great for some and too small for others. This difficulty has been partially met by constructing two tables, one for clear and the other for cloudy weather.

In the second place, it has been found that each set of tables has a fair degree of usefulness only in a limited district including the locality where the data for its construction were derived, and that it almost uniformly fails when applied to remote districts. The daily and yearly cycles of temperature depend so largely on purely local conditions that the order of change observed in one locality cannot be assumed in advance to obtain in any other.

A second method employed to eliminate the errors is to apply corrections, not to the observed temperatures, but to the computed altitudes. For this purpose also tables have been constructed, and they do not essentially differ from those described above, except that they aim to remove errors arising from the moisture of the air as well as from its temperature. They are open to the same criticisms, for they assume the similarity of consecutive days and include local peculiarities which prevent their universal application.

A third method is closely allied in principle to the preceding but seeks to avoid the errors instead of eliminating them from the result. It consists in the selection of favorable hours of the day. If we examine any table prepared for the application of either of the preceding methods we shall find that for each month of the year there are certain hours of the day when the indicated corrections are either very small or nothing at all, and it is evident that by selecting those hours for our observations of temperature and pressure we shall obviate at least the use of the tables of correction. The same difficulties, however, inhere in this plan. The critical moments at which the observed temperatures truly represent the conditions of the air column occur upon the average at about the same time of day in the corresponding seasons of each year, but they unfortunately vary so greatly from day to day that it is nearly useless to seek them; and when to this consideration is added that of the inconvenience of making observations at prescribed hours, the method retains little to recommend it. Moreover, the element of locality enters so largely, and in ways apparently so anomalous, that no general rules for the selection of hours are practicable. For example, the tables constructed by Whitney for California indicate that below the altitude of 2,400 feet the most favorable hour for barometric work in January is 6 p. m., while above 2,400 feet noon is preferable.

A fourth manner of procedure ignores altogether the readings of the thermometers at the two stations at the moment of barometric observation, and substitutes therefor the mean temperature for the day, deduced either from a series of observations extending continuously through the twenty-four hours, or else from observations at 7 a. m., 2 p. m., and 9 p. m.,—which have been found by trial to give approximately the same result. It is thus assumed, first, that the temperature of the included air column undergoes no change whatever during the twenty-four hours, and, second, that the daily mean of temperature as deduced from observation truly represents the actual temperature of the air column. Neither of these assumptions can be true; but they approximate so much more nearly to the truth than does the alternative assumption that the desired temperature of the air column is represented by the thermometric readings at the moment of barometric observation, that a great advantage follows their substitution. The error of the first assumption is not great, but it is certainly appreciable and should not be neglected if it is possible to apply a correction. Plantamour's discussion of the great series of Swiss observations shows that the temperature of the main body of the atmosphere is there in midsummer 4° Fahr. higher in the afternoon than it is at early morning, and such a difference of temperature, when converted into altitude, amounts to eight feet in each thousand.

We have at present no means of knowing that the conclusions derived from the Swiss observations are entitled to universal application, but it is reasonable to expect that future investigation will enable the construction of tables whereby an approximately true diurnal sequence of temperatures can be substituted for the assumed diurnal uniformity of temperature

The second assumption, that the daily mean temperature of the air column is equal to the half sum of the daily mean temperatures of the two stations as determined by continuous observations, is probably true when averages of long periods are considered, but is fallacious as applied to individual days. And there is little ground to hope that future investigation will discover any method of correcting the errors involved in the means of individual days as derived from observation.

The fifth method is one of avoidance rather than correction. It consists in having the base station at approximately the same altitude as the new station, so that the included air column is of small height and the error dependent on the inaccurate determination of its temperature inconsiderable. This method is highly efficacious, but the opportunities for its application are rare. It was successfully employed, however, by the survey in charge of Dr. Hayden for the measurement of the numerous high peaks of Colorado. A base station was established on one of the peaks and to it were referred all new stations of similar altitude.

A sixth method was proposed by Rühlmann, but has perhaps not yet been put in practice. His plan consists essentially in deducing the temperature of the air from barometric observations made at points of known altitude simultaneously with the observations at the stations whose difference it is desired to ascertain; the temperature thus obtained is then used in the computation of the desired altitude. The advantages of this method are believed to be great, but since it is closely allied in principle to the method it is the purpose of this paper to present, and will have to be discussed at length in a succeeding chapter, its consideration is deferred for the present.

HUMIDITY.

The errors which depend upon the humidity of the atmosphere resemble those due to temperature in that they arise from the imperfection of our means of ascertaining the actual condition of the air column. It is a common practice to make instrumental tests of the amount of moisture contained in the air at hypsometric stations, but there is reason to believe that these tests convey very little information as to the actual condition of the air column concerning which knowledge is desired. The error thus accruing is less than in the case of temperature, only because humidity is a much smaller factor of the hypsometric problem.

The variability of the distribution of moisture in the atmosphere arises from the atmospheric circulation, taken in conjunction with the laws of condensation. Aqueous vapor is diffused so slowly in air, and its relative amount in the atmosphere is so small, that its movements are not independent, and it is practically carried by the air. Whenever, therefore, a current of air moves upward and its temperature is lowered by rarefaction, a point may be reached where the accompanying vapor can no longer exist as such and is condensed to cloud or even to rain or snow.

Whenever a current of air moves downward, on the other hand, its capacity for moisture is increased, and it acquires a *quasi*-absorbent power so as to take up water from whatever moist surface it touches. At the surface of the earth there is an almost continuous passage of moisture from ground to air, only a part of the total exhalation being returned as dew. The daily circulation incited by the heat of the sun carries the moistened air upward, and eventually the water is returned to the earth in the form of rain. The acquisition of moisture by the air is greater by day than by night, and the precipitation is exceedingly irregular, so that in the distribution of the moisture there is a tendency toward heterogeneity, which is only imperfectly met by the slow process of molecular diffusion. Probably the most variable stratum of all is that next the earth, and it is to this that psychrometric observations are almost invariably confined. A change of station of a few feet, or a slight variation in the direction or force of the wind, will often cause a very important difference in the indications.

Similar irregularities are observed by aeronauts, who rarely if ever obtain humidity records indicating an orderly diminution from the ground upward, and the irregularities which they observe are more striking than the associated irregularities of temperature.

It is therefore generally conceded that the moisture observations which the hypsometer is able to make are of little service to him, unless it be in the form of means derived from long series.

DEVICES FOR THE ELIMINATION OF ERRORS DUE TO HUMIDITY.

Several of the devices employed to obviate errors of gradient and errors of temperature include at the same time errors of humidity, and it will be unnecessary to repeat their description here. The following methods apply to the moisture element only.

First. It is a common practice to ignore the changes announced by the psychrometers from hour to hour, and from day to day, and to use instead of individual readings the mean of observations for a considerable period of time, such as a week or a month.

Second. It is also a common practice to ignore altogether the indicated changes of moisture, and assume that the influence of moisture upon the density of the atmosphere is strictly proportional to that of temperature. This is done by ascribing to the temperature an effect slightly greater than that due to the expansion of the air and omitting altogether the moisture term of the hypsometric formula.

This practice finds a certain warrant in the general fact that warm air can hold, and on the average does hold, more moisture than cold, but it is to be doubted whether the results thus obtained are as accurate as those by the first method. It is not easy to test the matter, for the errors due to temperature, while they are to a certain extent analogous to those arising from humidity, are so much greater in amount that they mask them and render their discussion a matter of difficulty. There can be no doubt that either of these methods is preferable to that which employs a single psychrometric observation made in conjunction with the reading of the barometer as an indication of the coincident condition of the atmosphere; either of them is sufficiently accurate for the present, or until the more serious difficulties arising from gradient and temperature are more successfully met than they have been hitherto.

ERRORS OF OBSERVATION.

It has been assumed in the preceding pages that the instruments employed faithfully record the condition of the atmosphere in which they are immersed, that they are not exposed to abnormal local conditions, and that they are accurately read. As a matter of fact, however, meteorological instruments are neither perfect in their construction nor capable of giving trustworthy indications unless handled with skill and care, while it is a matter of the utmost difficulty to secure strictly normal local conditions. We will give brief consideration to the principal errors of observation, and to the precautions which are found to diminish them.

Take, first, the thermometer which is used to measure the temperature of the air. The mercury in the bulb exchanges heat with the surrounding air by conduction, and would acquire precisely the temperature of the air if cut off from the influence of all other sources of heat. There is, however, a constant interchange of heat between all bodies, including the thermometer, by radiation, and if the surfaces in the vicinity of the thermometer have a different temperature from it, they influence its temperature. Even the body of the observer communicates an appreciable thermic effect to the thermometer before him. It is important, therefore, that the thermometer be insulated from all bodies which have not the temperature of the air; but this must be accomplished without depriving the air itself of free access to the bulb. At fixed observatories insulation is usually attained by surrounding the thermometer stand by a wooden lattice, but when observations are made out of doors by itinerary topographic parties the most that is ordinarily done is to place the thermometer in the shade and in such position that it receives radiation from no greatly heated object nor brilliant reflector. The influence of the body of the observer is avoided by approaching the thermometer only when the moment has arrived for reading it, and then making the observation as quickly as possible, before the communication of heat has been great enough to acquire importance.

The psychrometer in ordinary use consists of a pair of thermometers, one of which is exposed to the air in the usual manner, while the other is exposed with a moistened bulb. The evaporation of moisture from the surface of the wetted bulb has a cooling effect, and causes that thermometer to indicate a lower temperature than the other. The difference between the readings of the two thermometers enables the humidity of the air to be computed. Observations with this instrument evidently suffer from all the defects of exposure which affect the measurement of the temperature, and they incur, moreover, some special difficulties, which need not be described because they are overshadowed by that arising from the inequality of the distribution of moisture in the air. Except in very moist weather the heterogeneity of the air near the ground is so great that the aqueous contents indicated by the psychrometer at any instant are, within wide limits, a matter of accident. The best that can be done by the observer is to avoid making his measurement on the lee side of a surface affording rapid evaporation.

The barometer, like the thermometer, is subject to errors caused by radiant heat, but in a somewhat different manner. The mercury of the barometric column, and the scale (usually of brass) by which its height is measured, expand in different degree for the same addition of heat, and it is necessary to know their temperatures in order to make proper allowance. The temperature of the instrument cannot be accurately measured unless it is uniform throughout, and unequal radiation from different sides interferes with this uniformity.

The barometer therefore is not merely hung in the shade so as to avoid the direct rays of the sun, but is insulated as far as practicable from all sources of radiant heat, and is not approached by the observer until the moment for observation has arrived.

The brass scale is usually so thin that it undergoes changes of temperature more rapidly than the mercury. If, therefore, the temperature of the surrounding air be gradually raised, the brass scale responds more promptly than the mercurial column and becomes relatively too long, while the reverse takes place if the temperature is lowered. It results that a rising temperature gives too low an estimate of barometric pressure, and a falling temperature too high. If the change is rapid, the record may be vitiated to the extent of ten or fifteen thousandths of an inch. The precaution generally recommended is to put the barometer in position and leave it with unchanged conditions for fifteen or twenty minutes before observation.

In portable barometers of the pattern in ordinary use in this country the tube containing the mercury is of so small caliber that the movements of the mercury are influenced by capillarity. The mercury is prevented from standing as high as it otherwise would, and its rise and fall are impeded. The errors thus occasioned have been corrected in various ways. They can be avoided altogether by giving to the tube a large bore, but the portability of the instrument is thus destroyed. Tables of corrections have been prepared, but their application is rendered difficult by the inequality of bore, not only of different tubes, but of different parts of the same tube. The greater part of the difficulty from sluggishness, but not the whole, is removed by jarring the tube immediately before the reading is taken, so as violently to overcome the *quasi* adhesion of the surface of the mercury to its sides. The only known practicable method of making due allowance for the individual peculiarities of each barometer is to compare it with a standard under all conditions of pressure, and record its errors, basing upon them afterwards a table of corrections.

A third occasion of false estimate of pressure, and the most insidious of all, is found in the influence of wind. If during a strong wind the room in which a barometer is placed have apertures on the windward side open, and all those on the opposite side closed, an abnormal quantity of air is forced into it, increasing its atmospheric tension and causing the barometer to rise. If, on the other hand, the windward apertures are closed and the leeward opened, a suction is produced whereby the quantity and tension of air in the room are abnormally diminished and the barometer is made to fall. Every aperture in every room contributes in some way to the influence of the wind upon the atmospheric pressure in the room, and this influence varies constantly, not only with the force of the wind, but with its direction. If the barometer be hung out of doors the wind does not lose its influence but merely changes the point of application. The cistern of the barometer is itself a room, communicating by an aperture or apertures with the external air, and is as truly subject to abnormal tension as a larger inclosure.

The errors which may thus arise in the case of strong winds are large, amounting in some instances to the 180th part of the atmospheric pressure,* and affecting the determinations of altitudes by more than one hundred feet. Recent investigations encourage the hope that the pneumatic principles upon which these abnormal tensions depend will soon be so well known that it will be possible either to avoid or to correct the errors they occasion, but for the present the only known method of escape is by choosing for observation periods of calm or of light wind.

GENERAL DEVICES FOR DIMINISHING HYPSOMETRIC ERRORS.

There are a number of the devices mentioned above under the several heads of gradient, temperature, and humidity, which in their appli-

* See Chapter IV for demonstration of the influence of the wind on the barometer observed on the summit of Mount Washington.

cation always have the effect of diminishing errors of more than one class; and there are, moreover, certain general methods of procedure, when many stations are to be treated together, which conduce at the same time to accuracy of result and economy of effort. These will now be taken up in order.

I. The chief of the general devices which have already been mentioned, is that of the empiric correction to the computed altitude. When the difference of altitude of two stations is computed repeatedly from a large number of observations, covering all parts of the year and all hours of the day, it is found that the results obtained at some seasons are on the average larger than those obtained at other seasons, and that those reached at certain hours of the day are on the average larger than those reached at certain other hours. From such series of results it is a simple matter to deduce corrections which, being added to the individual results, will make them accord better with each other and with the actual difference of altitude. Such tables of corrections have been prepared in India, in California, and in Europe. To be of value they must be based upon the means of long series of observations; and all of the best of them are so based. As a rule, they contain a correction for each month of the year and each hour of the day, and are therefore adapted to the elimination of all errors, from whatever source, which have either a yearly or a daily period. They include the errors dependent on annual gradient, on diurnal gradient, and on the annual and diurnal variations of temperature and moisture. The influence of non-periodic gradient escapes them, and so does the influence of all non-periodic variations of temperature and humidity; and with the latter is included a very important factor—the non-periodic variation of the amplitude of the diurnal oscillation of temperature. Nevertheless, the elimination of periodic errors is a matter of so great importance that the device would be eminently useful were it not for the local restriction to its application.

Such a table of corrections, when applied to the identical pair of stations at which were made the observations on which it is based, gives good results; applied to another pair of stations in the same neighborhood it affords results somewhat less accurate; and applied to stations at a distance it fails altogether to enhance the accuracy of the determinations. It is therefore not universal in its application, but strictly local, and, in order to give the device a general application, special tables of correction need to be deduced for every district in which it is desired to apply them.

It might at first seem natural that a system of errors dependent upon the periodicity of the supply of solar heat would be identical the world over and might be eliminated by a single system of corrections, but as a matter of fact they cannot be so eliminated, and the difficulties which stand in the way are not far to seek. While the sun is the prime cause of all atmospheric perturbations, and while the variations in the amount of solar heat which reaches any given spot are characterized by the most definite diurnal and annual periods, its influence is nevertheless greatly modified by conditions, and some of these conditions are purely local. The principal ones are as follows:

First. *Latitude.* If this were the only one it could be readily taken account of, and it would be a simple matter to compute empiric corrections for all latitudes.

Second. *Relation to ocean currents.* The circulation of the ocean causes the transfer of great bodies of warm water toward the poles, and of bodies of cold water toward the equator, and these moving bodies of water, having each a temperature differing from the mean temperature of the adjacent land, become themselves, so far as meteorologic problems are concerned, actual sources of heat and cold, and give to special localities which fall within their influence hypsometric conditions entirely independent of latitude.

Third. *Forms of land surface.* The reliefs of the earth, by modifying the direction of winds, by localizing precipitation, and in numerous other direct and indirect ways, have an influence upon the condition of the atmosphere, which is none the less actual because in the present state of meteorologic science it is difficult to formulate.

Fourth. *Textures of land surface.* The highly different powers of absorption and radiation possessed by surfaces of earth of various colors, by verdure, by naked rock, by snow, and by water, affect greatly the diurnal and even the annual variations of temperature, moisture, and gradient; and their influence is of a complex character that defies close analysis. The hypsometric periodicity of a locality is therefore controlled by the physical characteristics of its vicinity—by its environment, that is,—just as perfectly as is its weather, and we can hardly look forward to the time when meteorology will be so far enabled to analyze and weigh these various influences as to render it possible to adapt a system of empirical barometric corrections to all times and all places.

The hypsometric device which applies an empiric correction to the observed temperature of the air is practically identical with that which applies a correction to the computed altitude, for although the adjustment of the temperature is primarily for the purpose of correcting the periodic errors introduced by a false estimate of the thermic condition of the air, it is always deduced in such way as to correct at the same time all other errors having the same period. It is, therefore, subject to the same limitations in its application as the preceding device, and the same remarks apply to it.

The method which depends upon the selection of hours of observation relies also on the same principle, and has the same advantages and disadvantages.

The hypsometric method which substitutes series of observations for individual observations is ordinarily barred from use by its expense, but there are occasional circumstances which render it available. It is especially useful in determining the altitudes of meteorologic stations which are permanently occupied for other purposes. When the series of observations at each station is hourly and extends through an entire day, it serves to eliminate, either approximately or completely, all errors which exhibit a daily period. These are the diurnal gradient, the diurnal temperature error (which is the chief error arising from the temperature of the air), and the diurnal moisture error. The non-periodic and annual gradients are practically unaffected, and it is probable that there is usually a large residual inaccuracy in the determination of humidity.

If the series of observations be extended through so long a period as a month, errors dependent upon humidity are greatly reduced, and if they have no large local factor, such as that which arises from the proximity of a surface of rapid evaporation, they are practically canceled. The influence of non-periodic gradient is greatly diminished also, for usually in such a period of time it shifts its direction several times and approximately neutralizes itself in the mean result. If the series of observations embrace an entire year, the effect of annual gradient also disappears, and, theoretically, nothing remains but the perennial gradient. It is found, however, in practice that there is a small residual inequality.

The method which depends upon the establishment of numerous base stations in a vertical series is likewise highly efficacious, and might be widely employed but for its expense. It affords no relief to the troubles imposed by annual and non-periodic gradients, and it is a matter of doubt whether it greatly diminishes the influence of diurnal gradient, but it practically excludes all errors arising from our imperfect knowledge of the temperature and humidity of the air. Those errors are proportioned, *cæteris paribus*, to the difference of altitude between the new and base stations, and if the base station is in every case selected so that this difference of altitude is small, the errors are thereby rendered insignificant.

II. We now turn to the second class of general methods. Nearly everything that has been said in the preceding pages applies to the case in which it is desired to ascertain the height of a single station, but in by far the largest part of hypsometric work a great number of new stations, lying more or less in the same neighborhood, are visited in rapid succession, and are all referred to the same base station, where a continuous series of observations is maintained. This is the case wherever the barometer is employed to furnish the vertical data for a map of a mountainous region, and it is under such conditions that the barometer as a hypsometric instrument is chiefly employed.

When the scheme of stations consists of a base station where observations are made at short intervals for a long period, and numerous new stations at each of which the barometer is read either once only or at most a few times, temperature and moisture observations can be made of better quality at the base station than at the others. Such a base station is, or should be, provided with means for protecting its thermometers from all sources of radiant heat much better than is possible during the hurried observations of an itinerary party; and the uniformity of the local conditions by which it is surrounded tends to give a uniformity or harmony to the hypsometric results, which for most purposes is desirable even though constant errors are involved. It is usually more important that determinations of altitude within the field of a map be consistent with each other than that they be absolutely correct. For this reason some geographers have preferred to confine their observations of temperature and moisture to the base station and carry no instruments but barometers to the new stations. For purposes of computation, the temperatures of the new stations are deduced from those of the base by adding or subtracting a number of degrees corresponding to the difference of altitude, allowing a certain fraction of a degree for each unit of vertical distance; and a similar empiric rule is applied to the moistures. It is an advantage of this method that it admits of the substitution of the mean air temperature for the twenty-four hours in place of the temperature observed at the hour of barometric measurement, without prolonging the observations at the itinerary or new station into a daily series. It also admits of the derivation of a vapor correction from the mean of observations extending over a considerable period of time. There can be little question that it is superior both in economy and accuracy to the system which sends the thermometer and psychrometer along with the itinerary barometer and afterward employs their indications in the computation of altitudes.

Advantage is frequently gained, also, by the employment of intermediate stations, or temporary base stations. It often happens in the conduct of surveys that a field party retains its headquarters for several days in one place, during which time one or more barometric stations are made near by, and it is considered desirable in such case to carry on a series of barometric observations at the headquarters during the whole of the time. By means of these it becomes possible to determine the altitude of the headquarters station more accurately than could be done if a single observation only had been made, and if its situation is at some distance from the barometric base station it is better in the computation to refer the itinerary stations of the vicinity to it than to the principal base station. The principal error obviated by this means is that due to non-periodic gradient.

Another general method consists in the combination of barometric determinations with trigonometric. In any survey which is based upon triangulation the points occupied by the map-makers are necessarily intervisible, so that, if their distances are not great, it is possible to ascertain their relative altitudes by means of vertical angles, and this with a degree of accuracy to which the barometer has not yet attained. If, as is usually the case, the stations occupied by the topographer are also "new stations" of the barometric scheme, great accuracy can be attained by the combination of the two classes of data. The relative altitudes determined by means of vertical angles enable the computer to refer all the barometric determinations of altitude to a single point and there combine them. The mean result given by the combination has far higher claims to accuracy than any single determination, and affords a trustworthy initial point for the system of relative altitudes measured by the topographer. All classes of barometric errors are by this method diminished, and the altitude determination for each station of the entire system acquires an accuracy comparable with that which would be given by a continuous series of observations at a single new station extending through the whole period of field work.

RELATIVE IMPORTANCE OF DIFFERENT SOURCES OF ERROR.

In the preceding enumeration of the sources of error which affect the use of the barometer little has been said of their relative importance. It is indeed impossible to compare them in a strict way, because they are conditioned by different circumstances. The errors arising from non-periodic gradients are approximately proportional to the force of the wind and to the horizontal distance between the base and new stations. Those which arise from diurnal gradient are apt to be greater when the difference of altitude is great. Errors arising from temperature and moisture are proportional to the difference of altitude, but are influenced also by the time of day, the season of year, and the relation of the stations to the ocean. The errors, therefore, which affect the determination of the height of a mountain above its base are those of temperature, moisture, and diurnal gradient, while the difficulty encountered in determining the relative altitude of two stations upon a plain arises almost entirely from non-periodic gradient.

It will be instructive, however, to assume a case as representing the average of conditions under which barometric hypsometry is ordinarily conducted and show in what proportion the result is likely to be affected by the various factors. We will assume that one station is five thousand feet higher than the other, that they are fifty miles apart, and that they are situated in the temperate zone, remote from the ocean. We will assume further that the observations, a single pair, are made near the middle of a clear day in summer, and that a light wind is blowing at the time. The following table presents in its first column of figures the probable error in feet arising from each of the indicated sources, and in its second column the possible error,—all of the errors being estimated by the writer from the consideration of actual cases.

	Probable Error, in feet	Possible Error, in feet
From annual gradient	6	20
From diurnal gradient	8	30
From non-periodic gradient	20	50
From temperature	100	300
From moisture	10	20
From imperfection of observation	10	No limit
Totals	103*	420

The conspicuous feature of the table is that the temperature error is not only the greatest under ordinary circumstances, but that it exceeds the total of the others, so that it is with good reason that hypsometric students have given their chief attention to devices for avoiding or correcting it. That from non-periodic gradient stands next, and it may fairly be said that if these two are neglected it is a waste of time to provide against the others. It must be remembered, however, that these errors are estimated on the assumption that none of the special devices recited in the preceding pages are employed, save only the universal device of the base station. As a matter of fact very little work is now carried on without recourse to some of them, and it is probable that the average error of the determinations of altitude which have been made during the past decade is less by one-half than the table would imply.

THE PRACTICAL PROBLEM.

The difficulties which inhere in the use of the barometer for the measurement of heights are so numerous and so baffling that there is no reason to hope they will ever be fully overcome. The best that can be done is to mitigate them, and the real question to be answered is, What efficiency is it practicable to give to the barometer? The question is largely an economic one, for it is always possible to obtain by means of the engineer's level a degree of precision absolutely impossible to the barometer, and it can therefore never be profitable to employ a barometric method so elaborate that its cost will approach that of the use of the spirit level. Moreover, in that important branch of hypsometric work in which many points are to be determined within a limited district, the engineer's transit and allied instruments for the measurement of angles

* When a measurement is subject to errors from two or more sources, its *probable error* (using the term in its mathematical sense) is equal to the square root of the sum of the squares of the probable errors from the several sources

are able to do the work much cheaper than the engineer's level, and their degree of precision is in general higher than that of the barometer. In such cases the barometer must therefore be handled with still greater regard to economy if it is to retain its place in the field.

It has been practically demonstrated that in the work of mountain surveys protracted series of observations can economically be made at base stations, and it is almost equally certain that the protracted occupation of new stations, even for a single day, is economically inadmissible. The problem therefore which occupies the attention of those who have occasion to use the barometer in extended surveys is how to secure the best result from a single observation at a new station, combined with series of observations at one or more base stations.

The preceding pages have described all the principal methods of procedure that have been employed in the past; the following will set forth the new method which forms the theme of this paper.

CHAPTER II.

THE NEW SOLUTION.

In the following pages a new system of barometric hypsometry is presented.* It is not of universal application, but the range of work to which it is adapted is large, and it is believed that such tests as have been applied give it sufficient indorsement to entitle it to the attention of the geographer.

The new system proposes a new method of observation and a new method of computation.

The *method of observation* is as follows: Two base stations are established—one high, the other low. Their difference in altitude is made as great as practicable, and their horizontal distance is made as small as practicable. Each is furnished with a barometer, and a barometer only, and observations are made at frequent intervals through each day, as in the ordinary system. At each new station a barometer is observed, and no other instrument,—the psychrometer and all thermometers, except that attached to the barometer, being discarded. The difference in altitude of the two base stations is determined by spirit level and constitutes a vertical base line by which all altitudes are gauged.

The field-notes thus consist of three series of barometric readings, pertaining respectively to the upper base station, the lower base station, and the new stations.

The *method of computation* is as follows: The readings are first corrected for index error and temperature of instrument. They are then collected in groups of three, each observation at a new station being associated with the coincident observations at the two base stations. The altitude of the upper base station above the lower is now computed in the usual manner, except that no corrections for moisture, temperature, or gravity are applied—that is to say, it is computed on the assumption that the air is dry and has a uniform temperature of 32° F.; and the same computation is made of the altitude of the new station above the lower base. The results of these computations will

* The first publication of the system was made in a communication to the Philosophical Society of Washington, in 1877. (See page 131 of the Bulletin for that year.)

be called the approximate height of the base line and the approximate height of the new station.

The following proportion is then made—

{The approximate height of the base line (*B*)} : {The true height of the base line (B)} :: {The approximate height of the new station (*A*)} : {The true height of the new station (A)}

whence

$$\frac{B}{\mathrm{B}}=\frac{A}{\mathrm{A}} \quad \ldots\ldots\ldots\ldots \quad (1)$$

Here all the terms are known except the true altitude of the new station (A) and that is deduced by the solution of the equation. This is the essential nature of the computation. As will be presently explained, its form is changed as a matter of convenience, and a small correction is added.

The theoretic basis of this procedure will now be given. The weight (W) of the air column included between the upper and lower bases is determined by the barometers for the instant of observation. It is equal to the product of the mean density (d) of the column, multiplied by its height (B), multiplied by a constant factor (E)*.

$$\mathrm{W}=\mathrm{d\ B\ E} \quad \ldots\ldots\ldots\ldots \quad (2)$$

B is the approximate height of the same column, computed on the assumption that its mean density is that which would obtain if it were free from aqueous vapor and had a uniform temperature of 32° F. Calling this assumed standard density *d*, we have

$$\mathrm{W}=d\ B\ \mathrm{E} \quad \ldots\ldots\ldots\ldots \quad (3)$$

Dividing this last equation by the preceding, member by member, we obtain

$$1=\frac{d\ B}{\mathrm{d\ B}} \quad \ldots\ldots\ldots\ldots \quad (4)$$

whence

$$\frac{B}{\mathrm{B}}=\frac{\mathrm{d}}{d} \quad \ldots\ldots\ldots\ldots \quad (5)$$

The ratio of the approximate height of the base line to its true height is thus found to equal the ratio of the actual density to the assumed or standard density; and it is the measure, therefore, of the temporary condition of the column with respect to density.

Evidently an identical process of reasoning will show that the ratio of the approximate height of the new station to its true height is the

* The composition of this factor is omitted from the text because it is not essential to the discussion. It includes the area of the cross-section of the air column and the weight of a unit volume of dry air at a standard temperature of 0° Cent., and under the standard pressure of 760^{mm}

measure of the temporary condition, with respect to density, of the air column included between the new station and the lower base station.

Equation (1) postulates that the temporary condition of one air column is identical with the simultaneous condition of the other—with respect to an assumed standard of density. It does not postulate equality of densities, for the assumed standard is not a uniform density, but is that system of densities which would obtain under the logarithmic law in both columns if the air were dry and of a uniform, standard temperature. It merely postulates that the temporary accidents of temperature and moisture affect both columns alike.

What is practically done is to deduce from the comparison of the computed height of the base line with its true height a ratio or coefficient expressive of the temporary local variation of density, and then to apply this coefficient in the simultaneous determination of the height of a partially coincident air column. The first member of Equation (1) deduces the coefficient; the second applies it.

One of the distinctive characteristics of this hypsometric method is that it observes density directly, whereas other methods observe temperature and moisture only and deduce density. The only reason which has ever existed for measuring air temperatures in hypsometric work has been to ascertain the density of the air, and the only reason for measuring the moisture of the air has been to ascertain its density. A second distinctive feature is that the new method employs in its determination of density a column of air comparable in height with the one to be measured and fairly representative of it, while other methods base their diagnosis of the column to be measured on density determinations made close to the ground, where, as a rule, the conditions are not representative. A third is that the process which determines the density is the simple inverse of the process which applies it in the computation of the desired height.

THE FORMULA.

We shall now proceed to develop the full formula for the computation of altitude, considering, first, what may conveniently be called the *logarithmic term*, and, second, what may be called the *thermic term*. The logarithmic term will embody the relation postulated by Equation (1); the thermic term will express a necessary qualification of that postulate.

Let L, U, and N represent the altitudes of the lower base station, the upper base station, and the new station, respectively, and assume $L < N < U$. Let l, u, and n represent the synchronous barometric readings at the same stations, corrected for temperature of instrument and index error.

Let B=the vertical base line, or the difference of altitude of the two base stations. $B = U - L$.

Let A = the required difference of altitude, N − L, and a its uncorrected value as deduced by Equation (1)*. Since B = U − L and A = N − L, B − A = U − N.

All vertical distances are referred to the lower base station as an origin.

The approximate height of the base line, deduced by the logarithmic law (p. 406) from the barometric readings at the two base stations, is—

$$C (\log l - \log u),$$

in which C is a constant. The approximate height of the new station above the lower base station is—

$$C (\log l - \log n).$$

With the substitution of this notation the proportion on page 438 becomes

$$C (\log l - \log u) : B :: C (\log l - \log n) : a,$$

whence

$$a = B \frac{\log l - \log n}{\log l - \log u}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

an expression free from the constant C.

This is the logarithmic term of the formula. It would need no companion if the atmospheric column were uniform in temperature and if its aqueous vapor were uniformly distributed; but since this is never the case there must be added to it a term representative of the influence of the distribution of temperature and vapor on the distribution of densities.

In a general way it is known that the upper layers of the air are cooler than the lower, but the law of variation eludes discovery, being concealed by its multitudinous exceptions. In a general way, too, it is known that the upper layers of air contain a smaller per cent of moisture than the lower, but in this case also the law of variation is obscured by its exceptions. In order, however, to give these elements a place in the formula it is necessary to embody their law of variation, known or postulated, and we shall therefore assume that the collective influence of the two factors upon the distribution of densities in an air column follows a simple arithmetic law, modifying the density of each part of the column by an amount strictly proportioned to its height above the base. Whenever a better assumption becomes possible the term here deduced will need to be replaced by another.

The distribution of densities in the air is determined by three factors: pressure, temperature, and aqueous vapor. They are in reality intimately conjoined, but the considerations about to be adduced will be

* The mathematical reader will observe a change of notation here; a is now used to designate a quantity denoted by A in Equation (1), while A is used for the same quantity plus a correction. In another sense, however, the notation is consistent, for A is continuously used to indicate the quantity sought, the necessity for a correction being ignored until the foundation of the formula had been laid.

rendered clearer by treating them for a moment as independent. If the air were of uniform density at all heights, and the element of weight were introduced alone, the lower strata would be compressed by the weight of those above, and the resulting system of densities would exhibit a diminution from below upward. If the air were of uniform density, and the element of temperature were introduced alone, the high temperatures at low altitudes would cause a dilatation there, the low temperatures at high altitudes would cause a contraction, and the resulting distribution of densities would be characterized by an increase from below upward. If the air were of uniform density, and the element of vapor distribution were introduced alone, the greater per cent of aqueous vapor (which is a rarer gas than dry air) in the lower strata would cause them to be relatively rare, and the resulting distribution of densities would be characterized by an increase from below upward. The pressure factor would make the lower layers of the atmosphere the denser; the temperature and vapor factors would make them the rarer. The pressure factor is by far the most important, and in the actual distribution of densities there is a diminution from below upward; but this upward decrease is a resultant of the upward decrease due to pressure, combined with the upward increase due to temperature and aqueous vapor.

It will be convenient to speak of the factors dependent on temperature and vapor collectively as *thermic*, calling the upward increase of density due to them the *thermic increase* and the density they would by themselves establish the *thermic density;* and it will be convenient to speak of the factor dependent on pressure as *logarithmic*, since its influence is expressed by the logarithmic law. The logarithmic term of our formula gives an approximate altitude for the new station, dependent on the logarithmic factor of density; the thermic term will have the relation of a correction to this.

The mean thermic density of the air column comprised between the new station and the lower base station is by postulate equal to the thermic density of the stratum midway between the two, the altitude of which is $\frac{N+L}{2}$. The mean thermic density of the column comprised between the base stations is in like manner equal to that of the stratum at the height expressed by $\frac{U+L}{2}$. The vertical space between these two midway strata is—

$$\frac{U+L}{2}-\frac{N+L}{2} = \frac{U-N}{2} = \frac{B-A}{2}$$

The difference between the two mean densities will be found by multiplying the number of units contained in this vertical space by the thermic increase of density for each unit of vertical space. The rate of thermic increase being assumed to be uniform from the ground upward, we may suppose that at some height its total amount becomes equal to the density at the ground, or that when expressed in terms of the initial density it becomes unity. Call that height $\frac{D}{2}$. The thermic increase of density for each unit of vertical space is then expressed by $1 \div \frac{D}{2}$, or $\frac{2}{D}$; and the expression for the difference between the mean thermic densities becomes—

$$\frac{B-A}{2} \times \frac{2}{D} = \frac{B-A}{D}$$

This expression has a linear space for its numerator and another for its denominator, and is itself a ratio. It denotes the fraction by which the thermic increase of density affects the relative densities of the two columns, B and A. Since the heights of the columns are inversely as their densities, the same ratio expresses the fraction by which the deduced altitude, A, is affected by the thermic variation of density. The correction for thermic density is therefore found by multiplying this ratio by A, and is—

$$\frac{A\,(B-A)}{D}$$

Since by postulate $N < U$, the midway stratum of the column A is lower than that of the column B, its temperature is higher, and its thermic density is less. Hence, the neglect of the thermic factor of density in the computation assumes too great a density for A. And since the height varies inversely with the density, the assumption which makes the density too great makes the height too small. The neglect of thermic density therefore gives too small a computed altitude, and the thermic correction should be given a positive sign. The full formula accordingly reads:

$$A = B\,\frac{\log l - \log n}{\log l - \log u} + \frac{A\,(B-A)}{D} \quad . \quad . \quad . \quad (7)$$

The assumption that $L < N < U$, or that the new station is intermediate in height between the upper and lower base stations, was adopted for a temporary convenience, but is in reality not essential to the demonstration, and can now be laid aside. When the new station is higher than the upper base, $B-A$ becomes negative and renders the thermic term negative. When the new station falls below the lower base, A becomes negative and renders the thermic term negative. In the latter case, however, $\log n$ becomes at the same time greater than $\log l$, and the logarithmic term is rendered negative; so that, both terms being negative, their numerical combination is by addition.

It was also assumed for simplicity's sake that the altitude of the new station was to be referred to the lower base station. Let us now make the opposite assumption, referring it to the upper base station, and making that station the origin of vertical distances. Calling B′

the base line as referred to the new origin, and A′ the height of the new station referred to the same, we have—

$$B' = -B, \quad \text{and} \quad A' = A - B, \qquad (8), (9)$$

whence $$A = A' - B', \quad \text{and} \quad B - A = -A' \qquad (10), (11)$$

Substituting these values in Equation (7) we obtain—

$$A' - B' = -B' \frac{\log l - \log n}{\log l - \log u} + \frac{(A' - B') \times (-A')}{D},$$

whence $$A' = B' \frac{\log u - \log n}{\log u - \log l} + \frac{A' \; (B' - A')}{D} \qquad (12)$$

This equation is identical in form with Equation (7), but u and l have exchanged places. This is as it should be, because the relations of the upper and lower base stations, severally, to the new station have been reversed. Equations (7) and (12) are indeed special cases of a more general formula. If we designate the barometer reading at that base station used as the origin of distances by o, and the reading at the other base station by s, and call the base line and computed height, as referred to the same station, B_0 and A_0, we may deduce from either equation the following—

$$A_0 = B_0 \frac{\log o - \log n}{\log o - \log s} + \frac{A_0 (B_0 - A_0)}{D} \qquad (13)$$

It is a matter of indifference, so far as the result in absolute altitude is concerned, whether new stations are referred to one base station or the other. As a matter of convenience, however, it is preferable to use the lower; and the remainder of the discussion will be based on Equation (7).

The application of the logarithmic term to the computation of altitudes is simple, and no table is required except a table of logarithms, but the thermic term is not conveniently constituted for direct computation and should be put into the form of a table, with a and B as arguments; a being the briefer designation of the uncorrected altitude, $B \frac{\log l - \log n}{\log l - \log u}$. Such a table is appended to this paper, giving the thermic correction for each 100 feet of a and of B. It will suffice for all general use, but the computer who has a large number of stations referred to a single base line may find it advantageous to construct a special table for the individual value of B, and thus avoid interpolation.

To apply the formula (7) directly without the intervention of a table is inconvenient because the thermic term involves the unknown altitude, A. The following form, which is not strictly identical but approximates closely, is free from this objection—

$$A = B \frac{\log l - \log n}{\log l - \log u} + \frac{a \; (B - a)}{D + a - (B - a)} \qquad (14)$$

It remains to consider the constant D, to which no value has yet been assigned. By definition $\frac{2}{D}$ is the increment of thermic density for an ascent of a unit of space, and $\frac{D}{2}$ is the vertical distance at which the total increment of thermic density amounts to unity. D is therefore a linear space to be counted in feet, or meters, or whatever other unit is used for B and A in the formula. It is also a function of the vertical distribution of heat and moisture in the atmosphere, and since that distribution is a function of the vertical circulation of the air as modified by a great complex of conditions both local and seasonal, it is impracticable to derive D deductively. It can only be ascertained experimentally. Indeed it is only in a mathematical sense that it is a constant; for it is far from being a fixed natural factor, such for example as the coefficient of expansion of dry air. It is rather the average value of a perpetually fluctuating quantity, which we are content to consider in its totality, only because its component elements vary with time and space in a manner too complex for analysis.

Our best means of ascertaining it is to apply our formula to the computation of altitudes already known, and see how large D must be to give the best average result. For this purpose we give Equation (7) the following form,

$$D = \frac{A\,(B - A)}{A - B\,\frac{\log l - \log n}{\log l - \log u}} \quad . \; . \; . \; . \; . \; . \; . \quad (15)$$

and apply it to the barometric observations of stations (in groups of three) whose relative altitudes have been determined by spirit level.

It is important that the stations differ greatly in altitude, each from each, that they be not widely separated horizontally, and that the series of observations include all portions of the year and all parts of the day. At the present time data for a satisfactory determination do not exist, but there are available two series of observations which satisfy some of the conditions.

1. The Geological Survey of California, in charge of Prof. J. D. Whitney, conducted observations for a period of nearly three years at Sacramento, Colfax, and Summit, the barometers being read at 7 a. m., 2 p. m., and 9 p. m. The differences in altitude and the distances of the stations are as follows:

	Distance	Difference in Altitude
	Miles	*Feet*
Sacramento to Colfax	45	2,399
Colfax to Summit	36	4,590
Sacramento to Summit	77	6,989

Unfortunately the distances are so large that all results derived from the observations are affected by atmospheric gradients; but a certain use can still be made of the annual means.

2. Rühlmann, in his Barometric Hypsometry, gives a table of means of observations made at three stations on the Miesing, citing Bauernfeind as his authority. The series is for a week in August, 1857, and includes the mean for each hour of the day from 8 a. m. to 6 p. m. The altitudes of the stations are.

Station	In Meters	In Feet
Upper	1,883 5	6,179 6
Middle	1,355 6	4,447 6
Lower	815 4	2,675 2

The distances are not given by Rühlmann, and unfortunately the original record from which he quotes is not at this time accessible to me.

The Californian observations embrace the years 1871 and 1872 and portions of the years 1870 and 1873; but for the present purpose, only the series for the two entire years have been employed.

The observations for each year were first divided into two equal parts, the first including the warmer months (May to October) and the second the colder months; and from the means of the barometric observations during each of these periods of six months the constant D was computed by Equation (15). The observations were next grouped according to the hour of day, those at 7 a. m., 2 p. m., and 9 p. m. for each year being considered separately, and the constant was again computed. Finally a separate computation was made from the mean of all the observations.

In the following table the first column of figures gives the several values of D, in feet, and the second the corresponding values of $\frac{2}{D}$, an expression now representing the increment of thermic density for each foot of ascent, and which it will be convenient to call the *coefficient of thermic density.*

The last column contains a comparative expression for the increment of thermic density, derived from the temperatures observed at the highest and lowest stations during the same periods. To obtain it the difference between the temperature means of the two stations was multiplied by Regnault's coefficient of the expansion of gases for each degree of temperature, and the product, which represents the total difference of density at the two stations as dependent on temperature, was divided by the number of feet in the difference of altitude.

TABLE I

Values of the Thermic Constant, deduced from Californian Observations.

Groups of Observations	D	$\frac{2}{D}$	Density Increment derived from Observed Temperatures.
Warm half-year, 1871	1,356,085	00000 148	00000 379
Warm half-year, 1872	434,204	00000 461	00000 462
Mean	.... ..	00000 304	00000 420
Cold half-year, 1871	392,144	00000 510	00000 597
Cold half-year, 1872	411,949	00000 486	00000 576
Mean	....	00000 498	00000 586
7 a m, 1871	921,457	00000 217	00000 332
7 a. m, 1872	768,417	00000 260	00000 451
Mean	....	00000 238	00000 391
2 p m, 1871	577,118	00000 347	00000 527
2 p m, 1872	365,221	00000 548	00000 580
Mean	....	00000 447	.00000 553
9 p m, 1871	476,066	00000 420	00000 603
9 p m, 1872	328,503	00000 609	00000 527
Mean	....	00000 514	00000 565
Whole year, 1871	608,361	00000 329	00000 488
Whole year, 1872	422,781	00000 473	00000 519
Period of two years	497,354	00000 401	00000 504

The most striking feature of the table is the variability of the increment. For the year 1872 it was nearly 50 per cent greater than for 1871, and for the warmer half of that year it was three times as great as for the corresponding months of 1871. The cold and warm halves of 1871 gave results strongly contrasted, while for 1872 their results are nearly identical.

A second feature of interest is that the increment of density is greater at 2 p. m. than at 7 a. m., and is greater at 9 p. m. than at 2. This might perhaps have been expected, because the increment is chiefly due to the fact that the heat of the atmosphere is received by its lower layers and passes upward by convection. The resulting gradation of temperature from below upward may be supposed to be heightened during the day while the lower layers are being rapidly heated, and diminished during the night while the lower layers are losing heat.

Analogous considerations would lead us to expect the summer increment of thermic density to be found greater than the winter; but the reverse is true. The mean of two years' observations gives an increment in the warm months only three-fifths as great as in the cold. It is possible that this relation is anomalous, being dependent on the exceptional climate of the great Californian Valley, in which the lower station is situated, but comparative data are wanting.

It is interesting also to note the general correspondence of the two columns of increments. The right hand column contains values of the upward increment of density due to temperature alone, the values being derived from observed temperatures. The left hand column contains values of the upward increment of density due to temperature and moisture combined, the values being derived from observed pressures. The range of values is smaller in the thermometric series than in the barometric, but nearly all the irregularities of the latter are copied in the former. They agree in giving a larger increment in winter than in summer, at evening than at morning, in 1872 than in 1871.

But while the two series of results show by their parallelism that they have a common basis, they are quantitatively unequal. For each section of the data which was computed separately (with a single exception), the thermometric means give a higher value for the increment than do the barometric, and in the general mean this difference amounts to 12 per cent.

Table II contains the value of the constant and of the density increment computed from the Miesing observations. They are hardly comparable with the Californian results, because they are based on the observations of a single week only, and, in the absence of more precise information in regard to the topographic relations of the stations, it would be hazardous to draw conclusions from them. It is to be noted, however, that they give a decidedly greater value to the increment than do the Californian observations, and they indicate at the same time a greater range of variation dependent on the hour of day.

TABLE II.

Values of the Thermic Constant, computed from Observations on the Miesing in August, 1857.

Hour	D	$\frac{2}{D}$
8 a m	592, 164	00000 337
9 a m	474, 934	00000 421
10 a m	204, 284	00000 979
11 a m	297, 022	00000 673
12 noon	220, 146	.00000 909
1 p m	187, 499	00001 067
2 p m	179, 237	00001 116
3 p m	219, 629	00000 911
4 p m	257, 746	00000 776
5 p. m	410, 359	00000 487
6 p m	531, 602	00000 376
Mean of eleven hours	274, 375	00000 729

In selecting a value of the constant for incorporation in the formula, the result derived from the Californian series of two years was given a large weight as compared with the result from the Miesing series of one week, and 490,000 feet (almost identical with the Californian value, 497,354 feet) was adopted. With its substitution the formula (7) reads:

$$\text{A (in English feet)} = \text{B}\frac{\log l - \log n}{\log l - \log u} + \frac{\text{A (B} - \text{A)}}{490000} \quad . \quad . \quad . \quad (16)$$

or

$$\text{A (in meters)} = \text{B}\frac{\log l - \log n}{\log l - \log u} + \frac{\text{A (B} - \text{A)}}{149349} \quad . \quad . \quad . \quad . \quad (17)$$

The value cannot be regarded as final, but is merely the best at present attainable. The series of observations on which it is based is far from being the series theoretically most desirable, and its guaranty of accuracy is not unimpeachable. The great horizontal distance by which the stations are separated, and the relative proximity of the lower station to the ocean, expose the result to the influence of gradients both non-periodic and perennial. The limitation of the observations to three hours of the day is another imperfection, for although the means of temperature readings at the three hours approximate closely to daily means, the means of pressure observations do not. Then, too, the leveling by which the altitudes of the stations were measured was conducted merely for the purposes of the railroad engineer and has presumably only the accuracy needed for such work, while the barometric observers at the upper stations were the station-agents of a railroad—men previously unaccustomed to such duties. Professor Whitney notes moreover that there were several breaks in the continuity of the observations, each comprising a number of days, which he filled by interpolation.

The formula here deduced (16 or 17) takes account of the logarithmic law of density, and of the variations of density dependent on the temperature and humidity of the air. In the formulas of Laplace and Bessel there are additional terms which afford corrections to the computed altitude by taking account of certain variations in the force of gravity.

The force of gravity varies with the latitude, and with the altitude of the station, and this variation affects the hypsometric problem in a variety of ways. First, it causes equal masses of air at different places to have unequal weights. Second, it causes equal masses of air at different heights in the same vertical column to have unequal weights; so that their pressures on the air beneath them produce a system of densities not strictly conformable to the logarithmic law. Third, it causes equal masses of mercury to have unequal weights at different places, so that the indications of mercurial barometers are subject to local corrections.

These variations are by no means inconsiderable. In Guyot's computation of the height of Mount Washington above its base, an allowance for them modifies the result by 16 feet; and in the computation of the height of Pike's Peak above its base, their influence amounts to twice as much. Careful consideration was therefore given to them in the construction of the new formula, and it was not without reason that a corrective term was omitted. The warrant for ignoring them lies in the fact that they affect the air column to be measured and the standard air column (base line) to which it is referred, in nearly equal degrees, so that their influence is approximately eliminated by the use of the standard column in the computation. In the logarithmic term of the formula the numerator of the fraction is an approximate measure of the height of the new station above the lower base—involving the local effect of the variation in the force of gravity. The denominator is an approximate measure of the height of the base line—likewise involving the local effect of the variation. The division of one measure by the other eliminates so much of the influence of the variation as is proportional to the heights, and in so doing eliminates nearly the whole of it.

The share that is not eliminated has been computed for a few special cases and found to be so small that it may be disregarded without appreciable error. For all ordinary determinations of altitude it amounts to less than one-fourth of a foot, and it will in no practical computation attain the magnitude of two feet. It is always less than the 100th part of the thermic correction, it never equals the 2,000th part of the computed altitude, and it falls far below the ordinary error of instrumentation.

EXAMPLE OF COMPUTATION.

In August, 1872, the mean pressure at Sacramento was 29.879 inches; at Colfax, 27.475 inches; and at Summit, 23.336 inches.

The altitude of Summit above Sacramento is 6,989 feet. Required the altitude of Colfax above Sacramento.

$\log l = \log 29.879 =$	1.47537
$\log n = \log 27.475 =$	1.43894
$\log u = \log 23.336 =$	1.36803
$\log l - \log n =$	0.03643
$\log l - \log u =$	0.10734
$\log 0.03643 =$	− 2.56146
$\log 0.10734 =$	− 1.03076
Difference =	− 1.53070
$\log B = \log 6989 =$	3.84441
Sum ($\log a$) =	3.37511
$a =$	2,372.0 feet.

Going to the table with the arguments.

$B = 7{,}000$ and $a = 2{,}300$, we obtain	+ 22.2
Interpolation for 7,000 − 6,989 =	− 0.1
Interpolation for 2,372 − 2,300 =	+ 0.3
Total correction,	+ 22.4
Required difference of altitude,	2,394.4 feet.

In practice nothing is written except the column of figures at the right.

When the data are given in inches and thousandths no higher accuracy is attained by using logarithms of more than five places. The value of a has an uncertainty in its tenths, and sometimes in its units, and this uncertainty affects the final result. It is a function of the limit to precision of instrumentation and cannot be avoided by any refinement of computation. So long as our instruments record no pressure changes smaller than the thousandth part of the barometric inch, we only delude ourselves if we consider less than an entire foot in the result. The tenths of a foot are given in the table only as an aid to the accurate determination of the units. After the completion of the computation the tenths are dropped.*

It may be well to direct attention to the fact that the formula (7, 13, or 14) does not require all its quantities to be expressed in terms of the same unit. There must be a common unit for the barometer readings, l, u, and n, and a common unit for B and D; but the algebraic relations permit these two units to differ from each other. The computed altitude, A, will be in terms of the unit employed to express B and D.

*In some of the serial results tabulated in the following pages, the tenths of feet are retained for the sake of their influence on the final mean

CHAPTER III.

COMPARATIVE TESTS.

The fact developed in the last section—that the constant of the formula is not a constant of nature, but varies from season to season, and even from hour to hour, as well as from place to place—and the uncertainty which attaches to the quantity adopted as the expression of its average value, may appear to condemn the new method of hypsometry in advance. In reality, however, they do not constitute a serious objection; for, in the first place, the uncertainty attaching to the constant affects only a correction which in practice is usually small; and, in the second place, the natural phenomena of which the uncertainty of the constant is an expression, are so intimately associated with the natural phenomenon which renders possible the barometric measurement of heights, that no known barometric method escapes their influence. It is on their account and on account of the impossibility of completely eliminating the errors of gradient from the problem that the determination of heights by means of the barometer must always be a matter of approximation only and never of precision. The question to be asked about the new method is not whether its application will afford an accurate result, but whether it furnishes a closer approximation than other methods without undue enhancement of expense. As compared with what may be called the ordinary method, the system here proposed involves the outlay necessary to establish and maintain two base stations instead of one, and unless it can show an advantage in accuracy of result it can have no claim to adoption. An attempt has therefore been made to compare it with the best methods in use by making parallel series of computations from the same records of observations.

The comparison has been necessarily restricted to localities where continuous observations were made at two stations differing considerably in altitude, which could be regarded as bases; and it has been still further controlled by the desire of the writer to contrast computations made by the new method, not merely with other computations made by himself, but so far as practicable with those made by the advocates of other systems. Three series of observations and computations have been found to answer the conditions; the first by Williamson, the second by Whitney, the third by Plantamour; and these will be discussed in the order named.

COMPARISON WITH WILLIAMSON'S METHOD.

In 1868 Colonel R. S. Williamson published, under the auspices of the Corps of Engineers, United States Army, a treatise* on the use of the barometer for hypsometric purposes, which has served as a guide for nearly all the hypsometric work that has since been conducted in the United States and still holds place in the front rank of barometric manuals. The method of procedure there set forth is especially adapted to reconnaissances and surveys, and, briefly stated, is as follows:

A single base station is used, at which the barometer, thermometer, and psychrometer are observed at stated hours each day. Itinerary observers visiting the new stations employ the same instruments, and take pains to have each of their observations correspond in time with one of the observations at the base station. Series of hourly observations are made for a number of days in each month at the base station and as frequently as practicable at semi-permanent camps of the field parties, the object being to ascertain the nature of the diurnal curves of pressure and temperature both at the base station and in various portions of the field of survey. In the reduction of the results the first step after the application of instrumental corrections is to apply what is called a "horary correction" to each of the barometric readings. This correction is derived from the diurnal curves of pressure, and theoretically eliminates diurnal gradient. The corrected barometer readings for the base station are then plotted upon ruled paper so as to exhibit their curve, and all readings shown by inspection to be influenced by abrupt and violent atmospheric disturbances, such as thunder storms, are discarded, their places being filled by interpolation. The computation of altitude is then made by Plantamour's formula, which takes account of both the temperature and the moisture of the air at the base and new stations. Instead, however, of employing the temperature recorded by the thermometers at the hour of barometric measurement, the mean temperature for the day is used, being deduced from observations at 7 a. m. and 2 and 9 p. m.; and instead of employing the psychrometer readings for the hour of barometric observation, the mean of the psychrometric determinations for a week or month is substituted.

In the year 1878 Colonel Williamson published the results of a series of comparative computations, in which his hypsometric method was contrasted with that of Professor Whitney,† and as a portion of these results were derived from stations to which the new method is applicable they were selected as the basis for a new comparison. In

* No 15, Professional Papers of the Corps of Engineers, U. S. A. On the Use of the Barometer on Surveys and Reconnaissances. By Major R. S. Williamson New York, 1868.

† On the Use of the Barometer—being a Compendium without plates of No 15, Professional Papers of the Corps of Engineers. By Lieut. Col. R. S. Williamson. Washington, 1878.

Williamson's publication the original data are not given, but only the results of the computations as exhibited in a table of mean and extreme errors; but he has courteously furnished the writer a copy of the barometric readings and thus enabled him to apply his method of computation to them.

The observations in question were made at the hours of 7 a. m., 2 p. m., and 9 p. m., during ten days of the month of August, 1860, at three stations on the western slope of the Sierra Nevada. The positions of the stations, as given by Williamson on page 28 of his Manual, are as follows:

Station.	Latitude.	Longitude.	Altitude
	° ′	° ′	*Feet.*
Placerville	38 44	120 46	1,965
Strawberry Valley	38 49	120 07	5,707
Hope Valley	38 47	119 54	7,072

From these data were deduced the following:

Stations.	Distance.	Difference of Altitude
	Miles.	*Feet.*
Placerville to Strawberry Valley	35	3,742
Placerville to Hope Valley	46	5,107
Strawberry Valley to Hope Valley	12	1,365

These differences in altitude appear not to have been determined by the aid of the spirit level, but only by computations from the means of a large number of barometric observations. The errors found by Williamson in his computations from single pairs of observations are not to be regarded as absolute errors but rather as wanderings from the mean of many determinations, and therefore, in recomputing the altitudes and making a table of the errors incurred by the new system, I have compared each individual determination with the mean of its own series, instead of taking Williamson's mean determination as a standard. It would, of course, afford a better test of the comparative value of the two methods if the result of each individual computation were compared with an accurately-ascertained, authoritative value of the difference in altitude; but, in the absence of such a standard, the only practicable criterion of comparison is the internal harmony of the several series of results. A method which, on successive trials, gives nearly the same result is manifestly preferable to one which gives widely different results.

In the preparation of the observations for the application of the new formula no correction was made for the diurnal oscillation of the barometer, and, with a single exception, the readings were used with no modification other than the usual corrections for the temperatures and index errors of the instruments. The exceptional case is that of the observation made at Strawberry Valley on the 17th of August, at 2 p. m., while a thunder storm was in progress. For this an interpolated reading was substituted.

Having three equally continuous series of observations, it was evidently possible to regard each of the three stations in turn as the new station and the other two as base stations, and this was accordingly done. The air column comprised between Placerville and Hope Valley, assumed to have a height of 5,107 feet, was first taken as a base line, and from it the altitude of the intermediate station, Strawberry Valley, was computed. Under the new method it is a matter of indifference whether the space between the new station and the upper base, or that between the new station and the lower base, is the quantity sought. But it is not so with Williamson's method, and a comparison is therefore made both with his determination of the difference in altitude between Placerville and Strawberry Valley and with his determination of the difference between Strawberry Valley and Hope Valley.

Table III exhibits the data for the computation, and the results. The first column shows the hours of observation; the next three give the synchronous readings of the barometer at the three stations; the fifth column contains the several determinations of the difference in altitude of the stations in Hope Valley and Strawberry Valley, and the seventh the corresponding determinations of the difference in altitude of the stations in Strawberry Valley and Placerville. The numbers in the sixth column were obtained by subtracting the mean of the numbers in the fifth from each of them, and exhibit the deviations of the individual results from the mean. It will be convenient to distinguish such deviations by the title "residual", reserving the word "error" to designate deviations from an absolute standard. The numbers of the eighth column are derived from those of the seventh in a similar manner. In the line beneath the columns their arithmetic means, taken regardless of sign, are given, and the numbers opposite the word "range" are derived in each case by adding the largest residual with the plus sign to the largest residual with the minus sign.

Strawberry Valley and Placerville were next taken as base stations, and from them the altitude of Hope Valley was computed. The assumed height of the base line was 3,742 feet, that being the altitude of Strawberry Valley above Placerville as given by Williamson; but it must be borne in mind that this quantity was itself determined by the use of the barometer, and is therefore presumably only approximate. Whatever error it involves must inhere in all results derived from it, affecting them all alike.

Hope Valley and Strawberry Valley were then taken as base stations, with an assumed difference of altitude of 1,365 feet, and from them the relative altitude of Placerville was computed. In the preceding case the base line was nearly three times as long as the height determined by means of it; in this case the relations are reversed, the base line having scarcely more than one-third the magnitude of the distance computed.

TABLE III

Differences of Altitude computed by New Method from Single Sets of Observations; New Station *intermediate* between Bases.

Day and Hour of Observation, 1860	Barometer Readings *			Hope Valley and Strawberry Valley		Strawberry Valley and Placerville	
	Placerville	Strawberry Valley	Hope Valley	Alt	Resid	Alt	Resid
	Inches	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Feet.*
Aug 11—7 a m	28 009	24 597	23 417	1,391 7	+ 12 8	3,715 3	— 12 8
2 p m	017	562	.381	1,380 8	+ 1 9	3,726 2	— 1.9
9 p m	27.985	544	375	1,374 0	— 4 9	3,733 0	+ 4 9
Aug 12—7 a m	944	471	277	1,387 6	+ 8 7	3,719 4	— 8 7
2 p.m	958	446	261	1,369 1	— 9 8	3,737 9	+ 9 8
9 p.m	.894	440	242	1,396.3	+ 17 4	3,710 7	— 17 4
Aug 13—7 a m	.903	446	.255	1,389 2	+ 10 3	3,717 8	— 10 3
2 p m	861	.401	230	1,371.2	— 7.7	3,735 8	+ 7 7
9 p m	.812	406	222	1,397 5	+ 18 6	3,709 5	— 18 6
Aug 14—7 a.m	826	387	214	1,378 7	— 0 2	3,728,3	+ 0 2
2 p m	823	.387	202	1,390 1	+ 11 2	3,716 9	— 11.2
9 p.m	.819	420	240	1,395 8	+ 16 9	3,711 2	— 16 9
Aug. 15—7 a.m	830	438	290	1,369 3	— 9 6	3,737 7	+ 9 6
2 p m	852	430	291	1,353 0	— 25 9	3,754 0	+ 25 9
9 p m	875	483	320	1,382 5	+ 3 6	3,724 5	— 3 6
Aug 16—7 a m	888	493	356	1,358 5	— 20 4	3,748 5	+ 20 4
2 p m	877	473	324	1,366 8	— 12 1	3,740 2	+ 12 1
9 p m	.861	494	333	1,387 7	+ 8 8	3,719 3	— 8 8
Aug 17—7 a m	865	485	354	1,357 3	— 21 6	3,749.7	+ 21 6
2 p m	820	[465]	319	1,377 9	— 1 0	3,729 1	+ 1 0
9 p m	.831	460	313	1,374 3	— 4 6	3,732 7	+ 4 6
Aug 18—7 a m	882	474	.315	1,374 6	— 4 3	3,732.4	+ 4 3
2 p m	855	.488	341	1,375.3	— 3 6	3,731 7	+ 3 6
9 p m	869	469	316	1,371 4	— 7 5	3,735 6	+ 7.5
Aug 19—7 a.m	914	497	334	1,375 3	— 3 6	3,731.7	+ 3 6
2 p m	925	477	323	1,359 2	— 19 7	3,747 8	+ 19 7
9 p m	941	532	356	1,389 1	+ 10 2	3,717 9	— 10 2
Aug 20—7 a.m	28.016	579	395	1,388 2	+ 9 3	3,718 8	— 9 3
2 p m	021	570	389	1,381 8	+ 2 9	3,725 2	— 2 9
9 p m	023	612	420	1,402 4	+ 23 5	3,704 6	— 23 5
Mean				1,378 9	10 4	3,728 1	10 4
Range				......	49 4	......	49 4
Comparative results from Williamson							
Mean				1,368 6	21 0	3,731 6	20 1
Range				......	90 2	......	194 5

*The barometer readings are from a manuscript copy of the original records furnished by Colonel Williamson, and are corrected for index error and temperature of instrument. The bracketed reading is interpolated. The comparative results in the lower line are derived from page 49 of his Compendium

The results of the former series of computations appear in the second and third columns of Table IV; those of the latter series in the fourth and fifth columns.

TABLE IV.

Differences of Altitude Computed by New Method from Single Sets of Observations; New Station *not intermediate* between Base Stations

Day and Hour of Observation. 1860.	Hope Valley and Strawberry Valley		Strawberry Valley and Placerville	
	Alt.	Resid	Alt	Resid.
	Feet	*Feet.*	*Feet*	*Feet.*
Aug 11—7 a. m	1,401 7	+ 17 6	3,643.7	— 47 7
2 p m	1,386 7	+ 2 6	3,683 0	— 8 4
9 p m	1,377.4	— 6 7	3,708.4	+ 17.0
Aug 12—7 a. m	1,396 0	+ 11 9	3,658.2	— 33 2
2 p m	1,370 7	— 13.4	3,726 7	+ 35 3
9 p m	1,407.9	+ 23 8	3,627 2	— 64 2
Aug 13—7 a. m	1,398 2	+ 14 1	3,652 5	— 38 9
2 p m	1,373 6	— 10 5	3,718 5	+ 27 1
9 p. m	1,409 6	+ 25 5	3,622 8	— 68 6
Aug 14—7 a m	1,383 8	— 0 3	3,709 8	+ 18 4
2 p m	1,399 5	+ 15 4	3,649 3	— 42 1
9 p. m	1,407 2	+ 23.1	3,629 3	— 62 1
Aug 15—7 a. m	1,370.9	— 13 2	3,726 0	+ 34 6
2 p m	1,348.6	— 35 5	3,787 8	+ 96 4
9 p m	1,389 1	+ 5 0	3,676 3	— 15 1
Aug 16—7 a. m	1,356.1	— 28.0	3,767 0	+ 75 6
2 p m	1,367 5	— 16 6	3,735 5	+ 44 1
9 p m	1,396 2	+ 12 1	3,658 0	— 33 4
Aug 17—7 a. m	1,354 4	— 29 7	3,771 8	+ 80 4
2 p m	1,382 7	— 1 4	3,694 0	+ 2 6
9 p m	1,377.8	— 6 3	3,707 6	+ 16 2
Aug 18—7 a. m	1,378 1	— 6 0	3,706 6	+ 15 2
2 p m	1,379 1	— 5 0	3,703 8	+ 12 4
9 p m	1,373 8	— 10 3	3,717 8	+ 26 4
Aug 19—7 a. m	1,379.4	— 4 7	3,702 9	+ 11 5
2 p m	1,357 1	— 27 0	3,764.1	+ 72 7
9 p m	1,398 1	+ 14 0	3,652 8	— 38 6
Aug 20—7 a m	1,396.9	+ 12 8	3,656 1	— 35 3
2 p m	1,388.1	+ 4 0	3,679 2	— 12 2
9 p m	1,416 2	+ 32 1	3,605 9	— 85 5
Mean	1,384 1	14 3	3,691 4	39 0
Range		67 6		181.9
Comparative results from Williamson:				
Mean	1,368 6	21 0	3,731 6	20.1
Range		90 2		194 5

Besides the results from the reduction of these August observations, Colonel Williamson has published a series of altitudes involving the same stations, based upon daily means of observations. They were not computed for the purpose of a comparative test, nor did he apply to them the formula published in his volume and of which he recommends the use. He applied, however, the formula of Guyot, which differs chiefly in failing to take separate account of the humidity of the atmosphere, and affords nearly the same results when applied to the means of daily sets of observations. His publication includes the observations as well as the computed altitudes, and selecting from them the series for July and January, I have made comparative computations of altitude by the method of two bases, hoping thereby to illustrate still further the relative value of the new method, and especially to ascertain whether its results are affected like those of other methods by variations depending upon the season of year. The results of the computations are given in Tables V, VI, VII, and VIII, where they are arranged side by side with those of Williamson.

TABLE V.

Differences of Altitude Computed from Daily Means. Hope Valley and Strawberry Valley. July, 1860.

Day of Month.	By Williamson, with Guyot's Formula.		By New Method, from—			
			Hope Valley and Placerville		Strawberry Valley and Placerville	
	Alt	Resid.	Alt	Resid	Alt	Resid.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet*
1	1,381	− 6	1,374 3	− 8 3	1,377 7	− 11 4
2	1,384	− 3	1,378 7	− 3 9	1,383 8	− 5 3
3	1,386	− 1	1,378 4	− 4 2	1,383 4	− 5 7
4	1,383	− 4	1,374 5	− 8 1	1,378 0	− 11 1
5	1,385	− 2	1,378.8	− 3 8	1,383 9	− 5 2
6	1,387	0	1,386 4	+ 3 8	1,394 4	+ 5 3
7	1,378	− 9	1,378 2	− 4 4	1,383 1	− 6.0
8	1,403	+ 16	1,396 4	+ 13 8	1,408 1	+ 19 0
9	1,415	+ 28	1,393 2	+ 10 6	1,403 6	+ 14 5
10	1,405	+ 18	1,371.4	− 11.2	1,373 9	− 15.2
11	1,390	+ 4	1,375.8	− 6.8	1,379 8	− 9 3
12	1,396	+ 9	1,379 9	− 2 7	1,385 5	− 3 6
13	1,400	+ 13	1,382 2	− 0.4	1,388 7	− 0 4
14	1,397	+ 10	1,386 8	+ 4 2	1,394 9	+ 5 8
15	1,399	+ 12	1,388 4	+ 5 8	1,397 0	+ 7 9
16	1,385	− 2	1,382 6	0 0	1,389.3	+ 0.2
17	1,383	− 4	1,384.5	+ 1 9	1,391.8	+ 2 7
18	1,407	+ 20	1,392 0	+ 9 4	1,402 1	+ 13 0
19	1,390	+ 3	1,385 9	+ 3.3	1,393 7	+ 4.6
20	1,391	+ 4	1,386 0	+ 3 4	1,393 8	+ 4 7
21	1,380	− 7	1,380.0	− 2 6	1,385 6	− 3 5
22	1,392	+ 5	1,383 1	+ 0 5	1,389 9	+ 0.8
23	1,391	+ 4	1,387 1	+ 4 5	1,395 4	+ 6 3
24	1,372	− 14	1,371.8	− 10 8	1,374 4	− 14 7
25	1,365	− 22	1,369.7	− 12 9	1,371 5	− 17 6
26	1,344	− 43	1,351.1	− 31.5	1,345 9	− 43 2
27	1,367	− 20	1,380 4	− 2 2	1,386.1	− 3.0
28	1,377	− 10	1,391.0	+ 8 4	1,400 8	+ 11 7
29	1,391	+ 4	1,396.4	+ 13 8	1,408 1	+ 19 0
30	1,384	− 3	1,399.4	+ 16 8	1,412.3	+ 23.2
31	1,386	− 1	1,395 5	+ 12 9	1,406 8	+ 17 7
Mean	1,387	10	1,382.6	7 3	1,389 1	10.1
Range	....	71	....	48 3	....	66 4

TABLE VI.

Differences of Altitude Computed from Daily Means. Strawberry Valley and Placerville. July, 1860.

Day of Month.	By Williamson, with Guyot's Formula		By New Method, from—			
			Hope Valley and Placerville		Hope Valley and Strawberry Valley.	
	Alt.	Resid	Alt.	Resid.	Alt	Resid
	Feet.	*Feet.*	*Feet.*	*Feet*	*Feet*	*Feet.*
1	3,782	+ 24	3,732 7	+ 8.3	3,707.5	+ 31.1
2	3,761	+ 3	3,728 3	+ 3 9	3,691.0	+ 14.6
3	3,760	+ 2	3,728.6	+ 4 2	3,692 3	+ 15.9
4	3,775	+ 17	3,732.5	+ 8.1	3,688.0	+ 11.6
5	3,754	— 4	3,728.2	+ 3 8	3,690.5	+ 14.1
6	3,752	— 6	3,720 6	— 3.8	3,662 4	— 14 0
7	3,761	+ 3	3,728.8	+ 4.4	3,693 0	+ 16.6
8	3,765	+ 7	3,710.6	— 13 8	3,627 0	— 49.4
9	3,789	+ 31	3,713 8	— 10.6	3,638 4	— 38.0
10	3,827	+ 69	3,735 6	+ 11.2	3,717.8	+ 41.4
11	3,781	+ 23	3,731.2	+ 6 8	3,701.8	+ 25 4
12	3,794	+ 36	3,727.1	+ 2 7	3,686.5	+ 10 1
13	3,783	+ 25	3,724 8	+ 0 4	3,677.8	+ 1.4
14	3,758	0	3,720.2	— 4 2	3,661.0	— 15.4
15	3,760	+ 2	3,718 6	— 5 8	3,655.2	— 21.2
16	3,747	— 11	3,724 4	0 0	3,676.4	0.0
17	3,742	— 16	3,722 5	— 1 9	3,669.6	— 6.8
18	3,764	+ 6	3,715 0	— 9.4	3,642 2	— 34 2
19	3,758	0	3,721 1	— 3 3	3,664.3	— 12.1
20	3,760	+ 2	3,721.0	— 3 4	3,664 0	— 12.4
21	3,742	— 16	3,727 0	+ 2 6	3,686 2	+ 9 8
22	3,755	— 3	3,723.9	— 0.5	3,674 5	— 1.9
23	3,740	— 18	3,719.9	— 4 5	3,660 1	— 16 3
24	3,748	— 10	3,735 2	+ 10 8	3,716 3	+ 39 9
25	3,756	— 2	3,737 3	+ 12.9	3,724 3	+ 47.9
26	3,763	+ 5	3,755.9	+ 31.5	3,795 0	+118 6
27	3,730	— 28	3,726.6	+ 2 2	3,684 6	+ 8 2
28	3,714	— 44	3,716.0	— 8 4	3,646 3	— 30.1
29	3,734	— 24	3,710.6	— 13.8	3,626.9	— 49 5
30	3,718	— 40	3,707.6	— 16 8	3,616 2	— 60 2
31	3,725	— 33	3,711.5	— 12 9	3,630 0	— 46.4
Mean	3,758	16	3,724.4	7.3	3,676.4	26 3
Range		113		48.3		178 8

TABLE VII.

Differences of Altitude Computed from Daily Means. Hope Valley and Strawberry Valley. January, 1864.

Day of Month	By Williamson, with Guyot's Formula.		By New Method, from—			
			Hope Valley and Placerville		Strawberry Valley and Placerville	
	Alt.	Resid.	Alt.	Resid.	Alt.	Resid.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1	1,349	+ 6	1,359 2	− 3 6	1,357 1	− 4 9
2	1,396	+ 53	1,388.2	+ 25 4	1,396 9	+ 34.9
3	1,393	+ 50	1,387.2	+ 24.4	1,395 5	+ 33 5
4	1,374	+ 31	1,373 1	+ 10 3	1,376 2	+ 14 2
5	1,313	− 29	1,347 8	− 15 0	1,341 4	− 20 6
6	1,350	+ 7	1,364.3	+ 1.5	1,364.1	+ 2 1
7	1,350	+ 7	1,366 1	+ 3 3	1,366 5	+ 4 5
8	1,321	− 22	1,354 8	− 8 0	1,351 0	− 11 0
9	1,289	− 54	1,334.0	− 28.8	1,322 4	− 39 6
10	1,328	− 15	1,355 6	− 7 2	1,352 1	− 9 9
11	1,388	+ 45	1,379 9	+ 17 1	1,385 5	+ 23 5
12	1,370	+ 27	1,368 1	+ 5 3	1,369 3	+ 7 3
13	1,372	+ 29	1,370 9	+ 8 1	1,373 1	+ 11 1
14	1,395	+ 52	1,384 1	+ 21 3	1,391 2	+ 29 2
15	1,374	+ 31	1,376.2	+ 13 4	1,380 3	+ 18 3
16	1,300	− 42	1,348 5	− 14 3	1,342 3	− 19 7
17	1,315	− 27	1,354 6	− 8 2	1,350 8	− 11.2
18	1,324	− 18	1,363 3	+ 0 5	1,362 8	+ 0 8
19	1,302	− 41	1,355 5	− 7 3	1,352 0	− 10 0
20	1,321	− 22	1,366 5	+ 3 7	1,367 1	+ 5 1
21	1,320	− 22	1,361 0	− 1 8	1,359 5	− 2 5
22	1,321	− 22	1,345 6	− 17.2	1,338 4	− 23 6
23	1,250	− 93	1,317 2	− 45 6	1,299 4	− 62.6
24	1,278	− 65	1,333 1	− 29 7	1,321 2	− 40.8
25	1,311	− 32	1,350.6	− 12.2	1,345 2	− 16.8
26	1,351	+ 8	1,366 8	+ 4 0	1 367 5	+ 5 5
27	1,357	+ 14	1,359 8	− 3 0	1,357 9	− 4 1
28	1,362	+ 19	1,367.1	+ 4 3	1,367.9	+ 5.9
29	1,401	+ 58	1,394 4	+ 31.6	1,405 3	+ 43 3
30	1,383	+ 40	1,382 3	+ 19 5	1,388 8	+ 26 8
31	1,368	+ 25	1,371.7	+ 8 9	1,374 3	+ 12.3
Mean	1,343	33	1,362.8	13 0	1,362.0	17 9
Range	....	151	....	77.2	....	105.9

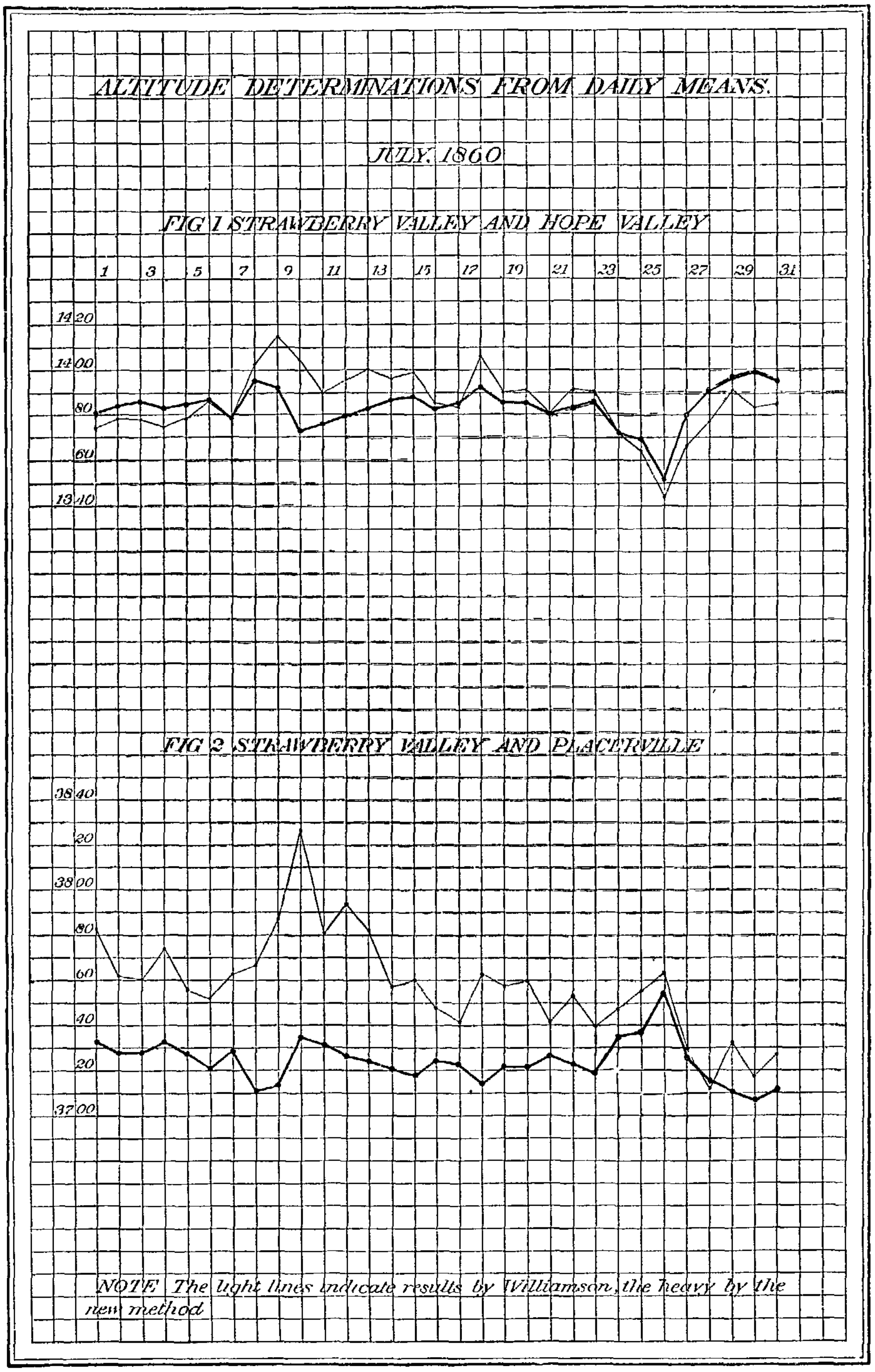
TABLE VIII.

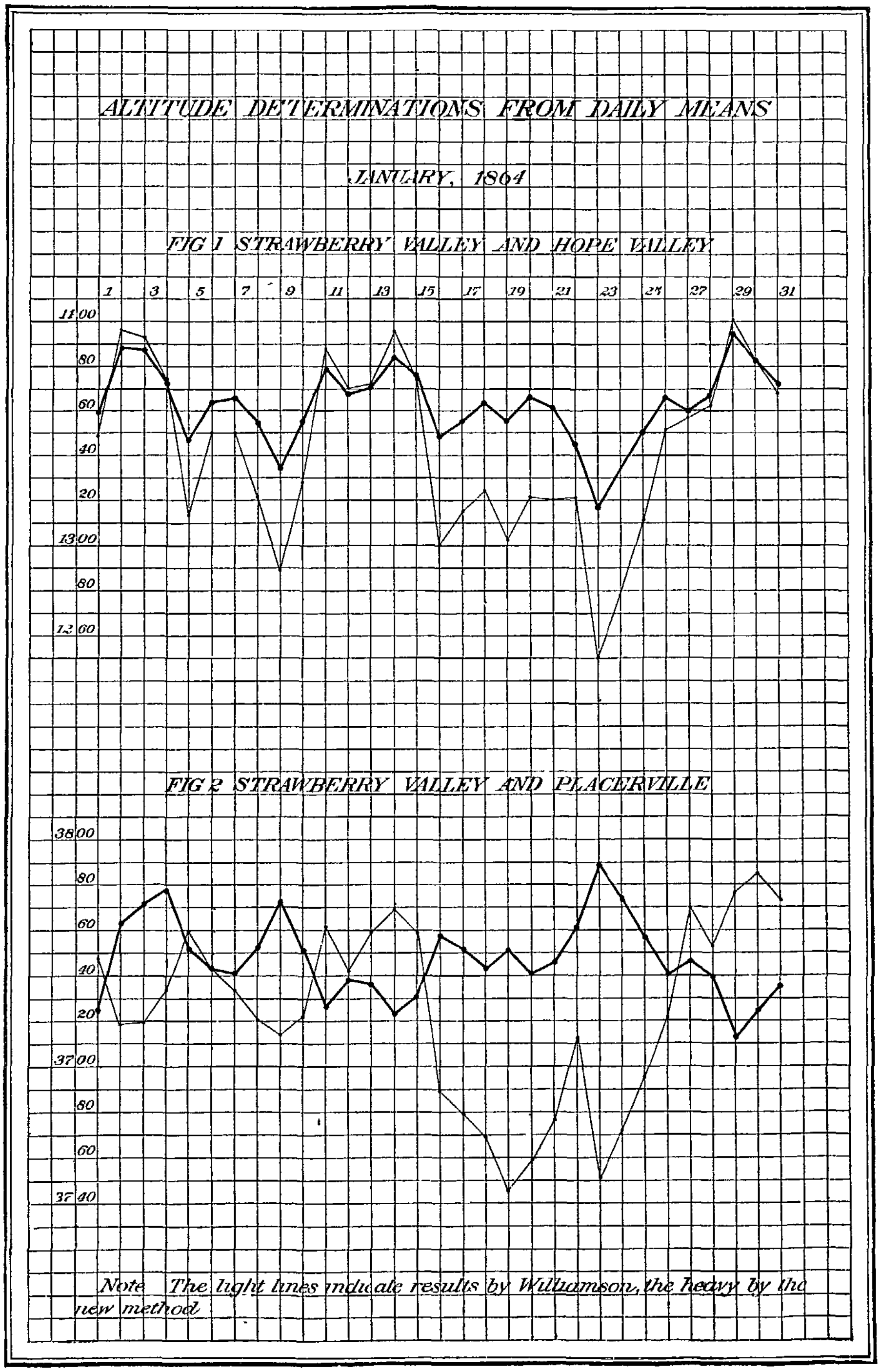
Differences of Altitude Computed from Daily Means. Strawberry Valley and Placerville. January, 1864.

Day of Month	By Williamson, with Guyot's Formula		By New Method, from—			
			Hope Valley and Placerville		Hope Valley and Strawberry Valley	
	Alt.	Resid	Alt	Resid	Alt	Resid
	Feet	*Feet*	*Feet.*	*Feet*	*Feet.*	*Feet*
1	3,725	− 1	3,747 8	+ 3.6	3,764 2	− 13.1
2	3,763	+ 36	3,718 8	− 25 4	3,656.0	− 95 1
3	3,771	+ 44	3,719 8	− 24 4	3,659 7	− 91.4
4.	3,777	+ 50	3,733 9	− 10.3	3,711.6	− 39.5
5	3,751	+ 24	3,759.2	+ 15 0	3,807 7	+ 56.6
6	3,744	+ 17	3,742 7	− 1 5	3,744.4	− 6.7
7	3,733	+ 6	3,740 9	− 3.3	3,738 1	− 13 0
8	3,720	− 7	3,752 2	+ 8 0	3,781 0	+ 29 9
9	3,714	− 12	3,773.0	+ 28 8	3,861 5	+ 110.4
10	3,721	− 6	3,751 4	+ 7 2	3,778 0	+ 26 9
11	3,761	+ 34	3,727 1	− 17 1	3,686 6	− 64 5
12.	3,742	+ 15	3,738.9	− 5 3	3,730.5	− 20 6
13	3,759	+ 32	3,736 1	− 8.1	3,719 8	− 31 3
14	3,769	+ 43	3,722 9	− 21.3	3,671 0	− 80.1
15.	3,759	+ 32	3,730 8	− 13 4	3,700 5	− 50 6
16	3,689	− 38	3,758.5	+ 14 3	3,805 0	+ 53 9
17.	3,679	− 47	3,752 4	+ 8.2	3,781 8	+ 30.7
18	3,669	− 58	3,743 7	− 0 5	3,748 3	− 2 8
19.	3,646	− 81	3,751.5	+ 7 3	3,778.5	+ 27 4
20	3,659	− 67	3,740 5	− 3 7	3,736 6	− 14 5
21	3,677	− 50	3,746 0	+ 1 8	3,757.1	+ 6 0
22	3,712	− 15	3,761 4	+ 17 2	3,815 4	+ 64.3
23	3,651	− 76	3,789.8	+ 45.6	3,928 3	+ 177 2
24	3,671	− 56	3,773 9	+ 29 7	3,865 0	+ 113 9
25	3,694	− 33	3,756.4	+ 12 2	3,797 0	+ 45 9
26	3,721	− 5	3,740 2	− 4.0	3,735 5	− 15 6
27.	3,769	+ 42	3,747 2	+ 3 0	3,761 8	+ 10 7
28.	3,753	+ 27	3,739 9	− 4 3	3,734 3	− 16 8
29.	3,776	+ 49	3,712 6	− 31 6	3,634 2	− 116.9
30	3,784	+ 57	3,724 7	− 19 5	3,677 4	− 73 7
31	3,772	+ 45	3,735.3	− 8 9	3,717 0	− 34 1
Mean	3,727	36	3,744 2	13 0	3,751.1	49 5
Range		138		77 2		294.1

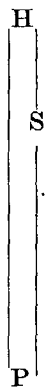
In Tables V and VI the results for July appear; in Tables VII and VIII the results for January. Tables V and VII give determinations of the height of Hope Valley above Strawberry Valley; Tables VI and VIII of the height of Strawberry Valley above Placerville. In each table Williamson's values appear at the left and are succeeded, first, by the values computed from the base line given by Hope Valley and Placerville, and, second, by the values computed from a shorter base.

A selection from the same results is graphically exhibited in the curves of Plates LIV and LV.


ALTITUDE DETERMINATIONS FROM DAILY MEANS.
JULY, 1860
FIG 1 STRAWBERRY VALLEY AND HOPE VALLEY
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
1420
1400
80
60
1340
FIG 2 STRAWBERRY VALLEY AND PLACERVILLE
3840
20
3800
80
60
40
20
3700
NOTE The light lines indicate results by Williamson, the heavy by the new method


ALTITUDE DETERMINATIONS FROM DAILY MEANS
JANUARY, 1864
FIG 1 STRAWBERRY VALLEY AND HOPE VALLEY
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
11 00
80
60
40
20
13 00
80
12 60
FIG 2 STRAWBERRY VALLEY AND PLACERVILLE
38 00
80
60
40
20
37 00
80
60
37 40
Note The light lines indicate results by Williamson, the heavy by the new method

It has been proposed to designate the height of the air column included between the two base stations as the "vertical base", or the "base line". It will be convenient to add a parallel term and call the height of the air column included between the new station and that base station to which it is referred, the *new line.* If we represent by the positions of the letters H, S, and P of the diagram, the vertical relations of the stations in Hope Valley, Strawberry Valley, and Placerville, then when Hope Valley and Placerville are used as base stations, the line H P becomes the base line, and either H S or S P the new line. When H S is taken as the base line and H P or S P is the new line, it is evident that every error which affects the barometric reading at H or S, and thereby affects the approximate determination of the base line H S, must appear in a magnified form in the corresponding determination of the new line; but when the new line is shorter than the base line the reverse holds true, and errors affecting the base line produce relatively small errors in the determination of the new line. The most favorable circumstances for the application of the method are therefore those in which the base line is greater than the new line, and this is always the case when the new station is intermediate in altitude between the two bases.



It will be proper, therefore, in making a general comparison of results, to distinguish those cases in which the new line is shorter than the base line from the less favorable cases in which it is longer.

In Table IX the results of Williamson's computations are compared with the best results by the new method—that is, with those obtained by the employment of a base line longer than the new line.

By the new method the same degree of accuracy, and indeed the same result, is obtained by regarding either H S or S P as the new line; but by Williamson's method the case is different, and two columns are therefore given for his results, the first for the case in which the computed height is about 1,365 feet, and the second for the case in which it is about 3,742 feet.

Two measures of precision are also indicated, the range of variation, and the mean of residuals, or the average residual. It goes without saying that a poor method will ordinarily exhibit a greater difference between its extreme results than a good one; but since extreme results are sometimes due to accidents altogether anomalous and exceptional, the rule does not invariably hold true. The arithmetic mean of residuals is a better criterion, for the amount of error or variation which by experiment is found to accrue *on the average* is a measure of the amount to be anticipated in future applications of the same method. In this case it happens that the general indication is the same by either criterion.

TABLE IX.

Comparison of Results for the case of a New Station *intermediate* in Altitude between two Base Stations.

Observations	Range of Computed Results			Average Deviation of Individual Results from the Mean.		
	By Williamson. Computed Height		By New Method	By Williamson Computed Height		By New Method.
	1,365 feet	3,742 feet		1,365 feet	3,742 feet	
	Feet	*Feet*	*Feet.*	*Feet*	*Feet*	*Feet*
Thirty Individual Hours in August, 1860	90	194	49	21	20	10
Daily Means for July, 1860....	71	113	48	10	16	7
Daily Means for January, 1864 . ..	151	138	77	33	36	13
Ratios	1 00		47	1 00		47

The ratios at the bottom of the table were derived by first taking the corresponding ratios in each line and then deducing their means. They indicate that by the application of the new method under favorable conditions the variation of results among themselves is reduced one-half, and they warrant the presumption that there is an absolute diminution of hypsometric error by the same amount. In the absence of an absolute standard, and so long as the individual computed altitudes can only be compared with a mean of altitudes barometrically determined, it is impossible to say that there are no constant errors which fail to be eliminated; but so far as the evidence goes it points to the advantage of the additional base station.

Turning now to the less favorable case in which the new station is not intermediate between the two bases, we find a less favorable result. With the line S P as a base, we might regard either H P or H S as the new line, but since Colonel Williamson has computed values for the shorter only of these lines, our comparison is necessarily restricted to that.

Table X gives first the results obtained by Williamson for the line H S, and compares with them the results by the new method, the line S P being used as a base. It then gives the results obtained by Williamson for the line S P, and contrasts them with results by the new method, the line H S being used as a base. The second case is manifestly the less favorable for the new method, because it determines a long new line from a short base line, and this difference is strikingly exhibited by the numerical ratios. With a relatively long base line the new method diminishes the mean residual one-fourth; with a relatively short base line it increases it two-thirds. We may therefore say without hesitation that the new method should not be applied to new stations falling outside the base line and separated from its nearest extremity by a vertical space greatly exceeding the length of the base line. And we may further say that for all stations falling outside the base line the advantage of the new method is less than for stations between the bases. The data are too meager, however, to enable us to indicate the precise ratio of new line to base line at which the applicability of the method finds its limit.

TABLE X

Comparison of Results for the case of a New Station *not intermediate* in Altitude between two Base Stations

Observations	Range of Computed Results				Average Deviation of Individual Results from the Mean			
	Computed Height, 1,365 ft		Computed Height, 3,742 ft		Computed Height, 1,365 ft		Computed Height, 3,742 ft	
	By Williamson	By New Method, base = 3,742 feet	By Williamson	By New Method, base = 1,365 feet	By Williamson	By New Method, base = 3,742 feet.	By Williamson	By New Method, base = 1,365 feet.
	Feet	*Feet.*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Thirty Individual Hours in Aug., 1860	90	68	194	182	21	14	20	39
Daily Means for July, 1860 ..	71	66	113	179	10	10	16	26
Daily Means for January, 1864 .	151	106	138	294	33	18	36	50
Ratios	1.00	.80	1 00	1.55	1.00	.74	1.00	1 66

It should be noted that in this comparison computation by the old method is made only of the distance between the new station and that base station lying nearest to it. Undoubtedly if we were able to examine results in which the more remote base station was the one used, the old method would appear to less advantage.

Yet another interesting comparison is afforded by the computations. It has been pointed out by many investigators that the results obtained in winter are different from those obtained in summer, being for some localities relatively high and for others relatively low. If these discrepancies depend upon the difficulty of determining the temperature of the air column by means of the thermometer, then theoretically they should be eliminated by the new method, and approximately the same mean results should be obtained at all times of the year—provided, always, the stations are so situated that the element of gradient does not largely enter. The stations in this case are so widely separated that the influence of gradient undoubtedly affects all the results, but it is nevertheless interesting to make the comparison. For this purpose the means of all the computed altitudes are assembled in Table XI. The second column gives the results for the period from August 11 to August 20, 1860; the third for the month of July, 1860; the fourth for the month of January, 1864. The remaining columns show the means of the quantities in these three and their range. The upper division of the table is devoted to determinations of the altitude of Hope Valley above Strawberry Valley, and the lower to determinations of the altitude of Strawberry Valley above Placerville, each giving, first, the determination by Williamson, second, the determination by the new method applied with the new station intermediate between the two bases, and third, the determination by the new method applied with the new station outside the space included by the bases. Here, again, the superiority of the new method, when favorably conditioned, is shown. The determinations of the middle station, obtained by referring it to the highest and lowest as bases, have a range in the three months of only 20 feet, while Williamson's determinations show a range of 44 feet when the upper station is taken as the base, and of 31 feet when the lower is taken. Here too the most discordant determinations of all are those obtained by the new method when the new line is longer than the base line and lies entirely without it: the results of the computation of Placerville from Strawberry Valley and Hope Valley exhibit a range of 75 feet.

TABLE XI.

Comparison of Means of Altitude Determinations.

	Ten Days in August, 1860	July, 1860	January, 1864	Mean	Range
	Feet	*Feet*	*Feet*	*Feet*	*Feet*
Hope Valley and Strawberry Valley:					
By Williamson	1,369	1,387	1,343	1,366	44
By New Method					
Base=5,107 feet	1,379	1,383	1,363	1,375	20
Base=3,742 feet	1,384	1,389	1,362	1,378	27
Strawberry Valley and Placerville.					
By Williamson	3,732	3,758	3,727	3,739	31
By New Method					
Base=5,107 feet	3,728	3,724	3,744	3,732	20
Base=1,365 feet	3,691	3,676	3,751	3,706	75

The data are too meager for generalization, but so far as they go their indication is favorable to the new method. Williamson's records and discussions show that the month of January, 1864, was characterized in California by storms, while the month of July, 1860, and the ten days selected in August, were not so characterized. It is therefore possible, if not indeed probable, that the residuum of 20 feet, which the best application of the new method fails to eliminate from the disparity of the results for July and January, is largely due to the gradients accompanying the January storms.

It will be noted that the determinations by the new method of the difference of altitude of the two upper stations is almost uniformly greater than by the old, while the determination of the difference between the two lower stations is almost uniformly less. The deficit in the one case is the correlative of the excess in the other, for any influence which tends to raise the estimate by the new method of the one distance, tends at the same time to lower the estimate of the other. In the absence of an absolute standard it is impossible to refer the discrepancy to one method or the other. In applying the new method, the mean altitudes obtained by the old method, as given by Williamson, were accepted as the basis of computation, and whatever errors they involve have been not only retained but slightly exaggerated.

COMPARISON WITH WHITNEY'S METHOD.

In the year 1870 Professor J. D. Whitney, at that time State Geologist of California, instituted a series of barometric and thermometric observations at three stations upon the western slope of the Sierra Nevada, and the observations were continued for about three years. In a report to the legislature,* to which we have already had occasion to refer, he discusses these observations and bases upon them a series of hypsometric tables and a hypsometric system. The three stations were Sacramento, Colfax, and Summit, all upon the line of the Central Pacific Railroad and determined in altitude by the railroad surveys. Their relations in distance and altitude are as follows:

Stations	Distance	Difference of Altitude
	Miles	*Feet*
Sacramento to Colfax	45	2,399
Colfax to Summit	36	4,590
Sacramento to Summit	77	6,989

Their latitude is about 39°. The observations were made daily at the hours of 7 a. m., 2 p. m., and 9 p. m., and from them Whitney derived monthly means for each hour. From these means of pressure and temperature he computed the difference in altitude of each pair of stations for each month of the three years and for each hour of observation, using Williamson's tables for the purpose, but neglecting the correction for humidity.

Comparing the results of these computations with the known differ-

* "Geological Survey of California J. D. Whitney, State Geologist Contributions to Barometric Hypsometry, with Tables for Use in California. Published by Authority of the Legislature. 1874."

The title page does not announce the author of the volume. The "Prefatory Note" is signed with Professor Whitney's initials, but speaks of the volume as "prepared by" Prof. W. H Pettee, and conveys an impression of joint authorship. It is therefore with a constant reservation in favor of Professor Pettee that I have referred to the book and the hypsometric method as Professor Whitney's.

ences of altitude, he made tables of errors for each year and for each pair of stations. The series of errors he found to be similar in the different years, but not the identical, and, making allowances for their irregularities, he deduced from them a system of corrections which he embodied in tables. The first of these tables is entitled "Corrections to be applied for each thousand feet from sea-level to 2,400 feet," and gives a separate factor for each month of the year and each hour of the day from 7 a. m. to 9 p. m., inclusive; the second table gives similar "Corrections to be applied for each thousand feet from sea-level to 7,000 feet"; and the third gives "Corrections to be applied for each thousand feet of difference of level between the altitudes 2,400 feet and 7,000 feet." For the application of these tables, Professor Whitney directs that the altitude of a new station above the base station shall be first computed by means of some such tables as Williamson's or Guyot's, but without the application of a correction for moisture, and that to the result the factor from some one of his tables shall be added, the particular table being determined by the positions and altitudes of the two stations.

These tables are not intended for universal application, but merely for the neighborhood, largely considered, in which the observations on which they are based were made. Similar tables prepared by others in other climates, differ widely in the amount of correction to be applied at different hours and seasons, and no one table or group of tables can possibly be used to advantage in all parts of the world. Professor Whitney takes pains to define this limitation, claiming no value for his tables outside of California, and saying that "in order to obtain the best results the world over, it will be necessary to have similar tables for each mountain region." His method thus demands for its application a large preliminary outlay in each district; and if the comparatively inexpensive system here proposed can be shown to equal his in precision of result, it will be entitled to preference on economic grounds.

Comparative tests have been made in three ways: by computing the altitude of Colfax from monthly means; by computing it from single observations; and by computing the altitudes of other points in California. They will be described in the order named.

I. In the preparation of his tables Whitney was unable to make his correction for any particular hour and month the precise equivalent of the corresponding error in *each* year, because those errors in the three years were different. There is, therefore, for each individual date a discrepancy between the correction he proposes and the error he wishes to eradicate; so that when his own tables are applied to the observations from which they were derived they do not produce for individual months a perfect result. Nevertheless, we must suppose that they were adjusted as closely as was practicable, so that, after applying his corrections to the original observations, the residual errors are approximately at a minimum. Certainly, in the application of his tables to the differences in height of Sacramento, Colfax, and Summit, a selection is made of the conditions most likely to display his method to advantage.

To render the comparison as just as practicable, the new method has been applied only under *its* most favorable condition,—the condition, that is, that the new station is intermediate in altitude between the two base stations. Sacramento and Summit were taken as bases, and from them the altitude of Colfax was computed for each month and hour of observation.*

Whitney's series includes parts of the years 1870 and 1873, and the whole of 1871 and 1872. For the purpose of comparison the entire years only were used.

For each month and each hour of observation Whitney has computed, by means of Williamson's tables, the height of Colfax above Sacramento, and his results are published on pages 75 and 76 of his volume. Similar results for the difference in altitude of Colfax and Summit are published on pages 78 and 79. To each of these results the writer has added the appropriate correction from Whitney's special table, so as to give for each month and hour the result by Whitney's method. He has then subtracted from each of these results the altitude as determined by level, and called the difference an error. These errors, for the years 1871 and 1872, appear in the first four columns of Table XII. The corresponding errors, deduced in the same manner from the results by the new method, appear in the two columns at the right. The footings show that the mean error in the determination of Colfax by the new method is about the same as by Whitney's method. Whitney's error is slightly greater if Summit is taken as base station, and slightly smaller if Sacramento is taken.

II. The published observations give only the monthly means of the readings at the three stations, but Professor Whitney has done me the favor to place the original records at my service, and I have thus been enabled to base a second test upon series of single observations. For this purpose the observations at the three stations for the month of November, 1870, were employed, their selection being determined by the accidental fact that of all the records which came into my hands the set for that month was most nearly complete.

Table XIII contains a copy of the original figures, excepting, first, that the barometric readings have been corrected for temperature of instrument; and, second, that in every case where an observation is lacking from the record all other observations at the same hour are omitted. There remain eighty-six sets of observations, giving simultaneous pressures and temperatures at the three stations.

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* The data for the computations are published on pages 32, 33, and 34 of the Californian "Contributions to Barometric Hypsometry."

TABLE XII.

Determination of the Altitude of Colfax, California, from Monthly Means. Comparison of Errors by Different Methods of Computation

Month and Hour	By Whitney's Method, the Base Station being—				By New Method from Summit and Sacramento	
	Summit		Sacramento			
	1871	1872	1871	1872	1871	1872
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet.*
Jan —7 a.m	+ 24.3	— 0.9	— 14.7	+ 4.3	+ 2.5	+ 8.2
2 p.m	+ 11.8	— 2.8	— 0.9	— 1.1	+ 2.9	— 1.9
9 p.m	+ 21.1	— 5.1	— 17.6	+ 8.8	— 8.2	+ 3.7
Feb —7 a.m	+ 28.4	— 47.7	— 8.2	+ 3.2	— 4.0	— 21.2
2 p.m	+ 6.2	+ 3.2	+ 3.0	— 8.1	— 11.9	— 20.1
9 p.m	+ 19.8	— 57.6	+ 13.5	— 4.2	+ 3.6	— 28.1
Mar —7 a.m	+ 9.4	— 8.6	— 6.6	+ 7.1	— 2.9	+ 2.3
2 p.m	+ 2.5	+ 8.0	— 1.0	— 12.1	— 5.7	— 10.3
9 p.m	+ 17.0	— 25.2	+ 0.9	— 3.9	— 14.5	— 18.7
Apr —7 a.m	— 16.1	— 1.6	— 30.1	+ 10.3	— 10.9	+ 6.1
2 p.m	— 18.0	+ 12.0	— 7.7	— 13.6	— 11.0	— 15.3
9 p.m	+ 30.9	— 9.6	— 30.5	— 11.4	— 16.1	— 14.4
May —7 a.m	— 23.5	+ 12.4	— 10.1	+ 3.0	+ 15.8	+ 17.3
2 p.m	+ 1.5	+ 22.6	— 0.7	— 14.4	+ 6.7	— 5.6
9 p.m	+ 30.8	+ 1.1	— 0.4	— 16.4	+ 8.9	— 7.8
June—7 a.m	— 27.8	— 1.8	— 15.2	— 4.5	+ 18.6	+ 18.6
2 p.m	— 1.9	+ 7.9	+ 5.4	— 44.6	+ 17.6	— 18.5
9 p.m	+ 14.8	+ 5.6	— 22.3	— 22.3	— 2.2	— 8.2
July —7 a.m	+ 4.7	+ 0.3	— 6.3	+ 17.8	+ 37.4	+ 39.3
2 p.m	— 4.6	+ 11.2	+ 3.0	— 5.8	+ 15.6	+ 8.2
9 p.m	+ 15.5	+ 0.6	— 2.8	— 4.1	+ 10.6	+ 5.7
Aug —7 a.m	+ 19.7	+ 12.0	— 3.2	+ 1.1	+ 33.9	— 7.0
2 p.m	— 15.3	— 15.6	+ 8.8	— 15.0	+ 10.7	— 14.3
9 p.m	+ 34.3	+ 16.4	— 6.7	— 13.5	+ 3.3	— 13.3
Sept—7 a.m	+ 3.9	— 4.2	+ 4.6	— 2.7	+ 23.7	— 4.1
2 p.m	+ 6.8	— 1.1	+ 20.5	— 24.8	+ 15.5	— 21.3
9 p.m	+ 23.0	— 22.2	+ 1.6	— 4.2	— 1.5	— 14.9
Oct —7 a.m	+ 12.7	— 28.8	+ 3.8	— 3.5	+ 18.1	— 0.5
2 p.m	— 4.8	— 25.9	+ 16.8	— 24.7	+ 19.0	— 20.9
9 p.m	+ 14.5	— 45.6	+ 3.9	— 25.7	+ 2.1	— 30.5
Nov —7 a.m	— 25.3	+ 7.3	— 2.2	+ 17.8	— 4.7	+ 28.3
2 p.m	— 12.2	— 8.1	+ 1.8	— 3.8	— 8.6	+ 0.7
9 p.m	— 27.3	+ 1.3	+ 3.4	— 6.6	— 14.0	— 4.9
Dec —7 a.m	— 45.1	+ 5.1	+ 14.8	— 10.4	— 0.9	+ 0.1
2 p.m	— 29.3	+ 5.4	— 35.3	— 32.1	— 7.0	+ 5.7
9 p.m	— 43.6	+ 6.9	+ 15.8	— 25.2	+ 7.2	— 1.9
Mean	18.0	12.5	9.6	12.0	11.0	12.3
Range	79.4	80.2	55.8	62.4	51.4	69.8
Mean of two years	15.2		10.8		11.6	
Range	91.9		65.1		69.8	

TABLE XIII.

Observations at Sacramento, Colfax, and Summit, California, during the Month of November, 1870. (Whitney.)

Day	Hours	Barometer (reduced)			Thermometer (Fahr.)		
		Sacramento	Colfax.	Summit	Sacramento	Colfax	Summit
		Inches	*Inches*	*Inches*	°	°	°
1	7 a m	30 046	27 523	23.304	40 0	49 0	26 8
	2 p m	29 984	.488	260	73 0	74 0	49 6
	9 p m	994	499	272	55 5	56 5	32.8
2	7 a m	30 096	546	272	55 0	48 5	27 5
	2 p m	089	519	235	67 0	63 0	46 8
	9 p m	092	568	245	55 0	51 5	37 2
3	7 a m	124	575	241	42 5	45 0	27.6
	2 p m	085	563	247	64 0	61 5	46 6
	9 p m	.114	579	276	50 5	48 5	29 4
4	2 p m	157	597	201	63 0	55 5	41 0
	9 p m	132	586	198	52 5	46 5	29 4
5	7 a m	104	.547	189	48 5	46 0	30 2
	2 p m	.072	.529	121	62 0	57 0	42 6
	9 p m	29 938	400	067	50 0	47 5	32 0
6	7 a m	833	284	22 901	45 0	42 5	31 4
	2 p m	817	261	851	53 5	43 5	26 2
	9 p m	892	364	.900	46 5	38 5	23 4
7	7 a. m	30 038	446	.984	40 5	40 0	21 4
	2 p m	087	489	23 029	49 0	40 0	26 6
	9 p m	180	622	.187	48 0	41 5	26 2
8	7 a m	.246	662	276	41 5	38 0	12 8
	2 p m	160	622	260	56 0	55 0	40 6
	9 p m	124	532	221	46 0	41 0	24 4
9	7 a m	069	510	128	39 0	42 5	27.2
	2 p m	.024	461	050	57 0	49.5	31 2
	9 p m	078	512	119	47 0	43 0	23 3
10	7 a m	174	603	321	37 0	37 0	17 8
	9 p m	190	641	323	45 0	44 5	28 3
11	7 a m	194	639	318	37 0	42 0	33 5
	2 p m	160	601	326	60 0	60 0	47 0
	9 p m	122	589	323	49 5	51 0	34 2
12	7 a m	123	570	299	40 0	45 0	28 2
	2 p m	063	524	283	64 0	65 0	47 4
	9 p m	050	.510	287	49 5	51 0	32 4
13	7 a m	079	536	322	37 5	45 5	33 4
	2 p m	.053	.540	376	63 0	65 0	49 0
	9 p m	084	517	421	49 5	51.0	38 0
14	7 a m	144	476	.453	39 0	48 5	35 0
	2 p m	103	530	438	68 0	64 0	49 2
	9 p m	103	612	440	50 0	50 0	38 2
15	7 a m	148	647	441	41 0	50 5	32 3
	2 p m	113	.609	.408	65 0	69 5	53 0
	9 p m	.085	607	412	55.0	56 5	37 8
16	7 a m	062	609	411	42.5	56 0	38 0
	2 p m	074	576	374	70 0	75 0	54 0
	9 p m	087	611	416	51 5	57 0	37.2
17	2 p m	.172	673	474	69 5	74 5	54 2
	9 p m	234	747	546	51 0	56 5	39 0

TABLE XIII—Continued.

Day	Hour.	Barometer (reduced).			Thermometer (Fahr.)		
		Sacramento.	Colfax	Summit	Sacramento	Colfax	Summit
		Inches	*Inches*	*Inches*	°	°	
18	7 a m	308	.797	.541	43.0	51 5	3? 5
	2 p. m	.234	789	.591	69.0	73 0	53 2
	9 p. m	.284	.780	.597	52.0	56.0	30 3
19	7 a m	.270	742	572	41 5	54 0	35 8
	9 p m	.223	.720	518	51 0	58 0	?6 3
20	7 a m	.243	731	.473	44 0	51 5	34.0
	2 p m	.186	.708	513	71 0	73 0	48.2
	9 p m	.211	.734	.536	52 0	57 5	36 4
21	7 a m	297	.796	.555	38 0	51 0	31 5
	2 p. m	235	720	.534	69 0	74 0	46.0
	9 p. m	.194	707	.542	52 5	56 0	43 4
22	7 a m	176	.691	.516	37.5	51 0	34.4
	2 p m	140	.641	.450	67 0	74.5	52 3
	9 p. m	.124	.686	.449	48 0	55 0	36 0
23	7 a m	.154	652	.434	40 0	52 5	31.4
	2 p m	.024	.646	408	65 0	73 0	51 4
	9 p. m	171	.672	426	50.0	53 5	34 2
24	7 a. m	.240	.723	.462	44 0	50 0	32.6
	2 p. m	.195	.697	433	69 0	68 0	51 4
	9 p m	226	.725	468	51 5	54 0	31 2
25	7 a m	.226	.696	.430	40 5	49 5	30 0
	2 p m	146	.573	360	66 0	66.0	52.0
	9 p m	.084	.586	298	52.0	52.0	38.3
26	7 a. m	.012	.486	124	44.0	46.0	34.0
	2 p m	29.964	405	.023	58 0	53 0	32 2
	9 p m	30.009	425	051	48 0	50.0	25 3
27	7 a m	.060	.469	119	43 0	40.5	23 0
	2 p m	030	467	.152	60 5	56 0	33.4
	9 p m	.054	529	181	48 0	49 0	19 4
28	7 a. m	.114	540	193	36 5	36 0	19 0
	2 p m	.066	505	161	58 0	54.0	34 0
	9 p m	050	506	.188	50 0	50 0	32.4
29	7 a m	076	531	181	47 0	48 0	31 2
	2 p m	.115	603	189	49.0	43 0	26 5
	9 p m	.164	626	213	48 0	43 5	28 5
30	7 a m	.182	629	.234	47 0	44 5	28 0
	2 p m	156	.601	.248	54 0	56 0	35 2
	9 p. m	.113	554	.249	48 5	47 5	29 0

From each set of observations the altitude of Colfax was computed three times: first, by Whitney's method with Summit as the reference or base station; second, by the same method with Sacramento as base station; and third, by the new method with Summit and Sacramento as joint bases.

Since the computations by Whitney's method were not made under his supervision, and since his instructions for the application of his method leave a certain latitude to the computer, it is proper to define precisely the manner in which the work was done. A first approximate altitude was in each case computed by means of Williamson's table marked D_1.* A correction for temperature was then obtained by subtracting 64 degrees (F.) from the sum of the observed temperatures, dividing the remainder by 900, and multiplying the resulting quotient by the approximate altitude; and this correction was applied to the approximate altitude. A number expressing the sum of the corrections due to the variations in the force of gravity was then added, and afterward a special correction derived from Whitney's table. It is stated by Whitney that the corrections assigned to the several months in his tables apply more especially to the middle days, and may be modified when the observations are made near either end. In these computations the tabulated values were applied without modification to the middle day only, and for the remaining days values were interpolated by the aid of the tabulated corrections for October and December, the preceding and following months.

After the completion of the calculations the error of each determination was deduced by subtracting from it the corresponding difference in altitude as determined by spirit level; and these errors have been tabulated for publication. In Table XIV the three columns of errors pertain in order to the determinations by Whitney's method with Summit as a base, by Whitney's method with Sacramento as a base, and by the new method. The plus sign indicates in each case that the corresponding determination made Colfax too high; the minus sign, too low.

In this series the average error by the new method is notably less than by either application of Whitney's.

III. The second edition of Whitney's treatise contains a series of practical examples illustrating the application of his tables and the advantage thereby accruing. Each illustration consists of a series of independent determinations of the altitude of a point visited by the field parties of the Californian Survey in 1870 or 1871. The computations were made first without the use of the tables and afterward with them, and each series of results was compared with its own mean for the purpose of ascertaining the harmony of its individual components among themselves. The publication does not include the data of observation, but Professor Whitney has kindly permitted me to copy a portion of them, and I have thus been enabled to repeat by the new method some of the computations. My work covers only six of his twenty-four examples, but serves sufficiently well the purpose of comparison.

The barometric data and the several hypsometric results, with their errors, are exhibited in Table XV. The first two columns following the dates give for each locality the barometric readings (reduced to 32° F.) at the two points used as base stations in the new computations,

* "Practical Tables in Meteorology and Hypsometry, being the Appendix to the Paper on the Use of the Barometer," p. 111.

Table XIV.

Determinations of Altitude of Colfax, Cal., from Single Observations made in November, 1870. Comparison of Errors by Different Methods of Computation.

Day.	Hour.	By Whitney's Method, the base station being— Summit.	Sacramento.	By New Method, from Summit and Sacramento.
		Feet	*Feet*	*Feet.*
1	7 a.m	+ 57	+ 13	+ 35
	2 p m	+ 1	+ 53	+ 15
	9 p m	+ 5	+ 41	+ 15
2	7 a m.	− 4	+ 72	+ 29
	2 p m	+ 5	+ 78	+ 37
	9 p m	− 91	+ 48	− 6
3	7 a m	− 50	+ 27	+ 4
	2 p m	− 18	+ 18	− 4
	9 p m	− 12	+ 38	+ 8
4	2 p m	− 49	+ 33	− 13
	9 p m	− 95	+ 47	− 18
5	7 a.m	− 99	+ 55	0
	2 p m	− 93	+ 25	− 28
	9 p m	− 87	+ 51	− 3
6	7 a.m	− 166	+ 51	− 17
	2 p m	+ 6	+ 3	− 23
	9 p m	− 154	+ 13	− 60
7	7 a m	− 161	+ 58	− 21
	2 p m	+ 5	+ 1	− 16
	9 p m	− 103	+ 30	− 29
8	7 a m	+ 17	+ 29	+ 6
	2 p m	− 5	− 9	− 13
	9 p m	− 29	+ 61	+ 38
9	7 a m	− 101	+ 24	− 8
	2 p m	− 9	+ 18	− 15
	9 p m	− 67	+ 47	+ 9
10	7 a m	+ 102	+ 8	+ 38
	9 p m	+ 8	+ 20	+ 12
11	7 a.m	− 38	+ 4	+ 14
	2 p m	+ 32	+ 40	+ 35
	9 p m	− 4	+ 37	+ 23
12	7 a m	+ 19	+ 23	+ 32
	2 p m	+ 31	+ 50	+ 36
	9 p m	+ 42	+ 51	+ 43
13	7 a m	+ 51	+ 12	+ 50
	2 p.m	+ 116	+ 24	+ 53
	9 p.m	+ 162	+ 75	+ 114
14	7 a.m	+ 236	+ 140	+ 204
	2 p m	+ 199	+ 90	+ 118
	9 p m	+ 96	− 4	+ 36
15	7 a m	+ 61	− 14	+ 28
	2 p m	+ 41	+ 25	+ 31
	9 p.m	+ 39	+ 13	+ 18
16	7 a m	+ 9	− 36	+ 2
	2 p.m	+ 1	+ 50	+ 27
16	9 p.m	+ 40	+ 3	+ 17
17	2 p m	+ 23	+ 39	+ 29
	9 p m	+ 50	0	+ 23
18	7 a m	− 1	− 9	+ 15
	2 p m	+ 56	− 24	− 2
	9 p m	+ 121	+ 13	+ 40
19	7 a m	+ 85	+ 13	+ 59
	9 p.m	+ 51	+ 20	+ 31
20	7 a m	+ 4	0	+ 14
	2 p m	+ 66	+ 18	+ 19
	9 p m	+ 59	− 4	+ 18
21	7 a m	+ 49	− 32	+ 15
	2 p m	+ 85	+ 51	+ 46
	9 p m	+ 67	+ 3	+ 37
22	7 a m	+ 92	− 40	+ 31
	2 p m	+ 30	+ 38	+ 34
	9 p m	+ 21	− 53	− 22
23	7 a m	+ 43	− 21	+ 24
	2 p m	− 14	− 85	+ 60
	9 p m	+ 25	+ 6	+ 11
24	7 a m	+ 13	0	+ 16
	2 p.m	− 11	+ 22	+ 3
	9 p m	+ 34	+ 7	+ 8
25	7 a m	+ 17	+ 3	+ 21
	2 p m	+ 32	+ 91	+ 68
	9 p m	− 52	+ 12	− 7
26	7 a.m	− 134	+ 17	− 21
	2 p m	− 36	+ 37	− 9
	9 p.m	− 106	+ 87	+ 8
27	7 a m	− 39	+ 59	+ 23
	2 p m	+ 32	+ 51	+ 20
	9 p.m	− 23	+ 22	− 16
28	7 a m	+ 20	+ 10	+ 14
	2 p m	+ 11	+ 35	+ 8
	9 p m	− 63	+ 49	+ 7
29	7 a m	− 106	+ 43	− 4
	2 p m	+ 40	− 71	− 48
	9 p m	− 97	+ 10	− 32
30	7 a m	− 107	+ 33	− 17
	2 p m	0	+ 15	+ 7
	9 p m	− 10	+ 48	+ 22
	Mean	55 9	33 2	26 9
	Range	402	225	264

TABLE XV.

Altitude Determinations in California, from Observations by the Geological Survey of California in 1870.

1.—ALTITUDE OF GOLD RUN ABOVE COLFAX

Day.	Hour	Barometer Reading			Altitude by—		Residual by—	
		Summit	Colfax	Gold Run	Whitney	New Method	Whitney	New Method
		Inches	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Feet.*
Oct 7	7 a m	23 383	27 494	26.765	804 2	767 5	— 5 3	—14 0
	2 p m	410	487	745	814 3	788 7	+ 4 8	+ 7 2
	9 p m	418	499	764	802 5	780 3	— 7 0	— 1 2
8	7 a m	409	520	.775	812 6	784 5	+ 3 1	+ 3 0
9	2 p m	311	.341	.597	820.5	800 1	+11 0	+18 6
	9 p m	251	340	611	804 3	772.0	— 5 2	— 9 5
10	7 a m	245	370	.631	807 9	774 6	— 1 6	— 6 9
	2 p m	227	371	.624	813 9	779 8	+ 4 4	— 1 7
11	7 a m	257	445	690	812.3	778 9	+ 2.8	— 2 6
	3 30 p m	262	458	690	819 7	791 0	+10 2	+ 9 5
	9 p m	316	460	725	792 7	766 8	—16 8	—14 7
12	7 a m	346	.488	736	816 1	785 1	+ 6 6	+ 3 6
	2 p m	364	493	.740	812 7	789 2	+ 3 2	+ 7 7
	9 p m	386	512	768	801 4	779 9	— 8 1	— 1 6
13	7 a m	424	556	805	796 7	786 5	—12 8	+ 5 0
	2 p m	388	.514	768	809 6	781 9	+ 0 1	+ 0 4
	9 p m	.396	523	.781	803.9	778 1	— 5 6	— 3 4
Mean					809.5	781 5	6 4	6 5
Range							27.8	33 3

2—ALTITUDE OF YOU BET ABOVE COLFAX

Day	Hour	Barometer Reading			Altitude by—		Residual by—	
		Summit	Colfax.	You Bet	Whitney	New Method	Whitney	New Method.
		Inches	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Feet.*
Nov 10	9 p m	23 323	27 641	27 080	585 3	558 2	+27 2	+12 2
11	7 a m	318	639	086	564 5	550 2	+ 6 4	+ 4 2
	1 45 p m	326	601	053	572 5	550 8	+14 4	+ 4.8
	7 25 p m	323	589	041	568 3	553 0	+10 2	+ 7 0
12	7 a m	299	570	26 997	597 9	577 1	+39 8	+31 1
16	2 p m	374	576	27 046	562 2	543 3	+ 4 1	— 2 7
	9 p m	416	611	095	540 6	529 7	—17 5	—16.3
17	1 p m	474	673	148	552 8	538 7	— 5 3	— 7 3
18	2 p m	591	789	260	550 8	542 7	— 7 3	— 3 3
20	7 a m	473	731	188	557 6	549.0	— 0 5	+ 3 0
	2 p m	513	708	187	544 5	535 5	—13 6	—10 5
	9 p m	536	734	211	542 8	536 9	—15 3	— 9 1
21	7.30 a m	555	796	263	549 3	541 3	— 8 8	— 4 7
	2 p m	.534	720	187	557 9	548 7	— 0 2	+ 2 7
	9 p m	542	707	185	540 6	540 3	—17 5	— 5 7
22	7 a m	516	691	170	539 9	537 9	—18 2	— 8 1
23	7 a m	434	652	125	549 9	538 2	— 8 2	— 7 8
Dec 8	2 p m	246	738	169	563 2	543 3	+ 5.1	— 2 7
	9 p m	293	729	165	564 0	545 3	+ 5 9	— 0 7
9	7 a m	329	659	109	553 1	546 4	— 5 0	+ 0 4
12	7 a m	.148	512	26.954	557 9	548 9	— 0 2	+ 2 9
	7 p m	171	.553	.985	551 7	556 5	— 6.4	+10.5
Mean					558 1	546 0	10.8	7.2
Range							58 0	47 4

TABLE XV—Continued.

3.—DISTANCE OF CAMP 9 BELOW COLFAX

Day.	Hour.	Barometer Reading.			Altitude by—		Residual by—	
		Summit	Colfax.	Camp 9	Whitney	New Method.	Whitney.	New Method
		Inches	*Inches*	*Inches*	*Feet.*	*Feet*	*Feet*	*Feet.*
Sept 21	9 p m	23 397	27 486	28 852	1,369 6	1,398	—13 4	—14
22	7 a. m	353	.471	854	1,361 4	1,406	—21 6	— 6
23	7 a. m...........	277	452	897	1,412 7	1,445	+20 7	+33
	2 p m	269	445	850	1,397 2	1,406	+14 2	— 6
	9 p m .	298	.466	871	1,381 9	1,408	— 1 1	— 4
24	7 a m	320	513	.945	1,384 6	1,425	+ 1 6	+13
	2 p m .	298	.481	854	1,363.6	1,372	—19 4	—40
	9 p. m... ..	.337	.483	.886	1,382 3	1,415	— 0 7	+ 3
25	7 a m...	350	.525	940	1,381 6	1,416	— 1 4	+ 4
26	7 a. m	315	.474	869	1,370 2	1,402	—12 8	—10
	9 p. m . .	325	493	925	1,407.7	1,435	+24 7	+23
Mean					1,383 0	1,411 6	12 8	14 2
Range					..... .	... .	51.3	73

4.—ALTITUDE OF LAKEPORT ABOVE SACRAMENTO.

Day	Hour	Barometer Reading			Altitude by—		Residual by—	
		Colfax	Sacramento	Lakeport	Whitney	New Method	Whitney	New Method
		Inches	*Inches*	*Inches*	*Feet*	*Feet*	*Feet.*	*Feet.*
Oct 19	7 a m.....	27 735	30 212	28.840	1,269 7	1,306	—55.8	— 7
	2 p m	.633	.149	760	1,323 2	1,301	— 2 3	—12
	9 p m	681	121	799	1,250 7	1,278	—74.8	—35
20	7 a m	635	115	758	1,259 7	1,289	—65 8	—24
	2 p m	571	044	646	1,339.1	1,334	+13 6	+21
	9 p m ..	542	29 987	641	1,269 1	1,298	—56 4	—15
21	2 p m ..	409	906	488	1,355 7	1,340	+30 2	+27
	9 p m	365	871	467	1,342.1	1,321	+16 6	+ 8
22	7 a m	.311	.834	.432	1,339 7	1,309	+14 2	— 4
	2 p m	303	847	389	1,355 1	1,352	+29 6	+39
23	7 a m	297	825	384	1,357 0	1,345	+31 5	+32
	2 p m	281	832	426	1,302.7	1,298	—22 8	—15
	9 p m...... ...	246	813	.424	1,307 3	1,274	—18 2	—39
24	7 a. m	245	798	424	1,287 2	1,268	—38 3	—45
	2 p m	278	.859	395	1,382 6	1,338	+57 1	+25
	9 p. m.	280	915	467	1,367 0	1,293	+41 5	—20
25	7 a m	369	.906	475	1,337 4	1,330	+11.9	+17
	2 p m	344	879	415	1,370 8	1,362	+45 3	+49
	9 p m	358	889	474	1,346.4	1,317	+20 9	+ 4
26	7 a m.	225	.781	388	1,320 6	1,318	— 4.9	+ 5
	2 p m	.312	.860	430	1,324 5	1,322	— 1 0	+ 9
	9 p m	396	30 010	552	1,357.7	1,332	+32 2	+19
27	7 a m .. .	.508	073	684	1,305 4	1,276	—20 1	—37
	2 p. m	567	167	.685	1,375 6	1,345	+50.1	+32
	9 p. m	635	.172	785	1,290.9	1,287	—34.6	—26
Mean......					1,325 5	1,313	31 6	22.6
Range					.. ..	....	131 9	94

TABLE XV—Continued

5.—DISTANCE OF GEYSER SPRINGS BELOW COLFAX

Day	Hour	Barometer Reading			Altitude by—		Residual by—	
		Summit	Colfax	Geyser Springs	Whitney	New Method	Whitney	New Method.
		Inches	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Feet.*
Sept 15	9 p m	23 215	27 398	28 398	993 0	1,004 3	+ 9 6	+ 5 0
16	7 a. m	.216	430	439	985 7	1,004.6	+ 2 3	+ 5 3
17	7 a m	.226	444	437	970 7	988 0	—12 7	—11 3
	9 p m	.277	457	452	984 1	1,000 5	+ 0 7	+ 1 2
Mean					983.4	999 3	6 3	5 7
Range							22 3	16 6

6.—DISTANCE OF LONG VALLEY BELOW COLFAX.

Day	Hour	Barometer Reading			Altitude by—		Residual by—	
		Colfax	Sacramento	Long Valley.	Whitney	New Method	Whitney.	New Method.
		Inches	*Inches*	*Inches*	*Feet*	*Feet*	*Feet*	*Feet*
Nov 8	7 a m	27 662	30.246	28 788	1,062 9	1,069	— 5 2	— 6
	2 p m	622	160	717	1,034 0	1,057	—34 1	—18
9	2 p.m	461	024	539	1,022 6	1,033	—45 5	—42
	9 p m	512	078	679	1,106 9	1,115	+38 8	+40
13	7 a m	536	079	684	1,091 9	1,107	+23 8	+32
	2 p m	540	.053	614	1,054 9	1,048	—13 2	—27
	9 p m	.517	084	662	1,103 7	1,094	+35.6	+19
Range					1,068 1	1,074 7	28 0	26 3
Mean							84 3	82 0

and the next gives the readings at the new station. The base station employed by Whitney is in each case a base station of the new method, and its locality is indicated by the title of the sub-table. The next two columns contain the altitudes determined by the two computations, and the final columns give the variations of the individual results from the means of their series. In the case of these six localities the barometric measurements are not checked by leveling, so that the only test of the methods is derived from the relative concordance of their results. Each determination was compared with the mean of its series and the difference was entered in the column of residuals.

The reader who compares this table with the corresponding tables on pages 99 to 109 of Whitney's treatise (second edition), will note certain discrepancies which need to be explained. It happened in several instances that the computations could not be made by the new method for certain hours for which Whitney had made them, by reason of the lack of observations at the second base station. Moreover, the writer was led by the internal evidence of the record to discard as erroneous certain observations at Colfax which had been retained in the earlier computations.* In each case the corresponding determinations by Whitney were omitted from the comparison. The changes wrought by these omissions were not prejudicial to his method, but on the contrary rendered his results more harmonious.

Four of the illustrative new stations are intermediate in altitude between the base stations to which they are referred; two, Camp 9 and Geyser Springs, are not. Four localities afford better results to the new method than to the old; two, Camp 9 and Gold Run, afford poorer. Upon the average, the residuals by the new method are 10 per cent smaller than by the old.

In Table XVI the results of the several comparisons are summarized. The second column indicates the points used as base stations in the several computations by Whitney's method, the indicated point being, in each case, one of the pair of bases employed in the corresponding computations by the new method. The second column shows the number of independent results compared. The fourth and fifth give for the two methods the average errors or residuals of the individual determinations. Where Colfax was the new station, each determination was compared with a result determined by spirit level, but in the other cases the standards were merely the means of individual determinations. The numbers in the last column were obtained by dividing those in the fifth by those in the fourth, and are the ratios of the errors incurred by the new method to the errors incurred by Whitney's. The footings show that in four hundred independent comparisons, falling into ten separate series, distinguished by locality or other conditions, the average error by the new method is 85 per cent of the average error by Whitney's method. Of the ten series, three exhibit ratios favorable to Whitney's method, and the remainder favor the new method. On the whole, the comparisons award the preference to the new method, but the preponderance is not great.

* The observer at Colfax, in September, 1870, appears to have been addicted to a mistake in the reading of the scale, which is frequently made by inexperienced barometric observers, and which produces an error in the record amounting to either the tenth or the twentieth of an inch. Pencil memoranda on the pages of the records loaned to me indicated that some mistakes of this sort had already been detected, but others were not marked. If the purpose of the computations had been the determination of the altitude merely, it would have been proper to assign the *probable* correction to those readings and use them, but for the actual purpose rejection seemed the only legitimate course.

Whitney states that while the majority of his tests exhibit a gain by the use of his tables, there are a few which show a loss. Two of these adverse examples he publishes (p. 109), and one of them—the determination of Geyser Springs—involves, as I believe, two errors by the Colfax observer. If the bad observations be rejected, or if they be assigned the highly probable correction of —0 05 inch, the unfavorable example is converted into a favorable one

The writer has been accustomed for several years, in the supervision of barometric work, to employ a check which effectually eliminates errors of this class. The portable barometer of Green, the instrument used by all American surveys, has two verniers, inseparably attached to each other but moving over different parts of the scale The upper one is used at low altitudes, the lower at high. The check is obtained by requiring the observer, after adjusting the proper vernier to the surface of the mercury, to read and record *both* verniers. The difference between the two readings is for each instrument a constant quantity, and each reading therefore checks the accuracy of the other

TABLE XVI

Summary of Errors of Altitude Determinations by Whitney's Method and by the New Method; derived from Tables XII, XIV, and XV.

New Station and Character of Data	Whitney's Base Station	Number of Results	Average Errors by— Whitney	New	Ratio
			Feet	*Feet*	
Colfax, triple means for twenty four months	Sacramento	72	10 8	11.6	1 07
Colfax, triple means for twenty-four months	Summit	72	15 2	11 6	76
Colfax, single observations in November, 1870	Sacramento	86	33 2	26 9	81
Colfax, single observations in November, 1870	Summit	86	55 9	26 9	48
Gold Run, single observations	Colfax	17	6 4	6 5	1 02
You Bet, single observations	do	22	10 8	7 2	67
Camp 9, single observations	do	11	12 8	14 2	1 11
Lakeport, single observations	Sacramento	25	31 6	22 6	71
Geyser Springs, single observations	Colfax	4	6 3	5 7	90
Long Valley, single observations	do	7	28 0	26.3	.94
Total		402	Mean		85

The computations were made and the tables were prepared for the purpose of comparing the *variations* in the results obtained by the two systems, these variations affording the best practicable measure of their relative precision. They serve another purpose, however, for they also show the relations between the mean altitudes determined by the two methods. In the determinations of Colfax there are no discrepancies, for these are based upon the very observations which served, on the one hand, to construct Whitney's table of corrections, and, on the other, to determine the constant of the new formula, and the application of the corrections and the formula could not fail to give *average* results in harmony with the original data and with each other; but when the methods are applied to other points, their determinations are found to exhibit constant differences. The altitudes given in Table XV are in each case differences in level between the indicated new station and the indicated base, the new station being in some cases higher than the base, and in other cases lower. In three of the six instances the mean difference in level determined by the new method is greater than the corresponding determination by the old, and in the remaining three it is less. If, however, we compare the altitudes of the new stations when referred to the sea level, or to any other uniform standard, we find that the divergence between the two series of results is always in the same direction.

This fact is exhibited in Table XVII, where each new station is referred to Colfax, the plus sign indicating that it is higher than Colfax, the minus sign that it is lower. The stations are arranged on the page in the order of their altitudes,—from Gold Run, 800 feet above Colfax, to Camp 9, 1,400 feet below. The figures in the right-hand column were obtained by subtracting the altitudes given by the new method from the corresponding altitudes obtained by Whitney, and show that in every case Whitney's method gives a higher determination to the new station than does the new. In the absence of determinations of the several points by level, it is impossible to lay the discrepancy to the fault of one method rather than the other, and the conditions of the computations, which were somewhat varied, throw no light upon the subject.

TABLE XVII

Comparison of Californian Altitudes, computed by Whitney and by the New Method

New Station	Base Stations		Month	Altitude above Colfax		(I) minus (II)
	Whitney	New Method		Whitney (I)	New (II)	
				Feet.	*Feet*	*Feet*
Gold Run	Colfax ..	Colfax and Summit ...	October .	+ 809	+ 781	+28
You Bet	.. do	.... do	November	+ 558	+ 546	+12
Geyser Springs	do . . .	. .. do	September	− 983	− 999	+16
Long Valley	do ...	Sacramento and Colfax .	November	−1,068	−1,075	+ 7
Lakeport . ..	Sacramento	.... do	October .	−1,074	−1,086	+12
Camp 9	Colfax ..	Colfax and Summit . .	September.	−1,383	−1,412	+29

The observations were made in three different months of the year 1870. In Whitney's computations Colfax was used as the base station in five cases and Sacramento in one: in three cases the new station was higher than the base, and in the remaining three it was lower. In the computations by the new method Colfax and Summit were the bases for four localities, and Sacramento and Colfax for the remaining two: in four cases the new station was intermediate in altitude between the bases; in the remaining two it fell below the lower base. The divergence of result is thus shown to be independent of the time of year and of the selection of base stations, retaining its character whether the base station for the old method lay above or below the new station, and whether the base stations for the new method included or excluded the new station.

It is not easy to see how a constant error, such as is here indicated, could be introduced by either hypsometric method. The corrections by each system are determined empirically from observations made in the very region where they are applied. Any change which might be made in the constant of the new formula would increase the discrepancies in some cases and diminish them in others, and no possible value could be assigned to it which would produce harmony in the results. The only competent explanation which occurs to the writer is *a priori* highly improbable. If the determination by the railroad surveyors of the vertical interspaces between the stations at Sacramento, Colfax, and Summit is grossly in error, and in such way that the estimated altitude of

Colfax is relatively 25 or 50 feet too low, the effect upon Whitney's determinations and those made by the new method would be such as to produce a divergence between them of the character and amount observed. It would be rash, however, to impugn the accuracy of the engineering work upon such grounds.

If all the altitudes published by Whitney were redetermined by the new method, it is quite possible that a satisfactory explanation would be reached; but lack of time forbids the pursuit of the subject, at least for the present.

Another relation of the two series of determinations is worthy of note, viz., their parallelism. An inspection of Tables XIV and XV, which exhibit the determinations from single sets of observations, shows that an exceptionally great error by one method usually corresponds to an exceptionally great error in the same direction by the other. In the former table there are 123 instances in which the errors incurred by the two methods have the same sign, and only 47 in which their signs are different. In the latter table the signs show 73 correspondences and only 18 discrepancies. The same relation appears when the series of results are plotted in the form of curves. In the case of each station the curves representing the errors by the two methods approach more nearly to parallelism than either of them approaches to coincidence with its mean line.

This relation does not hold good with the results contained in Table XII, which are based on monthly means; the correspondences of sign barely exceed in number the differences.

The proper interpretation of these peculiarities appears to be, first, that the devices employed in the two computations to eliminate error have been efficacious in the case of the same classes of error, and have agreed likewise as to the errors they have failed to reach; and, second, that the latter class of errors are partially eliminated by the use of monthly means. When we take into consideration the nature of the various possible sources of error, and the character of the corrective expedients employed by the two methods, it becomes evident that the chief error they both fail to eliminate from the determinations from single sets of observations is that of non-periodic gradient, and that the error with which they most successfully cope is the one arising from the diurnal variation of the density of air, due chiefly to temperature. The actual difference between the degrees of accuracy attained by the two methods may be taken, therefore, with some degree of confidence, to represent the difference in their success in eliminating errors due to temperature, and we are permitted to assume that the small residual temperature errors are masked in these results by the concurrent gradient errors. If the comparison could be repeated under such conditions that errors of gradient would not largely enter, it is probable that the slight actual advantage shown by the new method would be found to assume a relatively great importance.

COMPARISON WITH PLANTAMOUR'S METHOD.

Plantamour's hypsometric method resembles Whitney's in that it includes a table of corrections based upon a long series of observations; but the corrections are applied to the temperature observations and not to the altitudes, and there are other and important differences. The groundwork of his tables consists of eighteen years' continuous meteorologic observations at Geneva and the Great St. Bernard—a series of observations which his discussions have rendered classic, and which have made the most notable contributions alike to hypsometry and to meteorology. The Geneva Observatory is situated in a valley at the base of the Alps, and the Inn of St. Bernard stands high up in the mountains, with a great spur of Mont Blanc between. Their horizontal disance is 55 miles; their difference in altitude 2,070.3 meters, or about 6,792 feet.

For different months of the year and hours of the day Professor Plantamour computed the height of St. Bernard above Geneva from the means of the eighteen years' observations, making use not only of the barometric determinations of pressure and the thermometric determinations of temperature but also of the psychrometric determinations of humidity. He then compared each of these results with the actual altitude as determined by spirit level, and deduced from the comparison the correction necessary to be applied to the sum of the observed temperatures in order to eliminate the error. These corrections he embodied in a table which appears in the second part of Volume XVI of the Memoirs of the Geneva Society of Physics and Natural History. The table does not cover the entire year, but only the warmer months and the daylight hours, to which observations for the determination of altitude are usually restricted in the Alps. In the same place he describes his method of applying it, and publishes an extended series of illustrative examples, in each of which the new station was within or near the Alps, and either Geneva or St. Bernard was used as the base station. A separate computation was made for each observation at each new station, and the data and results are given in full, so that his method is completely exemplified. His procedure with each group of synchronous observations was as follows:

The barometer reading at the new station was first compared with the reading at Geneva, and an approximate difference of altitude was deduced in the usual manner. To this approximate altitude corrections for temperature, moisture, and gravitation were applied in the customary way, except that corrected temperatures at the two stations were substituted for the observed temperatures. The manner of correcting the temperatures was peculiar and needs to be given in detail. Since dense air acquires heat from the ground more rapidly than rare air, he ascribed a greater local variation to temperature at Geneva than at

St. Bernard, and assigned it a larger measure of correction. The tabulated correction is a correction to the sum of the two temperatures, and two-thirds of this correction was assigned to the Geneva temperature, leaving the remaining third to be applied to that observed at St. Bernard. Correspondingly, the temperature observed at the new station was increased or diminished by two-thirds of the tabulated correction if the station lay in the vicinity of Geneva, and by one-third of the tabulated correction if its altitude was nearly the same as that of St. Bernard. If its position was midway it received the half of the total correction, and if it had an altitude greatly in excess of that of St. Bernard the correction applied was less than one-third, or even in some cases nothing.

The difference in altitude of the new station and Geneva having been thus computed, a similar computation was made of the difference in altitude of the new station and St. Bernard, and in the final result these two determinations were given weights according to the vertical position of the new station, the determination by means of the nearer base station being considered the more trustworthy.

Where two or more observations were made at any new station, care was taken to assign to the result from each one a weight dependent upon the atmospheric conditions at the time the observation was made. For this purpose a computation of the altitude of St. Bernard above Geneva was made from the observations at the same hour, and from this was deduced the amount of change which would need to be made in the sum of the observed temperatures at these places in order to correct the error of the determined altitude. This temperature correction was then compared with the temperature correction of the table for the hour and month, and consideration was given to the force and direction of the wind and to the cloudiness or clearness of the sky. Since the tabulated correction was derived from the mean of many days, or from the average day, it must evidently be inapplicable to days which differ from the average standard. For clear and still days it is too small; for cloudy or very windy days it is too large; and an inspection of the recorded weather at the time of observation enables the computer to judge whether the temperature correction necessary to deduce the true altitude differs from the tabulated correction in a way that can be accounted for by the local conditions of sky and wind. If it can be so accounted for, there is presumptive evidence that the general condition of the air column between Geneva and St. Bernard is one of equilibrium, and that the altitude of the new station deduced at that time is entitled to receive a large weight. If it cannot be thus accounted for, then a gradient must be supposed to exist between those points, and the deduced altitude of the new station has less value. In assigning it a weight, Plantamour gave consideration, first, to the amount of gradient as indicated by the temperature corrections, and, second, to the geographic position of the station with reference to the two bases,—a matter in which the judgment of the computer was brought into play, and to which a knowledge of the geography and climate of the country was an important adjunct.

It will be seen that this barometric system is absolutely dependent upon a long preliminary series of observations at the pair of stations to be afterward used as bases. It is as strictly a local system as Professor Whitney's, and while in the skillful hands of Plantamour it undoubtedly afforded results of a high degree of accuracy, it demands in its use the application of so much knowledge and acumen that it can hardly be intrusted to the ordinary computer.

The series of examples published by Plantamour includes thirty-nine new stations, at some of which the barometer was read once only, but at most of which it was read from two to twenty-two times. For the purpose of comparative computation, a selection was made by the writer of the six stations which gave opportunity for the greatest number of individual comparisons, and the altitudes of these stations were computed by the new method, a separate result being obtained for each observation. From these separate results a weighted mean for the altitude of each station was derived, the weights being determined simply by the wind factor. Since the winds which accompany cyclonic movements of the atmosphere are approximately proportional in force to the gradients with which they are associated, gradient errors are liable to be greater during the existence of a high wind. The horizontal distances between the base stations and new stations under consideration are so great that the accuracy of the determinations is liable to be seriously impaired by high gradients. The winds are indicated in the record of observations by a notation which calls a calm 0 and a high wind 3. In the deduction of the means, all the results obtained when the strongest wind at either station was 1 were ascribed a weight of unity. Results affected by a wind with the force 2 or 3 were ascribed weights of one-half or one-third respectively.

In Table XVIII the first column gives the new stations and indicates the days and hours at which the observations were made. The second column shows for each hour the altitude of the station above the sea, expressed in meters, as deduced by the new method. The third column gives the remainders obtained by subtracting the weighted mean altitude for each station from the individual determinations. The fourth and fifth columns contain Plantamour's determinations of the same altitudes at the same hours from the two bases taken separately, Geneva being the base for all determinations in the fourth column and St. Bernard for all in the fifth. The numbers of the sixth and seventh columns were obtained by subtracting from the numbers of the fourth and fifth their respective weighted means.

TABLE XVIII.

Altitude Determinations in the Alps, from Observations published by Prof. E. Plantamour. (All Altitudes are referred to Sea Level)

Place and Time of Observation	Altitude by New Method	Deviation from Weighted Mean	Altitude by Plantamour, the Base Station being—		Deviation from Weighted Mean	
			Geneva	St. Bernard	Geneva	St Bernard
EVOLÉNA						
1859	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*
Sept 1—2 p m	1,380.1	+ 6 3	1,398 0	1,373 2	+19 4	— 5 4
1—4 p m	1,385 0	+11 2	1,402 3	1,381 9	+23 7	+ 3 3
1—6 p m	1,374 8	+ 1 0	1,389 7	1,376 6	+11 1	— 2 0
1—8 p m	1,366 1	— 7 7	1,377 2	1,370 5	— 1 4	— 8 1
2—6 a m	1,367 4	— 6 4	1,385 0	1,357 0	+ 6 4	—21 6
2—8 p m	1,371 1	— 2 7	1,382 9	1,367 4	+ 4 3	—11.2
3—6 a m	1,372 4	— 1 4	1,379 5	1,378 5	+ 0 9	— 0 1
Weighted Mean	1,373 8	5 2	1,378 6		9 6	7 4
Range	...	18.9	...		24 5	24 9
HOSPICE DE LA GRIMSEL						
1858						
July 31— 8 p. m	1,862.5	—13 6	1,869 1	1,868 0	— 8 2	— 9 3
31—10 p m	1,867.0	— 9 1	1,875.7	1,870 4	— 1.6	— 6 9
1859						
Sept 7—7 p. m	1,876 3	+ 0 2	1,883 5	1,879 2	+ 6 2	+ 1 9
7—8 p. m	1,878 8	+ 2 7	1,880 3	1,882.3	+ 3 0	+ 5 0
7—9 p m	1,880.5	+ 4 4	1,882.2	1,883 2	+ 4 5	+ 5 9
8—6 a m	1,877 3	+ 1 2	1,871 2	1,877 6	— 6 1	+ 0 3
8—6 p. m	1,873 3	— 2 8	1,882 6	1,874 9	+ 5 3	— 2 4
8—8 p m	1,877 9	+ 1 8	1,888.4	1,880.5	+11 1	+ 3 2
9—6 a m	1,876.1	0 0	1,879 5	1,875 2	+ 2 2	— 2.1
Weighted Mean	1,876 1	4.0	1,877 3		5 4	4 1
Range	...	18 0	...		19 3	15.2
SERRAVAL						
1852						
July 27— 9 p. m	833 3	— 3 6	841.2	...	+ 1 0	...
27—10 p m	835 3	— 1 6	842 5	...	+ 2 3	...
28— 7 a m	840 0	+ 3 1	846 4	...	+ 6 2	...
28— 8 a m	841 9	+ 5 0	847 4	...	+ 7 2	...
28— 2 p m	836 6	— 0 3	841 8	...	+ 1 6	...
28— 7 p m	826 7	—10 2	830 5	...	— 9 7	...
28— 8 p m	827 1	— 9 8	831 5	...	— 8 7	...
28— 9 p m	830 2	— 6 7	834 9	...	— 5 3	...
28—10 p m	831 9	— 5 0	838 8	...	— 1 4	...
29— 8 a m	836,0	— 0 9	838.9	...	— 1 3	...
29—10 a m	836 3	— 0.6	841 6	...	+ 1 4	...
29—12 m	836 4	— 0 5	840 4	...	+ 0 2	...
29— 6 p m	825 2	—11 7	825 6	...	—14 6	...
29— 8 p m	832 5	— 4 4	834 1	...	— 6 1	...
29—10 p m	832.8	— 4 1	834 7	...	— 5 5	...
30— 6 a m	834 0	— 2 9	837 4	...	— 2 8	...
1853.						
Aug 19—12 m	850 3	+13 4	848 4	...	+ 8.2	...
19— 2 p m	844 0	+ 7.1	842 8	...	+ 2.6	...
19— 3 p m	842 3	+ 5 4	841 6	...	+ 1 4	...

TABLE XVIII—Continued.

Place and Time of Observation	Altitude by New Method	Deviation from Weighted Mean	Altitude by Plantamour, the Base Station being— Geneva.	St Bernard	Deviation from Weighted Mean Geneva	St Bernard.
SERRAVAL—Continued						
1853	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*
20— 8 p m..	835 6	— 1 3	831 3	. .. .	— 8 9	.. ..
21— 8 a m	845 1	+ 8 2	845 9	....	+ 5 7	....
21—12 m	847 8	+10 9	846. 2	....	+ 6 0	....
Weighted Mean ..	836 9	5 3	840 2	....	4 9	....
Range	....	25. 1	....	....	22 8	....
CHAMOUNIX						
1857						
July 2— 8 a m	1, 039 4	— 0 5	1, 045. 4	1, 041 0	+ 1 3	— 3. 1
2—12 m	1, 043 8	+ 3 9	1, 051. 6	1, 040. 3	+ 7 5	— 3. 8
2— 2 p m	1, 040. 2	+ 0 3	1, 046. 4	1, 042 9	+ 2 3	— 1. 2
2— 4 p m	1, 037 8	— 2 1	1, 041 6	1, 050 8	— 2. 5	+ 6 7
2— 9 p m	1, 036 3	— 3 6	1, 044 0	1, 034 3	— 0 1	— 9 8
3— 6 a. m	1, 038 1	— 1 8	1, 048 7	1, 029 4	+ 4 6	—14 7
3—10 a. m	1, 042 3	+ 2 4	1, 053 1	1, 038 7	+ 9 0	— 5 4
3— 9 p m	1, 036 3	— 3 6	1, 039. 2	1, 046 2	— 4 9	+ 2 1
4— 6 a m	1, 042 3	+ 2 4	1, 039 5	1, 051 5	— 4 6	+ 7 4
4— 4 p m .. .	1, 043. 7	+ 3 8	1, 048 1	1, 041 5	+ 4 0	— 2 6
4—10 p m	1, 039 0	— 0 9	1, 035 8	1, 052 5	— 8 3	+ 8 4
Weighted Mean . .	1, 039 9	1. 4	1, 044. 1		4 5	5. 9
Range	....	7. 5	....		15 8	23 1
BOURG ST PIERRE						
1855						
July 28— 6 p m	1, 636 2	— 2 6	1, 650 5	1, 635 3	+10 4	— 4 8
28— 8 p. m	1, 635 2	— 3 6	1, 644 5	1, 136. 8	+ 4 4	— 3 3
29— 6 a m .	1, 635 8	— 3 0	1, 644 8	1, 636 5	+ 4 7	— 3 6
29—10 a. m	1, 637 2	— 1 6	1, 644 8	1, 635 4	+ 4 7	— 4 7
29— 6 p m . . .	1, 636 8	— 2 0	1, 636 3	1, 642 3	— 3 8	+ 2 2
29— 8 p m ...	1, 638 2	— 0 6	1, 641 8	1, 641. 0	+ 1 7	+ 0 9
30— 6 a. m .. .	1 635 9	— 2 9	1, 639 4	1, 639 2	— 0 7	— 0. 9
30— 8 a m	1, 639 6	+ 0 8	1, 646 6	1, 639 4	+ 6 5	— 0 7
30— 2 p m	1 644 9	+ 6 1	1, 661 5	1, 639 6	+21. 4	— 0 5
30— 8 p m .	1, 636 5	— 2. 3	1, 639 6	1, 644. 3	— 0 5	+ 4 2
31— 6 a. m ..	1, 640 4	+ 1 6	1, 639 9	1, 643 0	— 0 2	+ 2 9
31— 8 a. m	1, 642 4	+ 3 6	1, 637 4	1, 640 5	— 2 7	+ 0 4
Aug 5— 6 p m	1, 633 7	— 5 1	1, 648 8	1, 635 5	+ 8 7	— 4 6
5— 8 p m .. .	1, 629 9	— 8 9	1, 645 6	1, 630 6	+ 5 5	— 9 5
5—10 p m	1, 632 0	— 6 8	1, 643 5	1, 634 7	+ 3 4	— 5 4
6— 8 a m.	1, 638. 3	— 0 5	1, 634 4	1, 647 0	— 5 7	+ 6 9
6—10 a. m	1, 640 4	+ 1 6	1, 642. 6	1, 638 3	+ 2 5	— 1 8
6—12 m	1, 643 3	+ 4 5	1, 646 4	1, 639 6	+ 6 3	— 0 5
6— 2 p m.	1, 641 1	+ 2. 3	1, 648 5	1, 635 3	+ 8 4	— 4 8
7— 6 p m.	1, 639 3	+ 0 5	1, 648 5	1, 640 2	+ 8 4	+ 0 1
7— 8 p m	1, 641 9	+ 3 1	1, 650 3	1, 641. 9	+10 2	+ 1 8
8— 8 a. m........ ..	1, 643. 5	+ 4. 7	1, 653. 4	1, 640 3	+13 3	+ 0 2
Weighted Mean ..	1, 638. 8	3 1	1, 640 1		6 1	2 9
Range	....	15. 0	....		27. 1	16 4

TABLE XVIII—Continued.

Place and Time of Observation	Altitude by New Method.	Deviation from Weighted Mean	Altitude by Plantamour, the Base Station being—		Deviation from Weighted Mean	
			Geneva.	St. Bernard	Geneva	St. Bernard
CANTINE DE PROZ.						
1855.	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*
July 31—10 a. m	1,808.1	+ 1 9	1,805 1	1,806 6	— 3 8	— 2 3
31—12 m	1,811.8	+ 5 5	1,806.4	1,810 9	— 2.5	+ 2 0
31— 2 p m	1,809 0	+ 2 8	1,806 3	1,810 4	— 2 6	+ 1 5
31— 6 p m	1 805 7	— 0 5	1,801 5	1,812 2	— 7 4	+ 3 3
31— 8 p m	1,803 5	— 2 7	1,799 2	1,808 9	— 9 7	0 0
Aug 1— 6 a. m	1,806.4	+ 0 2	1,791 3	1,812 7	—17 6	+ 3 8
1— 8 p m	1,799.4	— 6 8	1,788 2	1,808 5	—20 7	— 0 4
2— 6 a. m.	1,805 4	— 0 8	1,785 7	1,815 5	—23 2	+ 6 6
6— 4 p m	1,806 9	+ 0 7	1,809 3	1,807 9	+ 0 4	— 1 0
6— 6 p m	1,807.7	+ 1 5	1,806 9	1,811 6	— 2 0	+ 2 7
6— 8 p m	1,805 0	— 1 2	1,797 3	1,809 6	—11.6	+ 0 7
Weighted Mean	1,806 2	2 2	1,808 9		9 2	2 2
Range	......	12 3	....		23 6	8 9

In this case, as in the case of Colonel Williamson's observations, there is no absolute standard of comparison. The individual determinations of each station by the new method are compared with their own weighted mean, and the individual determinations of each station by Plantamour's method are compared with the weighted mean deduced by him. It would be more satisfactory if it were possible to compare each determination of altitude with an independent determination made by more precise methods, but as this is impossible, the only practicable criterion of precision is the internal harmony of each series of results. This is shown in the table by the lines entitled "Mean" and "Range", where the average residual and the range of variation are exhibited.

In Table XIX the *mean residuals* shown by the preceding table to appertain to the determinations of the altitudes of the several stations, are brought together, and with them are conjoined the approximate heights of the air columns comprised between the new stations and the two bases. In the space assigned to Plantamour's results the first column exhibits the mean residuals of those determinations in which he used Geneva as a base station; the second column exhibits the corresponding means for the results obtained with the use of St. Bernard as a base station; and the third column shows the mean residuals resulting from the use of both stations, its numbers being the arithmetic means of the corresponding numbers in the first and second columns. It will be observed that each of the numbers of this third column is greater than the corresponding number of the final column, which shows the mean residuals by the new method, while of the eleven numbers in the preceding two columns there are only two which are less than the corresponding numbers in the column derived from the results by the new method. That is to say, in eleven sets of comparative computations, two only show smaller variations by Plantamour's method. There is one which shows the same variation, and the remaining eight show greater variations. The general means at the bottom of the table give 5.7 meters as the average residual of the entire series of Plantamour's results given in Table XVIII, and 3.5 meters as the average residual of the corresponding series of results by the new method, and it is probable that the ratio of 3 to 5 may fairly be taken as indicative of the relative precision of the two methods.

TABLE XIX.

Summary of Altitude Determinations in the Alps, showing Average Variation of Results.

New Station	Approximate Vertical Space between New Station and—		Number of Results	Mean Residual			
				By Plantamour, from—			By New Method
	Geneva	St Bernard		Geneva.	St Bernard	Geneva and St Bernard	
	Meters	*Meters*		*Meters.*	*Meters*	*Meters*	*Meters*
Evoléna	970	1,100	7	9 6	7 4	8 5	5.2
Hospice de la Grimsel	1,470	600	9	5.4	4 1	4 7	4 0
Serraval	430	1,640	22	4 9	......	......	5 3
Chamounix	630	1,440	11	4 5	5 9	5 2	1 4
Bourg St Pierre	1,230	840	22	6 1	2 9	4 5	3 1
Cantine de Proz	1,400	670	11	9 2	2 2	5 7	2 2
Mean	1,020	1,050	.....	6 6	4 5	5 7	3.5

TABLE XX

Summary of Altitude Determinations in the Alps, showing Range of Results

New Station.	Vertical Space between New Station and—		Range of Variation of Computed Altitudes			
			By Plantamour, from—			By New Method
	Geneva.	St Bernard	Geneva	St Bernard	Geneva and St Bernard	
	Meters.	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*
Evoléna	970	1,100	24 5	24 9	45 3	18 9
Hospital de la Grimsel	1,470	600	19 3	15 2	20 4	18 0
Serraval	430	1,640	22 8	.....	.....	25.1
Chamounix	630	1,440	15 8	23.1	23 7	7 5
Bourg St Pierre	1,230	840	27 1	16 4	30 9	15 0
Cantine de Proz	1,400	670	23 6	8 9	29 8	12 3
Mean	1,020	1,050	22 2	17 7	30 0	16 1

Table XX gives a similar summary of the indications to be derived from the *range of variation* of the several series of determinations.

Here again the advantage appears to be with the new method, but less decidedly. Of the eleven cases of comparison there are three in which Plantamour's results exhibit a smaller range than their competitors, and eight in which their range is greater, while in the line of general means their ratio is approximately that of 4 to 5, the difference being in favor of the new method.

TABLE XXI.

Summary of Altitude Determinations in the Alps: Comparison of Computed Altitudes.

New Station	Computed Height above Sea Level				Excess of Plantamour's Results above those by New Method		
	By Plantamour, from—			By New Method (weighted mean) (*D*)			
	Geneva (mean) (*A*)	St Bernard (mean). (*B*)	Geneva and St Bernard (weighted mean) (*C*)		Geneva (*A–D*)	St Bernard (*B–D*)	Geneva and St Bernard (*C–D*)
	Meters.	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*
Serraval	840.2	....	840.2	836.9	+ 3.3	..	+ 3.3
Chamounix	1,044.9	1,042.7	1,044.1	1,039.9	+ 5.0	+ 2.8	+ 4.2
Evoléna	1,387.8	1,372.1	1,378.6	1,373.8	+ 14.0	− 1.7	+ 4.8
St Pierre	1,645.0	1,634.4	1,640.1	1,638.8	+ 6.2	− 4.4	+ 1.3
Proz	1,799.7	1,810.4	1,808.9	1,806.2	− 6.5	+ 4.2	+ 2.7
Grimsel	1,879.2	1,876.8	1,877.3	1,876.1	+ 3.1	+ 0.7	+ 1.2
Mean	......	......	......		+ 4.2	+ 0.3	+ 2.9

It is instructive to extend the comparison one step farther and place in juxtaposition the absolute determinations of altitude by the two methods. This is done in Table XXI, where for each station there are given, first, the mean of all Plantamour's determinations with Geneva as a base; second, the mean of all his determinations with St. Bernard as a base; third, Plantamour's weighted mean deduced from the discussion of all his determinations from both bases; and, fourth, the weighted mean deduced by the new method. In three additional columns a series of residuals are given, which were obtained by subtracting the mean altitude by the new method from the several means obtained by Plantamour's method. From these residuals it appears, first, that the determinations of height by the new method correspond on the average with Plantamour's determinations based upon St. Bernard, while they are decidedly smaller as a rule than Plantamour's determinations with Geneva as a base; second, that in every instance the determination by the new method falls below Plantamour's weighted mean, the average difference being about three meters. This latter result indicates some defect of a constant nature in one system or the other. If it is in Plantamour's, it probably lies in his somewhat arbitrary assumption that two-thirds of his temperature correction should be assigned to the lower station and one-third to the upper. If it pertains to the new method, it undoubtedly inheres in the constant, the value of which has not yet been satisfactorily established. That value of the constant which would produce the best accord with Plantamour's results is 330,000 feet, being 160,000 feet less than the one provisionally adopted.

This test and the third of the series of tests derived from Whitney's observations are especially valuable because they involve that variety of station which must always be met in the actual use of any barometric method. The comparisons by means of Williamson's and Whitney's permanent stations are in danger of being vitiated by errors of local origin.

A further interest is given to the Alpine test by the fact that Plantamour distinctly recognizes the principle upon which the new method is based, but applies it in a different way. He even goes so far as to compute for each hour of observation at the new station the difference in altitude of the two base stations *for the purpose of ascertaining the condition of the intervening air column;* but instead of using this information directly, he endeavors to apply it indirectly by investigating the temperature and gradient. He attacks the problem in detail instead of in its totality, and the fact that his result is comparatively unsatisfactory is to be ascribed to the almost limitless complexity of the factors involved, eluding the analysis even of so skillful an investigator as the Genevan professor.

COMPARISONS BY MEANS OF OBSERVATIONS AT MOUNT WASHINGTON.

It has already been stated that the preceding series of computations were undertaken because they afforded a means of comparing the work of the new method with the work of other barometric methods as exhibited by their authors and advocates. The value of the result is somewhat impaired, however, by the fact that none of the groups of stations are strictly appropriate to the execution of such a test. Placerville and Hope Valley are 46 miles apart, Summit and Sacramento 77 miles, Geneva and St. Bernard 55 miles; and each of these distances introduces into the problem a large element of gradient, alike annual, perennial, and non-periodic. Neither the new method nor any of the three with which it has been compared undertakes to eliminate this gradient, and the presence in all the computations of a considerable error derived from this source cannot but have the effect of obscuring the actual accomplishment of each scheme of devices in the elimination of the errors to which it is theoretically adapted. Search was therefore made for a locality where the test might be repeated with base and new stations all comprised within a small radius, so that no considerable gradients, aside from those with a diurnal period, could enter; and Mount Washington was found to answer the purpose.

In the year 1873 the United States Signal Corps, under the direction of the late General A. J. Myer, conducted a series of hourly observations extending through the month of June at four stations upon the summit and flank of Mount Washington. The vertical space between the highest and lowest stations was about 3,600 feet, and the horizontal distance 3 miles. The observations were published in full in the Annual Report of the Chief Signal Officer, and numerous accessory data pertinent to the purpose of the writer have been furnished him from the original manuscript records through the courtesy of the present chief, General W. B. Hazen.

The stations are indicated by numbers, Station 1 being upon the summit of the mountain, Station 4 at its base, and Stations 2 and 3 upon the intervening slope. The altitude of Station 1 above the ocean has been determined by spirit level to be 6,285.4 feet,* but the other stations have not been connected by leveling. By means of simultaneous barometric readings at Station 1, Station 4, and Portland, Maine, the altitude of Station 4 has been computed by the new method, and with Station 1 and Station 4 as bases the altitudes of the intervening stations have been similarly computed. The relations of the four stations appear by the following table†:

	Above 2.	Above 3	Above 4
Station 1	779	2,355	3,607
Station 2	....	1,576	2,828
Station 3	....	....	1,252

The month of June, 1873, witnessed no notable storm, but its variety of weather nevertheless left room for selection; and the meteorologic record was carefully examined for the purpose of choosing the portion of it most favorable for hypsometric determinations. A period of eight days, beginning with the 22d and closing with the 29th, was selected as one of exceptional quiet, involving less wind than any similar period in the month, and therefore offering a series of observations comparatively free from non-periodic gradients. The observations for these days were plotted upon section paper for convenience of scrutiny, and all which revealed themselves as anomalous were investigated for the detection of errors of observation or reduction. A number of errors

* This is the altitude reported in connection with the record of observations. Its accuracy has recently been brought in question by the Signal Office, and it is possible that a correction to it will be made.

†The determinations given in the table were made at the commencement of this investigation; and some of the observations on which they are based were afterward ascertained to be untrustworthy. They are therefore not the best which could be deduced. The work was not repeated, first, because a more accurate set of determinations could not modify the result of the comparative test, and second, because the uncertainty affecting the altitude of the summit station rendered a satisfactory set of determinations impracticable.

of both kinds were detected and corrected,* and the observations were then made the basis of a series of computations for the purpose of illustrating the relative precision of different hypsometric methods.

* To any person who in the future may have occasion to use the observations published on pages 687 to 757 of the Annual Report of the Chief Signal Officer for 1873, it will be advantageous to note the following *corrigenda.* They all apply to the numbers in the column headed "Corrected barometer."

Page 687, Station 2, 1 a. m., for "24.633" read 24.731
Page 687, Station 2, 4 a. m., for "24.784" read 24.684.
Page 691, Station 2, 10 p. m., for "24.571" read 24.671
Page 698, Station 1, 8 p. m., for "23.541" read 23.521.
Page 705, Station 2, 4.57 p. m., for "24.500" read 24.700.
Page 705, Station 1, 7 p. m., for "24.020" read 24.024.
Page 707, Station 1, 7 a. m., for "24.993" read 23.993
Page 711, Station 3, 3 a. m., for "28.856" read 25.856.
Page 713, Station 2, 8 p. m., for "24.450" read 24.480
Page 713, Station 3, 4 a. m., for "26.999" read 25.999
Page 713, Station 2, 6 a. m., for "24.442" read 24.542.
Page 714, Station 1, 1 p. m., for "23.890" read 23.878
Page 719, Station 4, 12 m., for "27.240" read 27.249.
Page 719, Station 4, 4.57 p. m., for "27.081" read 27.181
Page 734, Station 1, 12 p. m., for "23.469" read 23.489
Page 735, Station 4, 4 a. m., for "23.496" read 23.498
Page 739, Station 3, 1 a. m., for "26.111" read 26.121.
Page 739, Station 4, 4 a. m., for "27.367" read 27.387
Page 742, Station 3, 5 a. m., for "26.183" read 26.173
Page 742, Station 1, 7 a. m., for "23.942" read 24.042
Page 743, Station 3, 4.57 p. m., for "26.154" read 26.194
Page 743, Station 3, 6 p. m., for "26.100" read 26.200
Page 746, Station 3, 5 a. m., for "26.489" read 26.389
Page 748, Station 2, 2 a. m., for "24.781" read 24.739
Page 749, Station 1, 11 a. m., for "24.985" read 23.985
Page 749, Station 1, 12 m., for "24.965" read 23.965.
Page 749, Station 2, 1 p. m., for "24.733" read 24.633
Page 751, Station 4, 2 a. m., for "27.112" read 27.012
Page 752, Station 1, 1 p. m., for "27.742" read 23.742

In all these cases the error of the printed numbers is demonstrated by comparing them with the published uncorrected barometer readings and the published readings of the attached thermometer. There are, however, a number of instances in which the published figures are manifestly erroneous, yet do not afford the data for their own correction. In every such case the recorded reading was rejected, and one more accordant with its companions in the series was substituted for use in the computations. These changes were made sparingly and cautiously, and it is believed that no aberration of natural origin has been referred to an error of observation,—but that, on the contrary, a large number of errors of observation were passed by. Only three of these arbitrary changes affect observations of the eight-day series described in the text in this place, but all of them affect the data of computations made for some portion of the present paper. In the following enumeration no attention is paid to the figures of the column headed "Barometer," although they need to be similarly modified. The quoted figures are from the column headed "Corrected barometer."

Page 688, Station 1, 11 a. m., for "23.827" substitute 23.877
Page 689, Station 1, 8 p. m., for "23.746" substitute 23.846.

In the conduct of this inquiry two limits were recognized. In the first place, since the new method aspires to supersede antecedent methods only in the performance of such work as falls to the lot of surveys—work in which many new stations are to be determined in a restricted area—no methods were considered which appeared inapplicable to that object. The sole case considered was that in which a single observation at a new station is compared with a single observation at a base station, or at each of several base stations, with such aid as may be derived from the other observations of a continuous series at the base stations. Restricted as this problem appears to be, it is nevertheless the one which practically arises in nine-tenths of the hypsometric work performed with the barometer.

The second limit confined attention to methods known to be actually in use, for manifestly it would be a work of supererogation to undertake in this place to test the efficiency of those tentative methods which have not in practice won a place for themselves.

The methods in actual use which are adapted to the ordinary needs of geographic work fall readily into two classes, the first of which employs in the computations only the data afforded by the field notes, while the second adds to these data certain empiric corrections derived from long series of observations. Of the first group, the method of Williamson is a representative; and since, in the opinion of the writer, it has no superior in its class, it was selected as a typical example to be used in the comparison. The second class includes among others the systems of Plantamour and Whitney; and while its members differ somewhat in their manners of deducing and applying empiric corrections, they attain so nearly the same result that it matters little which one is selected as representative. The one already described as devised by Whitney was employed, the selection being determined chiefly by the fact that his method of procedure is so fully and clearly set forth that it can be repeated without danger of mistake.

Page 689, Station 4, 8 p. m., for "27.208" substitute 27.228.
Page 698, Station 1, 6 p. m., for "23 561" substitute 23.511.
Page 700, Station 2, 4.57 p. m., for "24 452" substitute 24.352
Page 707, Station 1, 6 p. m., for "24.016" substitute 23 916
Page 714. Station 1, 10 a m, for "23.925" substitute 23.825
Page 718, Station 1, 7 a m., for "24.012" substitute 23.912
Page 720, Station 1, 1 a. m., for "23.910" substitute 23.810.
Page 720, Station 1, 2 a m, for "23.905" substitute 23.805
Page 721, Station 2, 11 a m, for "24 440" substitute 24.460
Page 722, Station 4, 9 p m., for "27 072" substitute 27.052
Page 732, Station 4, 1 a. m., for "26.909" substitute 26.809
Page 733, Station 2, 6 p. m., for "24.219" substitute 24.241
Page 734, Station 1, 10 p m., for "23.491" substitute 23.541.
Page 735, Station 4, 6 a. m., for "26.961" substitute 27.011.
Page 735, Station 1, 7 a. m., for "23.646" substitute 23.546
Page 739, Station 4, 3 a. m., for "27.342" substitute 27.372.
Page 745, Station 2, 12 m., for "24.906" substitute 24.945.
Page 747, Station 2, 3 p. m., for "24.926" substitute 24.860.

The restriction of the problem to the case in which only a single observation at the new station is employed made it impracticable to apply Williamson's method in its entirety, for he introduces a correction for the diurnal oscillation of the barometer at the new station, and that correction can be determined with accuracy only by the aid of a series of observations of some extent. He does not recommend the occupation of each individual station for the period necessary to determine its diurnal pressure cycle, but uses instead the known cycle of some other station conceived to be characterized by the same conditions; and there is a sort of uncertainty attaching to this practice which it was impracticable to represent in this series of computations. By omitting all correction for diurnal oscillation, an apparent injustice is done Williamson's method: but if the observations were corrected by means of diurnal curves derived from the *same* observations, an equally unfair advantage would be given, because no such facilities are afforded in practical hypsometry. The uncertainty attaching to the substitution of the diurnal pressure curve of one locality for that of another is so great that I am disposed to doubt the advantage of Williamson's "horary correction" in all cases where the new station affords but a single observation.

Failing thus to apply all of Williamson's rules in the computations, I have hesitated to connect his name with the results. Suffice it to say that while it is probable that they fairly represent the application of his system to the postulated case, it is nevertheless possible that in general practice his method would appear in a more favorable light.

In the application of Whitney's method there was no similar difficulty. The Californian tables were not employed, because their use is restricted by their author to the vicinity of the Sierra Nevada, but a special table was constructed for the time and place in a manner presently to be detailed.

The observations having been freed from error, so far as practicable, and the plan of comparison having been arranged, the computations were then performed in the following manner:

In the first place the altitude of Station 2 was computed by the new method, making use of Stations 1 and 4 as bases, and a separate determination was made for each hour of the day for the period of eight days, making 192 independent determinations. The same work was then repeated with Station 3, giving a total of 384 determinations by the new method.

Colonel Williamson's method was then applied to the determination of the heights of Stations 2 and 3, first with Station 1 as a reference station or base and then with Station 4. The total number of these determinations was 768, and each of them was comparable with one of the determinations by the new method. The method of computation was as follows: An approximate difference of altitude was first derived from the barometer readings by the aid of Williamson's Table D_1. To this a correction for temperature was then applied, the correction being furnished by his Table D_{II}, and being determined by the mean temperature of the day instead of the temperature of the hour. That is to say, for each of the eight days computations were made of the mean temperatures at the base station and new station, and the half sum of these temperatures was taken to represent the mean temperature of the air column for *each* of the twenty-four hours of the day. The correction for moisture was determined from the means of the psychrometer readings for each day, and was found to be so nearly uniform that no distinction was necessary, and the same correction was therefore applied to all the determinations of each station. The corrections for gravity were regarded as constant at each station through the entire period.

In the application of Whitney's method the first process was the same as in the case of Williamson's, but in the determination of the correction for temperature, the thermometer readings at the two stations at the individual hours were employed instead of the daily means. No correction was applied for humidity, and the corrections for gravity were regarded, as before, as constant. Finally a special empiric correction was added, which had been derived from the observations for the entire month in the following manner: Monthly means were taken of observations of pressure and temperature made at Station 1 and Station 4, at the hours of 3, 6, 9, and 12 a. m. and 3, 6, 9, and 12 p. m., and from these means eight values of the difference of altitude were obtained, the method of computation being identical with that afterward employed for the individual observations. These values were compared with the assumed altitude (3,607 feet) and the differences were called corrections. By the aid of a plotted curve their irregularities were slightly diminished and values were interpolated for the remaining hours of the twenty-four. These corrections were applicable directly to computations of the difference in altitude of Stations 1 and 4, and in applying them to the smaller intervals involved in the determination of Stations 2 and 3 they were proportionately diminished.

It will be observed that the stations upon which the table of corrections was based are the same stations afterward used as bases or reference stations in the computations, and it is also true that the new stations lie in the direct line between them. The series of observations affording the table include the series of observations to which the corrections were applied. The table, therefore, was not merely adapted to the White Mountains and to the average month of June, but to the specific locality and to the individual June from which the illustrative computations were made. It cannot often occur in the use of a system involving empiric corrections that the conditions under which it is applied are so favorable.

In the comparison of the various results of these computations the lack of an independent and trustworthy standard had again to be regretted, and no better measure of precision was afforded than the internal harmony of the several series of determinations. The mean of each series was calculated independently and was then subtracted from the several individual determinations. The series of differences thus obtained were then added so as to show the sum of each series independently of sign, and the several sums were divided by the number of terms. Each quotient gave the mean residual of a series of 192 determinations. The publication of the individual determinations of altitude is omitted by reason of their great number, and because the absence of a standard determined by leveling deprives them of any permanent value. The mean residuals are given in Table XXII. Each of the intermediate stations (2 and 3) was computed by the older methods by reference to Station 1 and Station 4 separately, while the new method used the two base stations conjointly. Each individual determination by the new method was therefore comparable with two distinct determinations by each of the others. In the table a single column only is given to the residuals by the new method, while each of the other methods is furnished with two columns for the corresponding residuals and a third to exhibit the mean of the preceding two.

TABLE XXII.

Comparison of Barometric Methods by means of Computations from Observations at Mount Washington, N. H., in June, 1873.

New Station	Average Deviation from Mean of 192 Determinations						
	By New Method, Station 1 and Station 4 as Bases	By Method with One Base Station and No Empiric Correction (Williamson.)			By Method with One Base Station and Local Empiric Correction (Whitney)		
		Referred to—		Mean of two series	Referred to—		Mean of two series
		Station 1	Station 4.		Station 1	Station 4	
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet.*
Station 2	11 8	15 1	15 8	15 5	14 4	13 5	14 0
Station 3	8 9	21 8	7 9	14 9	18 1	9 9	14 0
General Mean	10 4	....	... .	15 2	.....	...	14 0

The general result, as indicated by the footings, is that the average residual afforded by the determinations when one base station is employed and no empiric correction is used is 50 per cent greater than the residual when two base stations are employed by the new method; and that when the method with a single base station is modified by the use of local empiric corrections, the average residual is 40 per cent greater than that obtained with two bases.

After Table XXII had been prepared and the preceding paragraph had been written, the discovery was made that the observations on Mount Washington were affected in a peculiar and systematic way by certain high winds, so that a considerable share of their error is of an exceptional nature and so far avoidable that it may be considered not to affect the hypsometric problem strictly considered. A full account of this influence of the wind will be found in the fourth section of Chapter IV. In order to make sure that this special condition did not vitiate the conclusion reached above in regard to the comparative accuracy of hypsometric methods, the full series of 192 determinations was scrutinized with reference to the associated wind, and each determination made at a time when the wind at any one of the four stations exceeded ten miles per hour was rejected. The remaining determinations (which number 74 in each series) were then discussed by themselves in the same manner as the entire series had previously been. Their mean residuals are given in Table XXII *bis*.

TABLE XXII *bis*

Comparison of Barometric Methods by means of Computations from a Selected Series of Observations at Mount Washington, N. H., in June, 1873.

New Station	Average Deviation from Mean of 74 Determinations						
	By New Method, Station 1 and Station 4 as Bases	By Method with One Base Station and No Empiric Correction (Williamson)			By Method with One Base Station and Local Empiric Correction (Whitney)		
		Referred to—		Mean of two series	Referred to—		Mean of two series
		Station 1	Station 4		Station 1	Station 4	
	Feet.	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Station 2	7 7	8.7	17 7	13 2	9 2	12.9	11 0
Station 3	6 2	17 6	7 8	12.7	9.2	9 9	9 6
General Mean	7 0			13 0			10 3

The result of the second comparison is even more favorable to the new method than that of the first. The mean residual of the determinations by Williamson's method is 85 per cent greater than that by the new, and the residual by Whitney's is nearly 50 per cent greater. The new method does not suffer in comparison when the observations are improved.

COMPARATIVE COMPUTATIONS FROM MONTHLY MEANS.

When single sets of observations, made at individual hours, are employed in the computations of heights, the results are subject to all sources of error, but if the observations are first grouped in certain ways, so as to obtain mean values, certain classes of errors are practically eliminated. When the means of all the observations on a single day are employed, the results are freed from errors having a diurnal period; when monthly means are employed, the errors arising from non-periodic gradient are greatly diminished; and if annual means be employed, little remains but perennial gradient and constant errors dependent on temperature. When long series of monthly means are used, the fact is developed that there are inequalities dependent upon season which tend to repeat themselves from year to year. The ability of the new method to eliminate such inequalities has been tested in Table XII, where its results are compared with those given by Whitney's tables, but its performance in this regard has not yet been compared with that of the simpler hypsometric methods. Table XI indeed contrasts the results obtained by Williamson and by the new method for certain Californian stations in the months of June and January, but the result is unsatisfactory. In the first place there is no fixed standard of comparison, and in the second the number of terms in each series of determinations is too small to exclude the possibility of fortuitous accordance or discordance. The series of observations and computations published by Williamson afford no material adapted to a more extended comparison, and indeed there appear to be no published observations well suited to the purpose, but the need is partially met by the observations published by Whitney. Those observations cover a period of thirty-five months, and, as published, afford monthly means of barometric pressure and atmospheric temperature. They do not, however, contain the data necessary to the computation of the correction for humidity, and they therefore fail to accord to such a method as that of Williamson the means of producing its best results. When the observations at individual hours are considered it is probable that the harmony of results is enhanced by ignoring the psychrometric observations, but when monthly means furnish the data for computation there is an advantage in employing them. Despite this defect, the Californian observations are the best available, and a series of computations has accordingly been made from them.

For each of the thirty-five months a determination of the altitude of Colfax has been made by using Sacramento and Summit as bases, and the error of each determination has been ascertained by subtracting from it 2,399 feet—the difference in altitude established by leveling. The altitudes and errors are given in full in Table XXIII. The comparative computations were not made by the writer, because that work had already been performed by Professor Whitney. His results, with their corresponding errors, were transferred from pages 75–79 of his treatise, and incorporated in the same table (XXIII). They form two series: the first gives the determinations of Colfax when Sacramento was used as a base station; the second when Summit was thus used.

In the computations by Professor Whitney the tables of Williamson were employed for all elements except the temperature and humidity, and Guyot's formula was applied for the derivation of the temperature corrections.

TABLE XXIII.

Comparative Determinations of the Altitude of Colfax above Sacramento, Cal., from Monthly Means of Thrice-daily Observations.

Date.	By New Method, from Sacramento and Summit.		By Old Method, the Base Station being—			
			Sacramento		Summit	
	Altitude.	Error	Altitude	Error.	Altitude.	Error
1870	Feet.	Feet	Feet.	Feet.	Feet	Feet.
October	2391.0	— 8 0	2393 4	— 5 6	2454 3	+ 55 3
November	2386 5	— 12 5	2386 5	— 12 5	2462 1	+ 63 1
December	2391.7	— 7 3	2389 5	— 9 5	2479 6	+ 80 6
1871						
January	2398 1	— 0 9	2380 2	— 18.8	2454 9	+ 55 9
February	2394 9	— 4 1	2402.8	+ 3 8	2424 7	+ 25 7
March	2391 3	— 7.7	2412 9	+ 13 9	2410 9	+ 11 9
April	2386 3	— 12 7	2410 6	+ 11 6	2389 2	— 9 8
May	2409 5	+ 10 5	2435 6	+ 36 6	2380 7	— 18 3
June	2410 3	+ 11.3	2430 3	+ 31 3	2362 3	— 36 7
July	2420 2	+ 21 2	2435 5	+ 36 5	2376 7	— 22 3
August	2415 0	+ 16 0	2424 9	+ 25 9	2390 6	— 8 4
September	2411 6	+ 12 6	2409.6	+ 10 6	2407 9	+ 8 9
October	2412 1	+ 13 1	2398 9	— 0 1	2432 7	+ 33 7
November	2389 9	— 9 1	2389 9	— 9.1	2413 8	+ 14.8
December	2398 8	— 0 2	2400 9	+ 1 9	2404 1	+ 5 1
1872						
January	2400 7	+ 1 7	2395.4	— 3 6	2433.0	+ 34 0
February	2375 9	— 23 1	2397 5	— 1 5	2372 3	— 26.7
March	2390 1	— 8.9	2412.4	+ 13 4	2392 9	— 6 1
April	2391 1	— 7 9	2429 2	+ 30.2	2391 0	— 8 0
May	2400 3	+ 1 3	2431 1	+ 32 1	2391 1	— 7 9
June	2396 3	— 2.7	2416 5	+ 17 5	2371 3	— 27.7
July	2416 7	+ 17 7	2440 6	+ 41.6	2375 6	— 23 4
August	2387 5	— 11 5	2415 1	+ 16 1	2382.4	— 16 6
September	2385 4	— 13 6	2389 3	— 9 7	2389 2	— 9.8
October	2381 7	— 17 3	2372 9	— 26 1	2391 4	— 7 6
November	2407 0	+ 8 0	2392 1	— 6 9	2435.5	+ 36 5
December	2400 3	+ 1 3	2381 2	— 17 8	2449 5	+ 50 5
1873.						
January	2371 6	— 27 4	2393 3	— 5 7	2419 1	+ 20 1
February	2357 3	— 41 7	2402 8	+ 3 8	2375 5	— 23 5
March	2378 0	— 21 0	2417 3	+ 18 3	2407 3	+ 8 3
April	2402 0	+ 3 0	2472 8	+ 73 8	2390 9	— 8 1
May	2387.0	— 12 0	2454 4	+ 55 4	2369 4	— 29 6
June	2407.1	+ 8 1	2474 7	+ 75 7	2370 7	— 28 3
July	2402 0	+ 3 0	2451 2	+ 52 2	2370 8	— 28 2
August	2400 4	+ 1 4	2469 5	+ 70.5	2321 3	— 77 7
Mean	......	10 8	......	22 8	......	26 5

The footings of the several columns of errors indicate that the new method is greatly superior to the old in its ability to produce uniform results at different seasons of the year. The old method gives a better series of determinations with Sacramento as a base station than with

Summit, but even in that case its average error is more than twice as great as that by the new method. The disparity is so great as to render it improbable that the comparison would be materially affected by the introduction of the humidity correction.

SUMMARY.

By the preceding series of tests the new hypsometric method has been compared with the two general methods already in use. It will be convenient to designate these older methods by the words *ordinary* and *empiric;* indicating by the title *ordinary* the general method which employs a single base station only, and applies the formula of Laplace or that of Bessel with no special corrections not readily derivable from a short series of observations at the base station; and indicating by the title *empiric* the general method which introduces into the computation an empiric correction derived from a long series of observations made at two stations in the vicinity of the point to be measured.

The special procedure which has been used as an example of the ordinary method is that of Williamson, and its chief individual peculiarities consist in the rejection of the thermometric and psychrometric observations at the moment of barometric measurement and the substitution therefor of diurnal means of thermometric readings and weekly or monthly means of psychrometric readings. A point in California was found which had already been subjected to a series of determinations by Williamson, and which was at the same time well conditioned for the application of the new method. Ninety corresponding determinations by the new method afforded a mean error 53 per cent less than the mean given by the ordinary. A series of 384 computations from observations on the slopes of Mount Washington gave a mean error 32 per cent less than by the ordinary; and a series of 148 computations, selected from the last by reason of specially favorable conditions of observation, gave a mean error 46 per cent less than by the ordinary. In the case of the Californian work, the stations involved were at such distance that the observations and results were presumably largely influenced by cyclonic gradients, while at Mount Washington they were not. The tests at the second locality are therefore more valuable as indicative of the ability of the two methods to eliminate those errors to which alone they are applicable. Doubtless, if the computations were repeated from observations in other localities, or from observations in the same locality at another season of the year, notably different results might be obtained; but, in the absence of the necessary observations, we cannot do better than accept the Mount Washington results, and say that under conditions favorable to the application of both methods the substitution of the new for the ordinary reduces the error nearly one-half.

In comparing the new method with the empiric, illustrations were derived from Whitney's work in California and from Plantamour's in the Alps, and a computation after the manner of Whitney was applied to the Mount Washington observations. Eighty-six comparative determinations of Colfax, Cal., indicated a reduction of error by the new method of 35 per cent; 106 determinations of stations in various parts of California indicated a reduction of 10 per cent; 82 determinations of stations in the Alps, a reduction of 39 per cent; 384 determinations at Mount Washington, a reduction of 26 per cent; and 148 determinations at Mount Washington, from observations not affected by wind, a reduction of 32 per cent.

Here again all the determinations, except those at Mount Washington, were exposed to the influence of cyclonic gradients, but in such way that it is impossible to say whether one method was favored more than the other. The weighted mean of all the indicated reductions is 27 per cent, and from the data at hand we cannot do better than adopt that as the measure of the gain when the new method is substituted for the empiric.

All the computations referred to in the preceding paragraphs were based upon individual observations, and, with the exception of those for the determination of Colfax, were checked by no standards more authoritative than their own mean results.

The period of observation for each of these series is so short that it cannot be considered to include those variations dependent upon season of year; but the comparison has been extended so as to develop the ability of the several methods to cope with them. From Table XI and Table XXIII it appears that the new method reduces, by about one-half, the error incurred by the application of the ordinary method to monthly means; and Table XII shows that it equals the performance of the empiric method under conditions especially favorable to the latter. The error related to the season is not so great as the error related to the day and hour, but it is still not unimportant, and the superior ability of the new method to cope with this gives it an added advantage over the ordinary. Expunging, as compared with the ordinary, nearly one-half of the error related to the hour, and fully one-half of the error related to the season, it may with propriety be credited with a diminution of the total error of a single computation by about one-half. Equaling the empiric method in its ability to obviate seasonal irregularities, its relative power to cope with the total error of an individual computation is approximately measured by its relative power to cope with that element of error which pertains to the hour—a power indicated, as we have seen, by an improvement of 27 per cent.

If it be granted that the new method effects a reduction of one-fourth the error of the empiric and of one-half the error of the ordinary, it must of necessity be admitted that it is the more exact hypsometric method; but it does not necessarily follow that it will, or should, supplant them, for other conditions need to be satisfied. Of these we shall speak more fully in another chapter, here mentioning only the single consideration of cost. In the application of the ordinary method to the work of a survey, a barometer, or a number of barometers, are carried during the season of field operations from one new station to another and are read at each; during the same period a single base station is maintained continuously; and these are the only items of expense, unless it is also necessary to determine in some independent way the altitude of the base station. A similar application of the new method involves all these expenses, and, in addition, the cost of maintaining a second base station throughout the same period and of measuring with the level the difference in altitude of the two bases. For the similar application of the empiric method the outlay of the ordinary method is required during the season of field work, and it is additionally demanded that two stations in the vicinity shall have been antecedently maintained for a term of years. In every case, therefore, the empiric and new methods are more expensive than the ordinary, and in most cases the empiric is more expensive than the new. It may sometimes occur, as, for example, in the Alps, that the preliminary labors necessary for the application of the empiric method have already been performed for other purposes, and in such case that method can be as economically applied as the ordinary. It may also occur that the continuance of geographic work in the same district for a series of years will enable the empiric method to use for its base stations the identical observatories and observations employed for the deduction of its tables of corrections, and in such cases its expense is practically identical with that of the new method.

In the more frequent cases the empiric method is more expensive than the new, and there can be no reason for employing it. When circumstances place them on a parity in the matter of expense, the preference should go to the new method on the score of precision. But when the new method is compared with a less expensive application of the empiric, or with the comparatively inexpensive ordinary method, we may conceive that there will always be a weighing of utility *versus* cost, and various extraneous circumstances may determine the use of the one or the other.

The rarity of the circumstances which should lead to the preference of the empiric method may be supposed to narrow the choice in most cases to the ordinary on the one hand and the new on the other. As will be shown in the sequel, there is a considerable range of special cases in which the ordinary method can never be superseded by the new.

CHAPTER IV.

POSSIBLE IMPROVEMENTS.

In the preceding chapters an attempt has been made to give the new method a rationale and a *raison d'être*,—to show first that it is theoretically plausible, and second that it is practically successful. It has been pointed out that while the hypsometric methods now in use strive to ascertain the momentary density coefficient of an air column in an indirect way, by untrustworthy measurements of temperature and moisture, the new method undertakes to determine it by means of a direct measurement of the simultaneous density coefficient of a partially coincident air column. It has been shown that the only arbitrary assumption involved in the new departure—the assumption of a simple law for the vertical variation of the density coefficient—is so far unavoidable that it has been embodied in all the older practice. And it has been shown by an extended series of comparative computations that the application of the new formula actually accomplishes a diminution of hypsometric error. In the present chapter it will be assumed that the new method is destined to find a place in the hypsometric work of the future, and consideration will be given to the possibility of further developing it so as to increase its usefulness. Its merits having been sufficiently dwelt upon to establish its claim to recognition, its shortcomings will now be discussed with a view to their amelioration.

1. REDETERMINATION OF THE CONSTANT.

In the thermic term of the formula, $\frac{A(B-A)}{D}$, the quantity D is a constant, but it is not one which admits of determination from *a priori* considerations. Its value can be learned only by applying the formula to the computation of known heights, from means of long series of observations. To accomplish this in a satisfactory manner it is necessary to use a group of three stations whose differences in altitude are both great and known, and whose horizontal distances are small. There is no published long series of observations at stations fulfilling these conditions, and the value assigned to D, 490,000 feet, is merely provisional. It was derived, as has already been explained, from a two years' series of observations made in California at a group of stations of which the extreme members are 77 miles apart, and its accuracy is impugned by many considerations. In the first place, the values afforded by the two years, considered separately, are not closely accordant, while those afforded by the four half years into which the same series of observations may be divided are highly discordant. In the second place, the highest and lowest stations of the group are not merely widely separated, but one of them is in close proximity to the ocean, so that the observations are subject to the unfavorable influence, not only of non-periodic gradients, but of the annual and perennial gradients of a coast district, which theoretically are exceptionally great. In the third place, the leveling by which the altitudes of the stations were determined was not performed with special reference to this or any other scientific object, but merely for the less exacting needs of a railroad, and its guaranty of precision is insufficient. In the fourth place, a portion of the observations are of poor quality. The observers were chiefly occupied with other duties, and at two stations they were frequently changed. Their records are not perfectly continuous and are not free from patent errors. And, finally, the observations were restricted to the hours of 7 in the morning and 2 and 9 in the afternoon, and no other data exist for ascertaining the daily means. In observations of atmospheric temperature, it has been found that readings at these three hours enable the daily mean to be computed with a high degree of precision, and this at all seasons of the year; but the same rule does not apply to observations of atmospheric pressure. The daily cycle of pressure has it maximum at different hours in different seasons and at different stations, and the mean of the readings at the hours of 7, 2, and 9 frequently differs from the mean for the day by amounts which affect hypsometric results to the extent of several feet.

In comparing computations by the new method with corresponding computations by Professor Whitney for the determination of altitudes at various points in California, there was found to be a difference of a constant nature which would be explained if it should be discovered that the middle station of the Californian group had been assigned by leveling too low an altitude. The effect of such an error upon the estimate of D would be to make it too great. In the comparison, too, of Alpine altitudes computed by the new method, with corresponding altitudes computed by Professor Plantamour, there was found a discrepancy of a constant nature which would be explained if the assumed value of the constant D were ascertained to be too large. There is therefore a presumption that its real value will eventually be found to be somewhat smaller than the one provisionally assigned it.

The desiderata for the final and satisfactory computation of the constant are a series of barometric observations, made at every hour for a period of not less than two years, at three stations whose vertical relations are definitely known, the highest being separated from the lowest by a vertical space of several thousand feet and by a small horizontal space, and the intermediate station being approximately medial. An inland locality is preferable.

The table appended to this paper as an aid to the computer in the use of the formula, is based upon the provisional value of the constant, and will need to be changed when a more satisfactory value is obtained. Its reconstruction will not be a matter of difficulty, since it will merely be necessary to multiply each of its corrections by a constant factor.

2. PROVISION FOR DIURNAL PERIODICITY.

The factor of atmospheric density which finds expression in the thermic term of the formula is an inequality incited by the sun's heat. It would not be strange therefore if it should be affected by a periodicity dependent upon the periodicity of the reception of solar heat; and if it is, there would necessarily be a corresponding systematic inequality in the results given by the formula. Should such an inequality be discovered, it would be possible to make a counteractive modification of the formula and thereby increase its efficiency. The two principal thermic periods due to solar heat are the day and the year; and we will inquire, first, whether the altitudes computed by the formula exhibit any constant inequalities having a daily cycle.

To test the existence of a diurnal period we compute the same altitude by the aid of the same base stations at different hours of the day, and repeat the experiment for as many days and as many localities as practicable. If a diurnal change occurs it is easy to understand that it may vary in character or amount from place to place and from season to season.

The computations made for the purpose of comparing the efficiency of different hypsometric methods, and described in the last chapter, afford a considerable body of material pertinent to this inquiry, and their results have been rearranged with reference to it.

The observations at Placerville, Strawberry Valley, and Hope Valley, which form the basis of the results contained in Table III, were more extended than that table indicates. Colonel Williamson employed in his test computations only the readings made for ten days, at 7 in the morning and 2 and 9 in the afternoon, and the comparative computations by the new method were given the same limit. The observations were made, however, at every hour from 7 in the morning until 9 at night, and through the courtesy of Colonel Williamson, who kindly furnished me a copy of the record, I have been enabled to compute the altitude of Strawberry Valley, with Placerville and Hope Valley as bases, for each of the daylight-hours of ten days in August, 1860. On two of the ten days local thunder storms occurred, rendering the results inapplicable to the present purpose and reducing the length of the series to eight days. The results are exhibited in Table XXIV, and graphically by Figure 1 in Plate LVI, and plainly show a systematic change. The determinations of altitude from 7 in the morning until 3 in the afternoon are all lower than the mean, while from 4 to 9 p. m. they are higher; and the amplitude of their curve, after making allowance for abnormal irregularities, is fully 20 feet. Determinations made in the early evening ascribe to Strawberry Valley a height greater by 20 feet than do determinations made in the middle of the day. The curve in Plate LVI was constructed from the mean of the eight-day series. Similar curves were drawn for each of the individual days, and were found to exhibit in each case, although less perfectly, the same diurnal cycle, thus demonstrating its recurrent character.

TABLE XXIV.

Variations of Altitude Determinations from Hourly Means of Eight-day Series of Barometric Observations. August.

Hour.	New station, Strawberry Valley. Base Stations, Hope Valley and Placerville. Height of New Line, 1,365 feet Height of Base Line, 5,107 feet.	New and Base Stations on the Miesing Height of New Line, 1,772 feet Height of Base Line, 3,504 feet
	Feet	*Feet*
7 a. m	− 2	....
8 a. m	− 6	+ 6
9 a. m	− 3	+ 5
10 a m	− 8	− 4
11 a. m	− 9	+ 1
12 m	− 9	− 3
1 p. m	− 8	− 5
2 p m	− 10	− 6
3 p. m	− 3	− 3
4 p. m	+ 4	− 1
5 p m	+ 8	+ 4
6 p m	+ 13	+ 5
7 p m	+ 10	....
8 p m	+ 12	....
9 p m	+ 9	....

The observations made by Bauernfeind on the Miesing, to which reference was made in the discussion of the thermic constant (see Table II), have been utilized for the present purpose also. Like the last, they consist of an eight-day series in August and are limited to the daylight hours, the series beginning at 8 a. m. and ending at 6 p. m. The results of the computations, translated into English feet, appear in Table XXIV and in Figure 2 of Plate LVI. In this case no separate computation was made for the individual days, the available record of the observations containing only the means of the series; but the smoothness of the curve, which is interrupted by only a single aberrant term, vouches for the actuality of a diurnal period.

The Californian observations, to which our general investigation is so greatly indebted, make a valuable contribution in this place also. In Table XII of the preceding chapter the right-hand pair of columns contain the errors of altitude determinations for Colfax by the new method for each month of the year and for each of the three hours of observation. In Table XXV the same results are given, with a different arrangement and combination, for the purpose of expressing more definitely the relations of the errors to hours of the day. In the reconstruction, the results for the two years were first combined so as to obtain means, and then the figures for each month were increased or diminished by the quantity necessary to eliminate the variation peculiar to the month as a whole. The footings of the columns in Table XXV and Figure 4 of Plate LVI give the general result of the comparison and show that the new method of computation when applied to the determination of Colfax from Sacramento and Summit as bases gives a result at 7 in the morning 11 feet greater than its result at 2 in the afternoon and 15 feet greater than its result at 9 in the evening.

TABLE XXV.

Showing the Relation of Variations in the Computation of Colfax from Sacramento and Summit to Hours of the Day, the Computations being from Monthly Means of Observations.

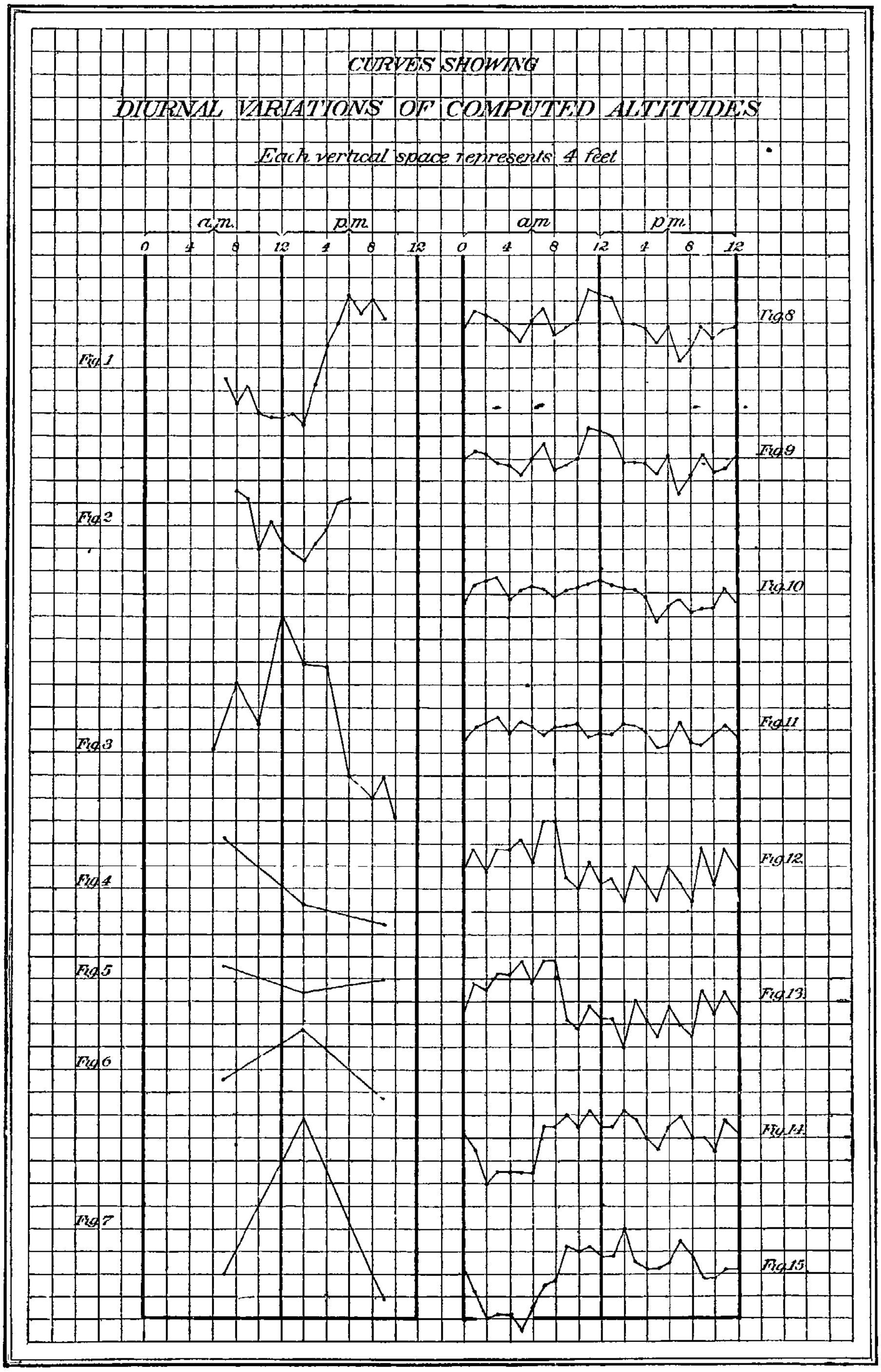
Month.	Variation from Monthly Mean, in feet		
	7 a. m.	2 p. m.	9 p. m.
January	+ 2.5	+ 0.1	− 2.6
February	+ 1.0	− 2.4	+ 1.4
March	+ 8.0	+ 0.3	− 8.3
April	+ 7.9	− 2.9	− 5.0
May	+ 10.6	− 5.3	− 5.3
June	+ 14.3	− 4.8	− 9.5
July	+ 20.5	− 10.9	− 9.6
August	+ 9.6	− 0.7	− 8.9
September	+ 10.2	− 2.5	− 7.7
October	+ 10.9	+ 1.2	− 12.1
November	+ 12.3	− 3.4	− 8.9
December	− 0.9	− 1.2	+ 2.1
Mean	+ 8.9	− 2.7	− 6.2

NOTE.—The altitude of Colfax above Sacramento is 2,399 feet; of Summit above Sacramento, 6,989 feet.

The results for the individual months do not accord perfectly with those for the entire year, but they have sufficient harmony to guarantee that the general result is not due to accident but to an actual, systematic, periodic variation in some condition affecting the measurements. They show, moreover, that the diurnal cycle is itself subject to variations dependent upon season. Its amplitude is less in the three winter months than in the remainder of the year, and is greatest of all in the hottest month.

EXPLANATION OF PLATE LVI.

No. of Figure	New Station.	Base Stations	Period of Observation.	A= Height of New Station above Lower Base	B= Height of Upper Base Station above Lower.	A/B
				Feet	*Feet.*	
1	Strawberry Valley, Cal	Hope Valley and Placerville	8 days in August	3,742	5,107	.73
2	Station 3 on the Miesing	Station 5 and Station 1.	8 days in August	1,772	3,504	51
3	6 points in the Alps	St Bernard and Geneva	18 days in July, August, and September	1,410 to 4,820	6,792	21 to .71
4	Colfax, Cal	Summit and Sacramento	2 years.........	2,399	6,989	.34
5	You Bet, Cal	Summit and Colfax	8 days in November and December	550	4,590	.12
6	Gold Run, Cal. ..	Summit and Colfax	6 days in October	780	4,590	17
7	Lakeport, Cal	Colfax and Sacramento	9 days in October	1,320	2,399	.55
8	Station 2, Mount Washington	Stations 1 and 4 .	Month of June	2,828	3,607	.78
9	Station 2, Mount Washington.	Stations 1 and 3...	..... do	1,572	2,355	67
10	Station 3, Mount Washington.	Stations 1 and 4...	.. .. do	1,252	3,607	.28
11	Station 3, Mount Washington	Stations 2 and 4...	......do	1,252	2,828	.44
12	Station 2, Mount Washington	Stations 1 and 4 .	8 days in June	2,828	3,607	78
13	Station 2, Mount Washington	Stations 1 and 3.	..... do	1,572	2,355	.67
14	Station 3, Mount Washington.	Stations 1 and 4 ..	..... do	1,252	3,607	.28
15	Station 3, Mount Washington	Stations 2 and 4 ...	..... do	1,252	2,828	44


CURVES SHOWING
DIURNAL VARIATIONS OF COMPUTED ALTITUDES
Each vertical space represents 4 feet
a.m.
p.m.
a.m.
p.m.
0 4 8 12 4 8 12 0 4 8 12 4 8 12
Fig.1
Fig.2
Fig.3
Fig.4
Fig.5
Fig.6
Fig.7
Fig.8
Fig.9
Fig.10
Fig.11
Fig.12
Fig.13
Fig.14
Fig.15

These monthly inequalities serve to warn us that a diurnal correction derived from observations at one season of the year cannot be applied in computations from observations made at another season.

TABLE XXVI.

Variations of Determinations in California, classified by Hours.

Station.	Altitude	Height of Base Line	Errors 7 a m	Errors 2 p.m	Errors 9 p.m.
			Feet.	*Feet*	*Feet*
Gold Run	780 feet above Colfax.	4,590 feet	−14.0	+7.2	−1.2
			+3.0	+18.6	−9.5
			−6.9	−1.7	......
			−2.6	+9.5	−14.7
			+3.6	+7.7	−1.6
			+5.0	+0.4	−3.4
	Mean		−2.1	+6.9	−6.1
You Bet.	550 feet above Colfax	4,590 feet.	......	......	+12.2
			+4.2	+4.8	+7.0
			+31.1	−2.7	−16.3
			......	−7.3	......
			......	−3.3	......
			+3.0	−10.5	−9.1
			−4.7	+2.7	−5.7
			−8.1	......	......
			−7.8	−2.7	−0.7
			+0.4	......	......
			+2.9	......	+10.5
	Mean		+2.6	−2.7	−0.3
Lakeport.	1,320 feet above Sacramento	2,399 feet	−7	−12	−35
			−24	+21	−15
			......	+27	+8
			−4	+39	......
			+32	−15	−39
			−45	+25	−20
			+17	+49	+4
			+5	+9	+19
			−37	+32	−26
	Mean		−8	+19	−13

An inspection of the results embodied in Table XV shows that some of the variations in the heights computed by the new method exhibit periodicity. The series at Camp 9, Geyser Springs, and Long Valley are too short to afford trustworthy indications, but the remaining three not merely exhibit changes in the altitude determinations from one hour of observation to another but show a recurrence of these changes from day to day. In Table XXVI the variations of the determinations of altitude by the new method for the remaining three stations are arranged according to hours of the day, and the means for each station are exhibited separately. The means are also plotted in Figures 5, 6, and 7, of Plate LVI. The diurnal variations in the determination of You Bet are somewhat similar to those in the determination of Colfax, but the variations at Gold Run and Lakeport are conspicuously different, the afternoon observations instead of the morning giving the maximum result.

A similar treatment was given to the variations shown by the determinations of altitudes in the Alps and embodied in Table XVIII, and the rearranged residuals will be found in Table XXVII. In this case the character of diurnal oscillation indicated by each of the stations is approximately the same, so that it seems preferable to take the means of the whole instead of individual means for the several stations. The hours of observation here include all those with even number from 6 in the morning until 10 in the evening, and the curve of variation (Figure 3, Plate LVI) is determined at so many points as to give it a definite character. Its maximum is in the middle of the day, its minimum occurs during the night, and its amplitude is in the neighborhood of twenty-five feet. Here again the recurrence of the diurnal change upon different days and at different stations testifies to its systematic nature.

TABLE XXVII.

Variations of Determinations in the Alps, classified by Hours.

New Station	Altitude above Geneva *	A. M				P M.					
		6	8	10	12	2	4	6	8	9	10
	Meters	*m.*	*m*	*m*	*m*	*m*	*m*	*m*	*m*	*m.*	*m.*
Grimsel	1,470	+1 2	....	....	....	....	....	−2 8	−13.6	....	−9 1
		....	....	....	....	....	....	0 0	+2 7	+4 4	....
		....	....	....	....	....	....	....	+1 8	....	....
Proz	1,400	+0.2	....	+1 9	+5.5	+2 8	+0.7	−0 5	−2 7	....	....
		−0 8	....	....	....	....	....	+1 5	−6 8	....	....
		....	....	....	....	....	....	....	−1 2	....	....
St Pierre	1,230	....	....	....	....	....	....	−2 6	−3 6	....	....
		−3 0	+0 8	−1 6	+4 5	+6 1	....	....	....	....	−6 8
		−2 9	+3 6	+1.6	....	+2 3	....	−2 0	−0 6	....	....
		+1 6	−0 5	....	....	....	....	−5 1	−2 3	....	....
		....	+4 7	....	....	....	....	+0 5	−8.9	....	....
		....	....	....	....	....	....	....	+3 1	....	....
Evoléna	970	−6 4	....	....	....	+6 3	+11 2	+1 0	−7 7	....	....
		−1 4	....	....	....	....	....	....	−2 7	....	....
Chamounix	630	−1 8	−0 5	+2 4	+3 9	+0 3	−2 1	....	....	−3 6	−0 9
		+2 4	....	....	....	....	+3 8	....	....	−3 6	....
Serraval	430	−2 9	+5.0	−0 6	−0 5	−0 3	....	−11 7	−9 8	−3 6	−1 6
		....	−0 9	....	+13 4	+7.1	....	....	−4 4	−6 7	−5 0
		....	+8 2	....	+10 9	....	....	....	−1 3	....	−4 1
Mean, in meters		−1 3	+2 5	+0 7	+6 3	+3 5	+3 4	−2 2	−3 6	−2 6	−4 6
Mean, in feet		−3 6	+8 2	+2 3	+20 1	+11 5	+11 2	−7 2	−11 8	−8.5	−15.1

*The height of the upper base station, St Bernard, above Geneva is 2,070 3 meters.

The observations at Mount Washington have been made to afford eight independent curves of a similar nature. This variety of result has been obtained, first, by giving separate consideration to the entire month of June and to the eight June days selected for the comparative computations described in the last chapter, and, second, by combining the different stations in various ways as base and new. It will be remembered that the stations of observation were numbered, from highest to lowest, 1, 2, 3, and 4. In each computation of altitude by the new method three stations are used. There are therefore four different ways in which the stations may be grouped in the computations, each of the four stations being in turn omitted.

TABLE XXVIII.

Showing the Relation of Variations in the Computations of Altitudes on Mount Washington, N. H, to the Hours of the Day.

Hour	Mean of Barometric Readings on Mount Washington for the Month of June, 1873				Variation of Computed Altitude from its Mean Value			
	Station 1	Station 2	Station 3	Station 4	Station 2, from Station 1 and Station 4	Station 2, from Station 1 and Station 3	Station 3, from Station 1 and Station 4	Station 3, from Station 2 and Station 4
	Inches	*Inches*	*Inches*	*Inches*	*Feet.*	*Feet*	*Feet.*	*Feet*
1 a. m......	23 8130	24 5119	25 9753	27 1711	+ 2 4	+ 1 8	+ 1.6	+ 0 5
2 a m......	8088	.5087	9718	1692	+ 1 8	+ 0 9	+ 2 4	+ 1.6
3 a m...	8042	5057	.9679	1669	+ 0 5	− 0 6	+ 3 2	+ 2 9
4 a m....	8008	5054	9736	.1719	− 1 1	− 0 9	− 0 8	− 0 4
5 a m...	.8035	.5111	9798	1821	− 2 8	− 3.0	+ 0 5	+ 1 9
6 a m.......	8094	5141	9853	1887	+ 0 6	+ 0 1	+ 1 4	+ 1 0
7 a m... ...	8162	5183	9917	1943	+ 3 2	+ 2 9	+ 1.0	− 0 5
7 57 a. m....	.8199	5259	9948	1951	− 1 7	− 1 7	− 0.2	+ 0.5
9 a m	8277	5311	9970	1951	− 0 5	− 0.7	+ 0.6	+ 0.7
10 a m	8347	5356	9986	1948	+ 0 6	+ 0.1	+ 1 4	+ 1 0
11 a m.......	8397	5335	9967	.1896	+ 6 4	+ 5 7	+ 1.9	− 1.0
12 m..........	8407	.5335	9921	1824	+ 5 7	+ 4.8	+ 2.4	− 0 2
1 p m... ...	8389	5319	.9886	1772	+ 4 7	+ 4 0	+ 1 9	− 0 3
2 p m	8343	5306	9823	1686	0 0	− 0.3	+ 0 9	+ 0 8
3 p. m	.8304	.5269	.9791	1654	− 0 1	− 0 3	+ 0 7	+ 0 6
4 p m... ...	8257	5225	9744	1592	− 0.7	− 0.6	− 0.3	− 0.1
4 57 p m....	8183	5183	9725	1541	− 3 8	− 2 2	− 4 6	− 3 1
6 p m	8219	5192	9756	1599	− 0 3	+ 0 6	− 2.7	− 2 6
7 p m.......	8189	.5239	9783	1679	− 6 4	− 6 0	− 1.3	+ 1.4
8 p m	8226	5253	.9833	.1702	− 4 2	− 3.0	− 3.6	− 1 9
9 p m	8278	5272	.9877	.1763	− 0.3	+ 0 4	− 2.2	− 2 1
10 p m	.8266	5282	9869	.1762	− 2.5	− 1 9	− 1.8	− 0 8
11 22 p m.....	8231	.5247	9848	.1781	− 1.3	− 1.4	+ 0.3	+ 0 8
12 midnight...	.8184	5192	.9820	1738	− 0.3	+ 0 2	− 1 5	− 1 5
Mean.......	23.8219	24 5222	25 9833	27 1762	.. ....	....	....	... .

In each of the groups the highest and lowest stations were regarded as bases and the intermediate as new station. In each of the eight cases the observations were arranged by hours, and means were taken, and from these means a separate determination of altitude was made for each hour of the twenty-four. Each determination was then compared with the mean of its own series and a set of residuals or variations derived. Table XXVIII gives the hourly barometric means for the month of June for each of the four stations, and gives also the variations from their several means of the corresponding determinations of altitude.

The same variations are plotted in Plate LVI, where they constitute Figures 8, 9, 10, and 11. The corresponding curves derived from the eight-day series of observations appear in Figures 12, 13, 14, and 15.

An inspection of the Mount Washington curves reveals some partial similarities, but none of a general nature. Curves 8 and 9 are closely alike, and so are curves 12 and 13, but the two pairs do not resemble each other. In all four the new station is the same, being Station 2. In curves 8 and 12 the base stations are Stations 1 and 4; in curves 9 and 13, they are Stations 1 and 3. The upper pair were derived from observations for the entire month; the lower pair from the eight-day series. The similarity of the members of each pair is due to the fact that the observations at the new station, which have a greater influence upon the result than the observations at either base station, are identical. The dissimilarity between the pairs arises from the fact that the series of observations from which they are derived, although the longer includes the shorter, are nevertheless inharmonious. The same remarks apply to the remaining curves. Figures 10 and 11 constitute a pair derived from monthly means with Station 3 as the new point; Figures 14 and 15, a pair derived from the eight-day means with Station 3 as new point.

The same disparity which exists between the curves for the entire month and the curves for the eight days is found when we pass to the curves of individual days, for none of the forms of the curves derived from means of observations can be detected in the curves for single days. Moreover, the character of the monthly curves (which, representing the longer series of observations, are the more authoritative) is not such as to indicate the existence of a diurnal period. The angularity of curves 8 and 9 cannot belong to a normal daily cycle, and must be referred to causes which, in their relation to the daily cycle, are accidental. And if the angular elements of Figures 10 and 11 were removed, the curves would approximate very closely to horizontal lines. The Mount Washington observations have therefore afforded no evidence of diurnal periodicity in the determination of altitudes.

If the reader will now compare together all the figures of Plate LVI he will see at once that they exhibit the most divergent characters. The curves of Strawberry Valley, of the Miesing, of Colfax, and of the Alps all represent indubitable, recurrent, diurnal variations, which cannot be ascribed to accident; but they have no single common element. The maximum of the Alpine curve corresponds approximately with the minima of the Miesing and Strawberry Valley curves. The Colfax and Alpine curves agree in making the evening result lower than the morning, but the Strawberry Valley curve makes it higher. The Lakeport curve and the Gold Run curve, which depend upon so few observations as not to be thoroughly established, agree in form with the Alpine curve, while the You Bet curve appears to be related to that of the Miesing. The Mount Washington curves, which rest upon longer series of observations than any of the others except the Colfax, have a smaller amplitude than any other, and are so indefinite and discrepant in their characteristics that they afford no comparative forms.

If these curves were accordant they would warrant the introduction of a diurnal factor in the thermic term of the formula, but their discordance serves to show that no such diurnal factor could be of universal application. The forms of the curves are evidently conditioned by some factor besides that of time, and it is highly probable that that factor is one of place. It is conceivable that an influence may be exerted by latitude, or by proximity to the ocean, or by the relation of the neighboring ocean to the prevailing winds, or by the aspect of the mountain slope—whether toward the rising or the setting sun—or by the approximation in altitude of the new station to the upper base on the one hand or to the lower on the other; but a comparison of the curves with the various data of locality fails to indicate that any such factor affords the key. It is conceivable also that the nature of the curve is determined by the modifications of the diurnal movements of the atmosphere wrought by the topographic peculiarities of the localities used as stations; and indeed this hypothesis appears to the writer more plausible than any other. It is a matter difficult to test, however, because, in the first place, there is no satisfactory theory of the diurnal movements of the air, and, in the second place, the relations of the various barometric stations to the surrounding topographic features are for the most part not recorded.

An altitude computed by the new formula depends upon the atmospheric pressures synchronously observed at three stations. At each station the pressure is subject to a daily cycle of change, and every variation from one hour to another tends to produce a corresponding variation in the computed altitude. The coincident variations at the three stations may be such as to neutralize each other in the computation, and in that case there is no actual variation in the computed altitude; but if they do not neutralize each other the computed altitude changes somewhat from hour to hour. The amount of this change depends strictly upon the three changes in atmospheric pressure, or, in mathematical phrase, the variation of computed altitude is a function of the variations of pressure at the three stations. If we conceive the diurnal pressure cycles of the three stations to be represented by curves, and the diurnal variation of computed altitude by another curve, then we may say that the curve of computed altitude is a function of the three curves of pressure. If the three pressure curves sustain among themselves such harmonious relations that the combination of their elements produces for each hour the same determination of altitude, the curve of computed altitude becomes a straight line.

Whether or not, therefore, there is a diurnal variation in the coefficient of thermic density, the diurnal variations of computed altitude are intimately and inseparably associated with those of atmospheric pressure.

If we were in possession of the true theory of the diurnal curve of pressure, and if we understood the part which topographic surroundings play in the determination of the pressure curve of a station, we should be able to use this knowledge in the improvement of our hypsometric result; but it is by no means certain that we should in such case find it best to incorporate a diurnal factor in the formula. Any diurnal fluctuation which may affect the coefficient of thermic density must have its influence upon the pressure curves of the stations, but those pressure curves are at the same time the expressions of other influences which it is practically impossible to discriminate. It is therefore probable that the best method to diminish the errors dependent upon diurnal periodicity would be by applying corrections for diurnal variations of pressure directly to the barometer readings, after the manner of Williamson. Such corrections, if they could be efficiently applied, would eliminate *all* errors affected by a daily period, and would make their separate discrimination unimportant. The introduction of a diurnal factor in the thermic term of the formula might conceivably counteract the effect of diurnal fluctuations in the coefficient of thermic density, but would leave untouched the greater errors arising from local peculiarities of the daily movements of the atmosphere, and might even interfere with the elimination of those errors by means of corrections to the barometer readings.

We are led to conclude, therefore, that while calculations by the new formula are subject to errors which have a daily period, and while it may at some time be possible to reduce those errors by the application of corrections dependent upon topographic relations, it is nevertheless impracticable to improve the formula by the introduction of a diurnal term or factor.

The subject of the diurnal movements of the atmosphere, to which brief allusion is made in the preceding paragraph, is destined to occupy a no less important place in the future studies of meteorologists than it has occupied in the past; and notwithstanding its difficulty and complexity it is exceedingly attractive. At the risk of obscurity it has been given the smallest possible attention in this connection, because, notwithstanding its vital importance to precise hypsometry, its discussion at the present time can lead only to negative results. It is proper, however, by way of corollary, to call attention to the fact that the considerations invoked to account for the diurnal variations in hypsometric result by the new formula, involve an impeachment of one of the postulates of the formula. It is postulated by the new formula, as well as by all other hyposometric formulas, that the difference between the observed air pressures at two stations expresses the weight of the differential air-column. If this were strictly true, the observed variations in the determined altitudes from hour to hour could only be due to corresponding changes in the coefficient of thermic density. Diurnal changes of thermic density must have a certain family resemblance in all localities; but, as we have seen, the diurnal curves of computed altitude have no family resemblance, and must therefore be referred, in part at least, to some other cause. Hence we are compelled to admit that our primary postulate is not strictly true, and that the column of air included between two stations may weigh something more or less than the differential column of mercury recorded by the two barometric readings. In a general way the explanation is a simple one. The air is daily heated by the sun, and is nightly cooled. The heating and the cooling cause expansion and contraction and therefore give rise to movements. These movements are resisted by the inertia of the air, and in the overcoming of this inertia there arise disturbances of the normal pressure. The observed diurnal changes of barometric pressure are due almost wholly to these disturbances. They are therefore dynamic in their nature; and they are beyond the reach of all existing hypsometric formulas, because it has been either tacitly or explicitly assumed in the construction of those formulas that the air is momentarily in a static condition.

The great advance that has been made in the dynamic study of the vertical or cyclonic movements of the air encourages the hope that a general theory of diurnal movements will soon be attained, but the day must be far distant when the part played by topographic features in the determination of diurnal movements will be so far understood that the knowledge will be of practicable service in hypsometry.

3. PROVISION FOR ANNUAL PERIODICITY.

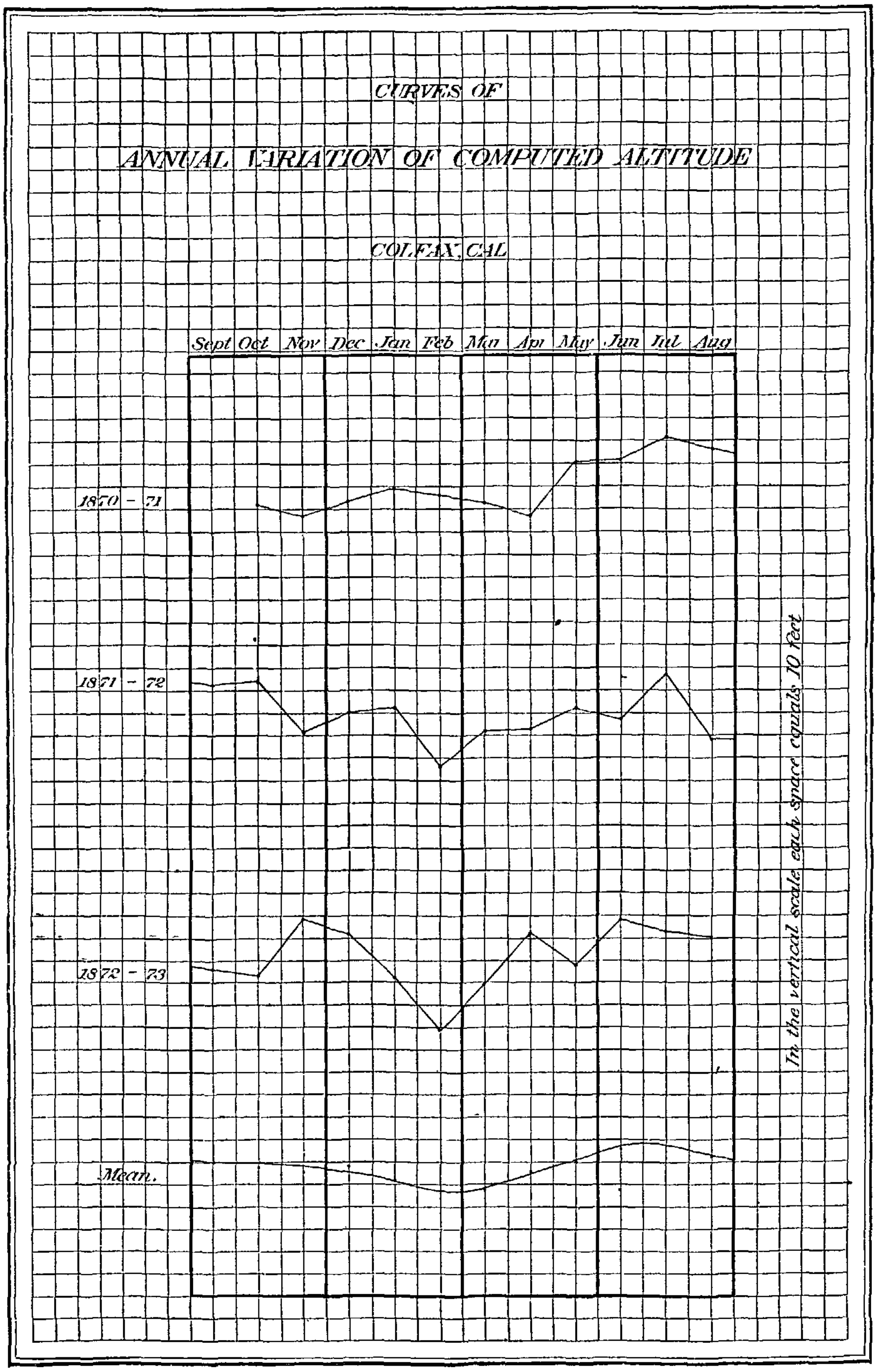
We have now to consider the annual variation in the quantity of heat received from the sun, and to inquire whether there is a corresponding annual inequality of the density coefficient.

It will be recalled that the thermic term of the formula is intended to take account of an inequality in atmospheric density depending chiefly upon inequalities of temperature. These inequalities of temperature are produced by the sun, and their existence depends upon the fact that the principal heating of the atmosphere takes place in the stratum next the earth, while the compensatory cooling is by radiation from all its layers, high as well as low. The sun thus continually disturbs the equilibrium of temperature and density by making the lower layers abnormally warm and rare, and a vertical circulation is thereby produced which just as continually tends to restore the equilibrium. The coefficient of thermic density at any moment is a result of, and an expression for, the excess of the solar influence over the compensatory influence of vertical circulation. It is *a priori* probable that the amount of this excess is greater at seasons when the solar influence is relatively great, and less at seasons when the solar influence is relatively small; or that the coefficient of thermic density is greater in summer than in winter.

If this be the fact, the constant D of the formula ought to be assigned different values at different seasons of the year, and it should be found that the application of the formula with a uniform value will give different results in different months. If the actual coefficient is greater in summer than in winter, it is evident that the use of its mean value for the entire year must afford a thermic correction too small in summer and too great in winter. Were we, therefore, with the formula as it stands, to compute the altitude of a well conditioned station at various seasons of the year, we should anticipate that our results in summer would be lower than our results in winter. If this anticipation were realized, and if a harmonious series of results were obtained from several localities, it would be possible to deduce from them a modification of the formula competent to take account of annual periodicity.

Unfortunately, there is no record of a suitable series of observations, and at present the annual variation of the coefficient can be neither established nor disproved. It will be instructive, however, to describe an attempt that was made to investigate it, because the result, although indecisive with reference to the point at issue, has nevertheless served to indicate the precautions necessary to be taken in order to reach a satisfactory conclusion.

The Californian observations published by Whitney extend over a period of thirty-five months and thus afford curves of computed altitude for three nearly complete years. The determinations of altitude for the individual months have already been given in Table XXIII, and the corresponding curves will be found in Plate LVII. The first three diagrams of the plate exhibit the variations for the individual years, and the fourth shows the monthly means for the entire period. In the fourth diagram the somewhat irregular line which would be produced by connecting the dots representing the determinations for individual months, has been replaced by a line of simple curvature, which probably expresses approximately the general law of variation. An inspection of the curves for individual years shows that the anomalous elements of the mean curve are due to inequalities which do not recur in each year, and may therefore be disregarded with propriety in a generalized expression. It thus appears that there is an actual annual periodicity in the determination of the altitude of Colfax, but it is almost the precise reverse of the one it seemed reasonable to expect as an expression of annual variation in the thermic constant. Theoretically, the determination of altitude should be least in summer, but practically it is greatest; theoretically it should be greatest in winter, but practically it is least


CURVES OF
ANNUAL VARIATION OF COMPUTED ALTITUDE
COLFAX, CAL
Sept Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug
1870 - 71
1871 - 72
1872 - 73
Mean.
In the vertical scale each space equals 10 feet

The assignment of the observed changes to variations in the coefficient of thermic density is therefore inadmissible, and an independent cause must be sought.

A possible cause, dependent upon the limitation of the observations at the several stations to three of the twenty-four hours, has already been suggested in another place (page 503), but the amplitude of the variation, which is indicated by the generalized curve to be approximately 20 feet, is too great to be accounted for in that manner.

Another and more satisfactory explanation is to be found in certain considerations dependent upon annual atmospheric gradient. The three stations of the Californian group are situated upon the long western slope of the Sierra Nevada, a great mountain range which on that side faces the Pacific Ocean. Its foot is indeed separated from the ocean by smaller ranges, but not in such way as to free its wind from maritime influences. It is a general fact that oceans are in summer cooler than the adjacent margins of continents, and in winter warmer than the same margins. These differences give rise to corresponding general atmospheric gradients which in summer are inclined toward the land, and in winter toward the ocean. It is therefore to be presumed that the general gradient between the highest and lowest Californian stations is in summer inclined toward the highest, and in winter toward the lowest. Assuming, for the sake of a standard, that the pressure at the lower station is normal, that at the upper is abnormally low in summer and abnormally high in winter. The same remark applies to the intermediate station, Colfax, but by reason of its smaller distance from the lower station the amount of its variation of pressure is less.

Affecting thus the relative pressures at the lowest and highest stations, the gradient affects the apparent weight and apparent height of the air column included between their levels; and in the same manner it affects the apparent height of the air column included between the lowest station and Colfax. These apparent heights are measured severally by the denominator and numerator of a fraction in the formula, and so long as they are affected in the same ratio the results given by the formula are unmodified. The apparent heights of the air columns are proportional to the real heights of the upper stations above Sacramento. The variations of pressure produced by gradient at the two upper stations we may assume to be proportional to their distances from Sacramento. If then the heights are proportional to the distances, the gradient cannot affect the computations; but if they are not proportional, an influence should be assigned to the gradient.

As a matter of fact, the distance of Colfax from Sacramento is something more than half the distance of Summit, while its altitude above Sacramento is only about one-third that of Summit. It results that the general gradients affect the estimated altitude of Colfax in greater ratio than they do the estimated altitude of the upper base, and thus exert a disturbing influence upon the computation of the altitude of

Colfax. The nature of this influence is to make the computed altitude of Colfax too high in summer and too low in winter.

Thus the theoretic influence of annual gradient is opposed to the theoretic influence of an annual variation of the co-efficient of thermic density, while it corresponds in character with the observed phenomena. We have no present means of judging whether it is quantitatively adequate to explain the phenomena, but recognizing it as a *vera causa* we are permitted to draw no conclusion in regard to the thermic density.

After the preceding paragraphs had been written, it was discovered that a group of stations belonging to the meteorologic system of India afforded data for the continuance of the inquiry. The figures are published in the official reports for the years 1875–1878, and exhibit monthly means for each year. The barometers were read four times daily, at the hours of 4 and 10, a. m. and p. m. The positions of the stations are given as follows:

Station.	North Latitude.	East Longitude.	Altitude
	° ′	° ′	*Feet*
Chakrata	30 40	77 55	7,051 58
Dehra	30 20	78 08	2,232 4
Roorkee	29 52	77 56	886 63

From which we deduce—

Stations.	Distance	Difference in Altitude
	Miles	*Feet*
Chakrata from Dehra	26	4,819 18
Chakrata from Roorkee	55	6,164 95
Dehra from Roorkee	34	1,345 77

It is recorded of Dehra and Roorkee that the altitudes of their barometers were determined by spirit level, and the conciseness with which the altitude of Chakrata is expressed probably indicates a like determination, although it is not so stated.

From these data the altitude of the intermediate station above the lowest was computed by the new formula for each of the forty-eight months, the vertical space between the extreme stations being assumed as a base line. The results appear in Table XXIX and are plotted upon Plate LVIII. The first four curves of the plate show the variations in the computed altitude from month to month for each of the four years of observation. The fifth curve is the mean of the four preceding. The sixth is a reproduction of the mean curve derived from the Californian observations,—introduced here for comparison.

TABLE XXIX.

Altitude of Dehra, India, above Roorkee, computed from Monthly Means; the Base Stations being Chakrata and Roorkee.

Month.	1875	1876	1877.	1878	Mean of 4 Years
	Feet	*Feet*	*Feet*	*Feet.*	*Feet*
January	1,376	1,342	1,339	1,337	1,348 5
February	1,373	1,335	1,337	1,330	1,343 7
March	1,371	1,335	1,332	1,323	1,340 2
April	1,361	1,335	1,324	1,312	1,333 0
May	1,349	1,312	1,324	1,319	1,326 0
June	1,335	1,336	1 324	1,316	1,327 7
July	1,344	1,338	1,324	1,311	1,329 2
August	1,357	1,333	1,327	1,325	1,335 5
September	1,332	1,322	1,332	1,327	1,328 2
October	1,337	1,319	1,333	1,324	1,328 2
November	1,331	1,326	1 334	1,327	1,329 5
December	1,338	1,335	1,340	1,328	1,335 2
Year	1,350 3	1,330 7	1,330 8	1,323 2	1,333 7

Considering, first, the mean curve (Figure 5), we see that it exhibits in August an aberrant element dependent upon an incongruous result appearing in the curve for 1875 and in no other; and we see, second, that it exhibits an aberrant element in May referrible to a still more incongruous determination shown by the curve for 1876. If we disregard the means for these two months, and draw the curve independently of them, as indicated by the dotted lines, we find it assuming a regular form with a single maximum and a single minimum. The maximum is relatively acute and occurs in midwinter; the minimum is broad and includes the entire summer. It therefore agrees in its essential features with the one theoretically anticipated, while it differs in every respect from the one derived from the Californian observations.

Comparing, now, the mean curve for the four years (Figure 5) with the curves for the individual years, we are able to detect its presence in the curves for 1877 and 1878, and less evidently in that for 1875, while the curve for the remaining year, 1876, betrays no trace of it. A system of corrections based upon it would plainly improve the harmony of the results in three of the four years, and would, on the whole, work to advantage.

The fact must not be overlooked, however, that the periodic variations expressed in this curve are of small magnitude as compared with the irregular variations exhibited by the same series of determinations. Even when the determinations are grouped by yearly means they exhibit inequalities greater than those with an annual period. The value of the altitude given by all the observations of 1875, collectively, is 21 feet greater than the values afforded by the years 1876 and 1877, and 28 feet greater than the value for 1878, while the amplitude of the curve of the annual change is only 13 feet. The application of corrections derived from the mean curve would therefore diminish the general irregularity in small ratio only.

It must be remembered, also, that the extreme stations of the group are separated by a horizontal distance of fifty-five miles—a space which admits the possibility of a large factor of annual gradient. It is true that in this case the ocean is not near; but the lowest station lies at the edge of an immense plain, while the highest is upon the slope of the loftiest mountain mass of the world, and such contrast of conditions can hardly fail to give rise to great periodic movements of the atmosphere. The relation of the vertical and horizontal interspaces of the stations is somewhat similar to that of the Californian group; the intermediate station is vertically nearer the lowest but horizontally nearer the highest.

On the whole, the question of the existence of a general annual period in the determination of hypsometric values by the new formula must be regarded as unanswered. The Californian and the Himalayan groups of stations give contradictory results; the former inconsistent with theoretic considerations, the latter consistent therewith. The Californian results are manifestly untrustworthy by reason of the proximity of the sea, but the trustworthiness of the Himalayan results is not assured. The question must remain open until a sufficient series of observations has been made at some properly conditioned group of stations. In such a group the horizontal distances should be small and the vertical great; the intermediate station should be approximately midway between the others; the observations should be equally distributed throughout the twenty-four hours, and for at least one year of the series they should be hourly; the locality should be inland.

It should be said by way of corollary that if the coefficient of thermic density changes with season, it should for the same reason change also with latitude and, in general, with local temperature. If, therefore, its variability shall at some time be recognized in the formula, it will be more logical to employ the general local temperature as its argument than to employ the season of year.

4. ADDITION OF A THIRD BASE STATION.

We shall now consider the possible advantage of increasing the number of base stations in the vertical series from two to three; and to make clear the bearing of such a change we shall recall the analysis of the subject of atmospheric density. The general law of the vertical distribution of density in the atmosphere is a function of Boyle's law of the relation of gaseous tensions to pressures, and is itself here called the logarithmic law. It is simple in its nature and would need no qualification if the atmosphere were homogeneous in temperature and in moisture content. The modifying factor dependent upon moisture and temperature we have called the thermic density.

The thermic factor of density is divisible in thought into three parts, each of which requires consideration in the solution of the hypsometric problem. The first is its mean value, the second its law of vertical distribution, the third its rate of vertical change. The mean thermic density of any air column is known to vary from day to day and from hour to hour, and it is the especial object of the new hypsometric formula to determine its value in a given atmospheric column by means of a simultaneous measurement of its value in a similarly conditioned atmospheric column of known height. This is accomplished by the aid of two base stations, at each of which the pressure of the atmosphere is measured as a means of deducing the weight of the column between them.

The law of vertical distribution of the thermic density is not known, but the formula postulates for it a simple nature. It is probable that it, too, is subject to variation, and in another section the possibility of subjecting it to analysis and discussion will be considered.

The rate of vertical change of thermic density, or the rate at which the divergence of the actual density from the density indicated by the logarithmic law increases upward, is likewise known to be variable; but in the formula it is assumed to be constant, and its "constant" value finds expression in the denominator (D) of the thermic term. In the preceding sections the possibility of making provision in the formula for periodic changes of its value has been considered, but no reference has been made to non-periodic changes; yet a very brief consideration will suffice to show that it is liable to vicissitudes of as irregular a nature as those which affect any other atmospheric factor.

The vertical distribution of moisture and temperature is controlled primarily by the vertical circulation of the air, or rather by the relation of that circulation to the inequality of its heating by the sun. If the rate of vertical change were dependent upon that cause alone, it might be approximately equable, but it is really influenced by a variety of other factors, the most important of which is probably the horizontal circulation. The horizontal movements of the upper and lower strata of the atmosphere, at any locality, are frequently in different directions, and the movements of the upper strata are usually more rapid than those of the lower. The relations between the densities of high and low layers, so far as these are controlled by temperature and moisture, are therefore to a great extent independent of local conditions, and are liable to changes both abrupt and great whenever the winds change.

Every such change occasions a corresponding change in the rate of vertical increase of thermic density, and consequently in the actual value of the constant D. It would appear desirable then that some means be employed to ascertain the value of that constant in the field of hypsometric work at the moment of barometric measurement. Our attempts to ascertain the *mean* value of the constant have been by computations based upon pressure observations at groups of three stations whose differences of altitude were known, and it appears perfectly feasible to ascertain its *momentary* value by the same method. To do so would require the establishment of an additional base station, so as to make the series consist of three bases instead of two, and as this would proportionately increase the expense of the hypsometric work, the consideration of economy demands that it shall first be shown to yield a compensatory advantage in precision.

The general principle upon which the new hypsometric method is based is that of determining the condition of the atmosphere at the moment of hypsometric measurement by means of a direct measurement of the density of a comparable column of known height. As the formula stands, only the mean density is determined by direct measurement. By the aid of a third base station, not only the mean density, but the rate of variation of the thermic density, would be measured.

It is easy to adapt the formula to this change. Assume that the new base station is placed intermediate in height between the upper and lower, and represent its barometer reading by i. Call the readings at the upper and lower base stations, as before, u and l, and that at the new station n. Represent by B the height of the upper base station, by b the height of the intermediate base station, and by A the height of the new station—all vertical distances being referred to the lower base station as an origin. Then, by the formula already developed,

$$A = B\frac{\log l - \log n}{\log l - \log u} + \frac{A(B-A)}{D} \quad . \quad . \quad . \quad (18)$$

and

$$b = B\frac{\log l - \log i}{\log l - \log u} + \frac{b(B-b)}{D} \quad . \quad . \quad . \quad . \quad (19)$$

From (19) we obtain

$$D = \frac{b(B-b)}{b - B\dfrac{\log l - \log i}{\log l - \log u}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

in which all the quantities of the second member are known. Substituting in (18) the value of D given by (20), we have

$$A = B\frac{\log l - \log n}{\log l - \log u} + \frac{A(B-A)}{\dfrac{b\ (B-b)}{b - B\dfrac{\log l - \log i}{\log l - \log u}}} \quad . \quad . \quad (21)$$

an equation in which A only is unknown. B and b are, by postulate, known altitudes; and l, u, i, and n are observed barometric pressures.

If the law of the vertical distribution of thermic density were simple, or even if it were invariable, the application of this formula should give results of the utmost uniformity; but it is evident that any disturbing causes, such as have been described, which induce abrupt changes in the *rate* of vertical variation, must also interrupt the vertical continuity of the *law* of distribution. It is not to be anticipated, therefore, that the application of the formula, even under the most favorable conditions, will eliminate all irregularities from hypsometric results. Theoretically, however, it should diminish those irregularities; and if it does so in any notable degree, there may be an economic advantage in the introduction of the third base station. The true test of the question is the practical one, and to this we now proceed by discussing the only available series of observations applicable to it.

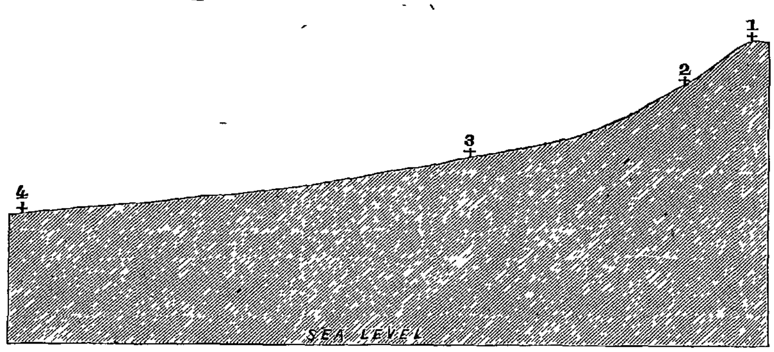


FIG. 30 Profile of the Western Face of Mount Washington showing the Positions of the Meteorologic Stations in June, 1873

The four stations upon the profile of Mount Washington have the relative positions indicated by the accompanying diagram. Station 1 is upon the summit; Station 2 is about 800 feet lower, and the descent to it is very steep; Stations 3 and 4 are so far down the valley which drains the mountain upon the west that they are somewhat shut in by spurs. They rest upon an easy slope, but nevertheless they are fairly upon the flank of the mountain, and the distance of the lowest from the summit is only three miles. For the purpose of comparison the altitude of Station 2 above Station 4 was first computed by reference to Stations 1 and 4 jointly, and second by reference to Stations 1, 3, and 4 jointly. The formula applied in the first case was that given in Equation (7), on page 442; in the second case, that given in Equation (21). Three series of computations were made. In the first series the means of the barometric pressures at the several stations for each day of the month of June, 1873, were used, each method affording thirty independent results, which are exhibited in full in Table XXX. For the second series the hourly means of the month's observations* were used, the results affording twenty-four comparisons. For the third series the individual hourly observations for the period of eight days, from June 22 to June 29, were used, affording one hundred and ninety-two comparisons. The second and third series

* See Table XXVIII.

of results are not here published in full, but are summarized in Table XXXI, from which it appears that whether the observations are taken individually, or by hourly means, or by daily means, the triple base yields a more uniform result than the double. The variation of the individual results among themselves appears to be reduced about 25 per cent by the use of the intermediate base station.

TABLE XXX.

Determinations of the Height of Station 2, Mount Washington, from Daily Means of Barometric Pressure.

Date	Base Stations			
	Stations 1 and 4		Stations 1, 3, and 4	
	Altitude	Residual	Altitude	Residual
	Feet	*Feet*	*Feet*	*Feet.*
June 1	2,795 6	−23 1	2,819 7	+ 1 0
2	2,781 1	−37 6	2,796 2	−22 5
3	2,825 6	+ 6 9	2,826 2	+ 7 5
4	2,825 9	+ 7 2	2,836 5	+17 8
5	2,801 9	−16 8	2 814 8	− 3 9
6	2,827 1	+ 8 4	2,827 7	+ 9 0
7	2,819 7	+ 1 0	2,819 8	+ 1.1
8	2,835 9	+17 2	2,834 9	+16 2
9	2,831 3	+12 6	2,833 3	+14 6
10	2,831 2	+12 5	2,832 6	+13.9
11	2,813 9	− 4 8	2,828 1	+ 9 4
12	2 808 5	−10 2	2,816 1	− 2 6
13	2,830 2	+11 5	2,830 1	+11 4
14	2,839 4	+20 7	2,837 4	+18 7
15	2,825 5	+ 6 8	2,824.4	+ 5 7
16	2,826 2	+ 7 5	2,828 4	+ 9 7
17	2,769 8	−48 9	2,778 7	− 40 0
18	2,800 9	−17 8	2,800 2	−18 5
19	2,812 0	− 6 7	2,815 8	− 2 9
20	2,797 9	−20 8	2,808.5	−10 2
21	2,792 5	−26 2	2,796 3	−22.4
22	2,822 7	+ 4 0	2,812 7	− 6.0
23	2,837 3	+18 6	2,818.9	+ 0 2
24	2,838.8	+20 1	2,823.2	+ 4 5
25	2,837 5	+18 8	2,820 9	+ 2 2
26	2,827 1	+ 8 4	2,817 6	− 1 1
27	2,814 9	− 3 8	2,809.6	− 9.1
28	2,814 3	− 4 4	2,808 6	−10 1
29	2,833 2	+14 5	2,816 0	− 2.7
30	2,839 5	+20 8	2,822 3	+ 3.6
Mean	2,818.6	14 6	2,818 5	9.9

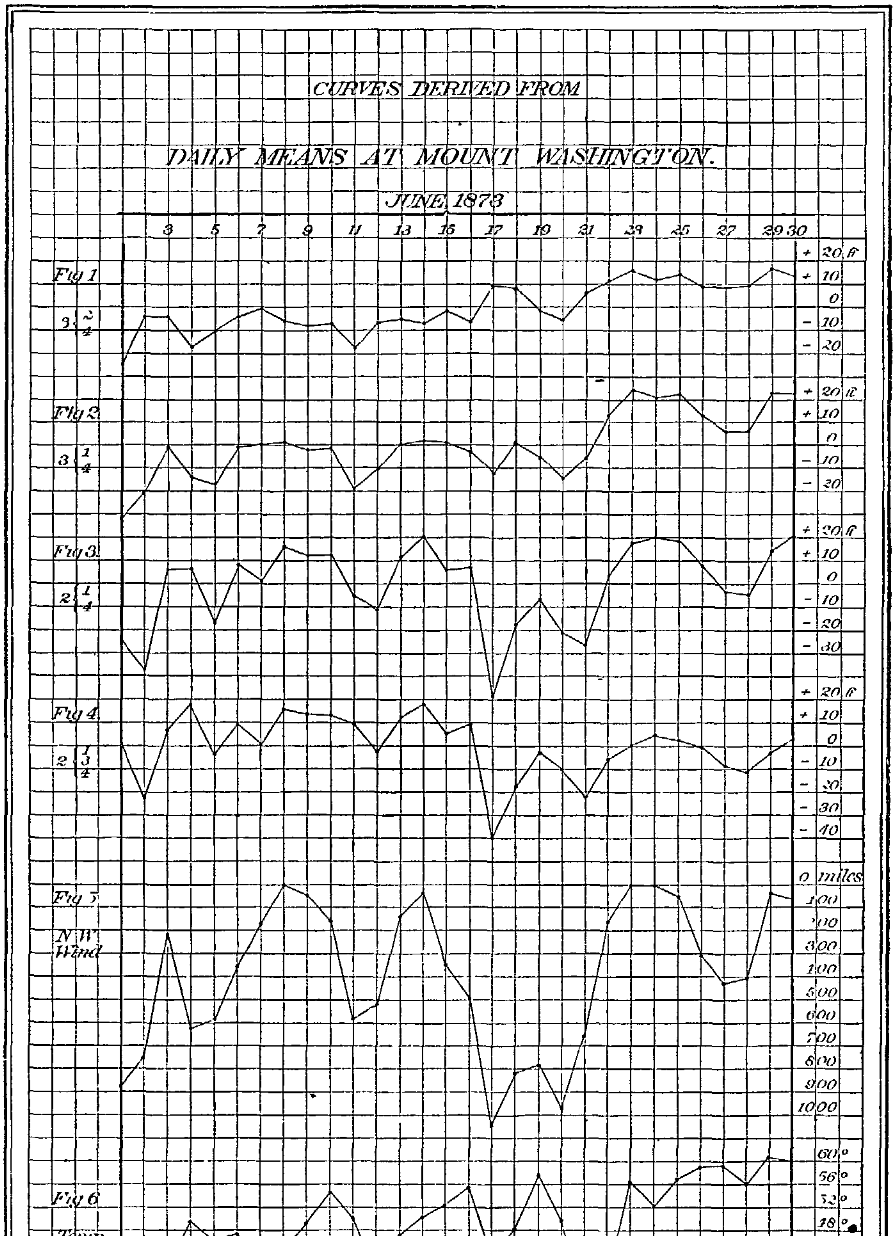

CURVES DERIVED FROM
DAILY MEANS AT MOUNT WASHINGTON.
JUNE, 1873
3 5 7 9 11 13 15 17 19 21 23 25 27 29 30
Fig 1
Fig 2
Fig 3
Fig 4
N W
Wind
0 miles
100
200
300
400
500
600
700
800
900
1000
Fig 6
Temp
60°
56°
52°
48°
44°
40°

TABLE XXXI

Comparing Mean Residuals of Determinations of the Height of Station 2, Mount Washington, by means of Two Bases and by means of Three Bases

Observations.	Base Stations		Ratio
	Stations 1, 4.	Stations 1, 3, 4	
	Feet	*Feet*	
30 daily means	14 6	9 9	100 68
Hourly means for the month of June	2 2	1 6	100 . 73
192 individual hours, June 23 to June 29	11 8	9 4	100 80
Mean			100 · 75

There is one feature of this table the appearance of which was not anticipated, and which has led the writer to extend the inquiry. It is a familiar general fact that the employment of means of observations in computations of this character diminishes the discordance of results, but in this particular case the determinations from thirty daily means are less accordant than the determinations from observations at the individual hours of the eight-day series. It would appear, therefore, that there is some disturbing factor which is subject to great variation from day to day and whose influence neither formula succeeds in eliminating; and it is manifestly important to our discussion that the nature of this factor be ascertained.

In Plate LIX various data derived from daily means of the month's observations are plotted, so as to exhibit their relations to the eye. The vertical lines indicate days and the horizontal lines for each of the upper four curves indicate computed altitudes, the space between each two consecutive lines representing ten feet. The curves therefore present the daily variations of computed altitude. In the computations affording the first curve the determined point was Station 3 and the base stations or reference points were Stations 2 and 4. In the case of Figure 2 the new station was the same, but the reference points were Stations 1 and 4. In the computations for Figures 3 and 4 the new station was Station 2, and the reference points were Stations 1 and 4 and Stations 1, 3, and 4, respectively. Figures 3 and 4 are plotted from the data contained in Table XXX.

An inspection of these curves shows, first, that they have a general similarity, differing chiefly in the magnitude of their undulations; and, second, that their most aberrant elements are minima, the maxima not ranging so far from the mean line. A comparison of the third curve, which was derived from a computation by means of two bases, with the fourth curve, which represents the same quantity derived from a computation by means of three bases, shows that the effect of the addition of the third base station was to diminish, but not remove, all the greater inequalities.

The curve exhibiting the least irregularity (Figure 1) is the only one derived independently of the observations at Station 1; and by this we are led to suspect that the influence of the disturbing factor is especially exhibited by the observations at that station. This suspicion is strengthened by a comparison of Figures 2 and 3, for the nature of the computations upon which they are based is such as to give a relatively small influence to the observations at Station 1 in the determination of the elements of Figure 2. In searching for the disturbing factor, we are therefore led to give especial attention to the observations made at the summit.

The published record of the observations gives for each of the four stations, not merely the barometric pressure, but the temperature and humidity of the air, the direction and velocity of the wind, the character and extent of the clouds, and the amount of precipitation; and thus enables us to compare our hypsometric variations with all the important meteoric factors. The curves of computed altitude were compared in turn, first, with the general humidity of the air; second, with the difference between the humidity observed on the summit and that observed at the lower station; third, with the rainfall; fourth, with the prevalence of clouds, and especially with the presence or absence of clouds enveloping the summit of the mountain; fifth, with the force of the wind, especially on Station 1; sixth, with the direction of the wind, especially on Station 1; seventh, with the temperature on Station 1; eighth, with the general temperature of all the stations; ninth, with the progressive rise and fall of the barometer; and tenth, with the difference between the atmospheric pressures on Station 1 and on Station 4. Among all these factors only two were found to exhibit any sympathy with the variations in computed altitude, the first being the general temperature and the second the wind.

The curve at the bottom of the plate (Figure 6) shows the oscillation of the mean temperature at the four stations, taken collectively, during the month,* and it is evident that there is a general correspondence of its maxima and minima with those of the most strongly marked curves of computed altitude. Whenever the hypsometric results were especially low the general temperature also appears to have been exceptionally low. Nevertheless, there appears no good reason to believe that the variations in the computed altitude were caused by the variations in temperature, for the only manner in which the temperature of the air can affect computations of altitude by the new formula is through differences of temperature between higher and lower layers of the air, and the records show that the differences of temperature between the highest and lowest stations of the series underwent far less change than the general temperature,—and, moreover, *that its changes did not* sympathize

*In the derivation of these means the observations for the entire twenty-four hours were not employed, but only those at 7 a. m., 2 p. m., and 9 p. m., that at 9 o'clock receiving double weight.

with the hypsometric variations. Our attention is therefore directed to the wind as the most probable source of the difficulty.

In the relation of the wind to the hypsometric results, not only force but direction and locality are concerned. That is to say, at one of the stations a great influence appears to have been exerted by wind in a certain direction—an influence proportioned to its strength—while winds from other directions had comparatively little influence. As will be shown in the sequel, the potent wind was that from the northwest (including also the north and west winds), and when that blew, all determinations of altitude involving the summit as a base station were comparatively low. Figure 5 of the plate exhibits for each day the total amount of wind reaching Station 1 from the northwest, expressed in miles, and a comparison with the curves above shows the close sympathy between the wind and the hypsometric results.

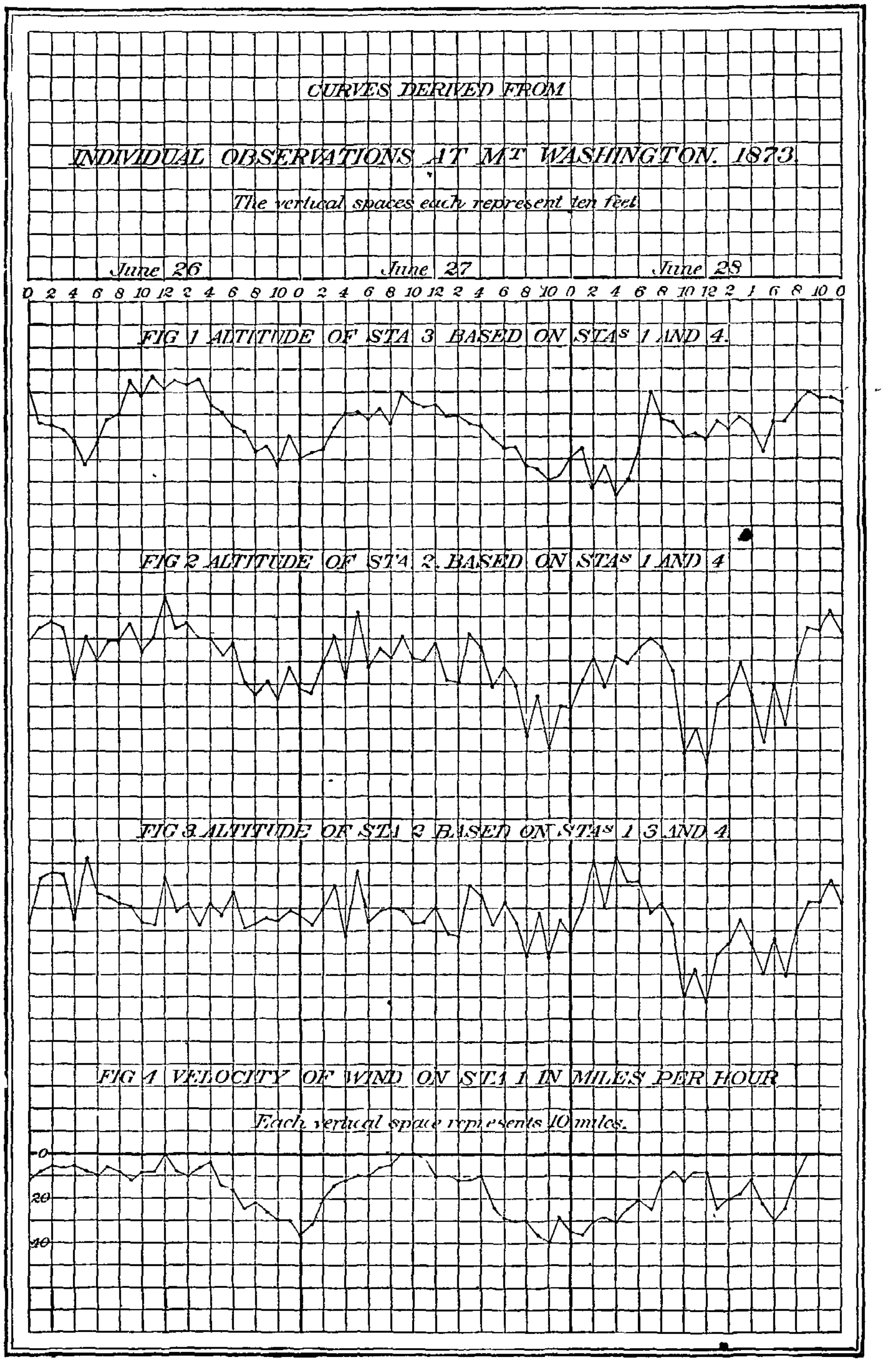
There are several different ways in which wind may be conceived to influence the computation of altitude. In the first place, it may by mere horizontal transfer give to the upper parts of the local atmospheric column an abnormal and incongruous temperature or degree of humidity. The winds upon the summit of Mount Washington are of great velocity as compared with those at the lower stations, and not unfrequently have a different direction, and it must often happen that they bring about changes in the condition of the upper strata of air which are not immediately shared by the lower. Nevertheless, when the record is scanned to ascertain the nature of these changes, it is found that in the case in question the cold air introduced from the northwest has very quickly brought the temperature of the valley into a normal relation with that at the summit, and that the differences in moisture, although they have frequently been considerable, have not been of such nature as to account for the variation of altitude determinations.

A second method of connecting winds with hypsometric inequalities is by means of gradients. The prevalence of a high wind upon the summit of the mountain, even though the valley at its base is possessed by a calm, is indicative of gradient; but the most rapid gradient it is possible to assign to it would amount to very little in the short space of three miles, and could not account for more than the tenth part of the observed discrepancies in computed altitude.

A third manner in which the wind might exert an influence, and the only manner in which its influence appears competent to produce the results, is by affecting the tension of the air in the observatory. It has already been pointed out that the wind tends to modify the tension of the air in every room to which it has access, rendering it abnormally great in some cases, and abnormally small in others, and that the effect produced in any particular room may vary with the direction of the wind. In the case of the Mount Washington observatory we do not know what the arrangement of the apertures was during the making of these observations, and even if we did know we might be unable to determine deductively their influence upon the barometer; but we have reason to believe that such velocities of wind as were recorded by the observer are competent, under suitable conditions, to affect the barometer as it seems to have been affected, and we are therefore permitted, in the absence of other explanation, to ascribe the anomalies of the hypsometric results to errors wrought by the horizontal pressure of the wind in the observations of the vertical pressure of the atmosphere.

A further illustration of the same relation appears in Plate LX, where a series of altitude determinations from individual observations are compared with the simultaneous velocities of the wind upon the summit. The first and second curves show for three consecutive days the hourly variations in the determinations of the altitudes of Stations 2 and 3, referred to two base stations (1 and 4). The third curve shows the corresponding variation in the altitude of Station 2, as computed by the aid of three bases (1, 3, and 4). The fourth curve gives the recorded velocity of the wind at Station 1, in miles per hour, the direction of wind being continuously from the northwest. Not all the oscillations of the hypsometric curves reappear in the wind curve, but the greater number of them do.

These comparisons of curves, however, serve to do little more than illustrate the general relations of the phenomena. More precise conclusions have been reached by a series of classifications, to which we now proceed. The plotted wind curves refer to a single station only, but while that station experienced the strongest winds, the other three were yet subject to winds of greater or less force, and the inquiry would be incomplete if these were ignored. We have therefore classified the winds at each of the stations according to the magnitudes of the coincidently determined altitudes. For this purpose we have employed the series of determinations made from the hourly observations during the eight days from June 22 to June 29. The determinations of the altitude of Station 2 above Station 4 by reference to Stations 1 and 4 as bases, range from 2,775 feet to 2,859 feet. We have grouped these in four divisions, as indicated by the first column of Table XXXII, the first group embracing a range of 25 feet and the other three groups of 20 feet each. For each station we have taken from the published record the corresponding wind velocities at the three stations involved in the computation, and for each group we have added these velocities and obtained their arithmetic mean; the mean velocities appear in the third, fourth, and sixth columns of the table. A parallel series of computations, by which the altitude of Station 3 was derived from Stations 1 and 4 as bases, has been treated in the same manner, and the figures are arranged in the second division of the same table. A third series of computations, by which the altitude of Station 3 was deduced from Stations 2 and 4 as bases, has been similarly treated, and the results embodied in the third and lowest division of the same table.


CURVES DERIVED FROM
INDIVIDUAL OBSERVATIONS AT M^T WASHINGTON. 1873.
The vertical spaces each represent ten feet.
June 26
June 27
June 28
0 2 4 6 8 10 12 2 4 6 8 10 0 2 4 6 8 10 12 2 4 6 8 10 0 2 4 6 8 10 12 2 4 6 8 10 0
FIG 1 ALTITUDE OF STA 3 BASED ON STA^S 1 AND 4.
FIG 2 ALTITUDE OF STA 2 BASED ON STA^S 1 AND 4
FIG 3 ALTITUDE OF STA 2 BASED ON STA^S 1 3 AND 4
FIG 4 VELOCITY OF WIND ON STA 1 IN MILES PER HOUR
Each vertical space represents 10 miles.
0
20
40

Inspecting the table, we note, first, that the mean wind at Station 3 and Station 4 was in all cases light, and that the numbers expressing it do not form progressive series as they stand in the table. As a matter of fact, the wind at those stations did not at any time during the eight days exceed ten miles per hour in velocity, and its influence upon the computations has in no wise been detected.

The wind at Station 1 attained a maximum velocity of forty miles per hour, and its mean velocities for the different groups of determined altitudes, as exhibited in the table, are not only of notable amount in some instances, but they form in each case a strongly characterized, progressive series, the strongest wind corresponding to the lowest determination of altitude, and *vice versa*. In the two cases here cited, Station 1 is regarded only as an upper base station, and the first and second divisions of the table agree in showing that the influence of wind at that station tends to diminish the dependent determinations of the altitudes of lower stations.

TABLE XXXII.

Velocities of Wind at Stations on Mount Washington, Arranged According to Corresponding Determinations of Altitude.

Altitude of Station 2, computed from Stations 1 and 4	Number of Determinations	Mean Velocity of Wind, in Miles per Hour			
		At Station 1	At Station 2	At Station 3	At Station 4
2775–99	9	20.9	19.4	...	3.9
2800–19	43	17.4	17.4	...	3.6
2820–39	108	5.9	9.4	...	3.4
2840–59	32	3.8	6.2	...	3.5
Station 3, computed from Stations 1 and 4					
1210–29	10	28.3	...	2.6	2.7
1230–49	60	13.5	...	2.8	3.6
1250–69	117	4.7	...	2.8	3.5
1870–79	5	5.0	...	1.8	2.8
Station 3, computed from Stations 2 and 4					
1210–29	4	...	15.7	2.2	2.0
1230–49	60	.	12.2	2.0	3.5
1250–69	127	.	10.1	3.2	3.5
1270–79	1		8.0	0.0	1.0

At Station 2 the maximum wind was thirty miles per hour, and the means, just as in the case of Station 1, form progressive series, the maximum velocities corresponding to low determinations of altitude and the minimum velocities to high. The sympathy of the wind with the altitude is less perfect in this case, however, than in the case of Station 1.

Moreover, while Station 2 is the upper base station in the case represented by the third example of the table, it plays the role of new station in the first example; and this difference of relation has an important bearing upon the interpretation of the figures. The barometer reading at Station 2 enters the computations in the two cases in such different ways that errors of the same nature have opposite influences upon the determinations of altitude. If, therefore, Station 2 as upper base station affords altitudes varying inversely with the force of the wind, as new station it should afford altitudes varying directly with the force of the wind. The indications of the two divisions of the table are therefore contradictory, and to harmonize them it seems necessary to assume that the more powerful winds upon Station 1 dominated in those computations involving both Station 1 and Station 2, and compelled the winds at Station 2 (usually sympathetic) to fall into the table in an order not truly representative of their influence in the computations. However this may be, the second and third cases exhibited by the table are preferable for the purpose of the investigation, because each includes only one station characterized by strong winds, and attention will be directed in the next procedure exclusively to them.

Having thus ascertained that the velocities of wind at Stations 1 and 2 are related to the magnitudes of altitudes determined by computations in which those stations enter as bases, and having reason to think that this relation is one of cause and effect, we now proceed to inquire how great effects are produced by winds of given velocities. For this purpose we reverse our previous process; first grouping the observations of wind according to velocities, and then determining the means of the corresponding computed altitudes. In the first case, winds were arranged according to computed altitudes; in the second, computed altitudes according to winds.

TABLE XXXIII

Hourly Determinations of Altitude at Mount Washington for eight days in June, 1873, Arranged According to the Velocity of the Wind.

Velocity of Wind at Station 1, in miles per hour	Altitude of Station 3, determined from Stations 1 and 4 as Bases		Velocity of Wind at Station 2, in miles per hour	Altitude of Station 3, determined from Stations 2 and 4 as Bases	
	Number of Independent Determinations.	Mean Altitude		Number of Independent Determinations.	Mean Altitude.
		Feet.			*Feet.*
0–5	96	1,254	0–5	46	1,252
6–15	60	1,251	6–15	97	1,254
16–25	19	1,248	16–25	43	1,248
26–35	13	1,231	26–30	6	1,249
36–40	4	1,228	....	....	.. ..

Table XXXIII comprehends two divisions. In each the determined altitude is that of Station 3 above Station 4, but in the first the upper base station is Station 1, while in the second it is Station 2. The first column in each division defines the groups of wind velocities at the upper station, the first group including all velocities from 0 to 5 miles per hour, and each succeeding group (except the last) including a range of 10 miles. The second column shows how many sets of observations fall within each group, and the third gives the means of the corresponding altitudes. The altitudes dependent upon the summit station as one of the bases exhibit a perfect sympathy with the velocity of the wind, forming a progressive series with a range of 26 feet. The altitudes dependent upon Station 2 exhibit a less perfect sympathy with the wind velocity and do not form a consistent series. Their range is 6 feet only, and they indicate that the influence of the wind is there very small. Nevertheless, the ways in which the barometer readings of Station 1 and Station 2 respectively enter into the computations of the altitude of Station 3 are such that the errors in the readings at Station 2 should have the greater influence. We are at liberty to conclude, therefore, that the element of locality enters largely into the influence of the force of wind upon the reading of the barometer, and that its influence was much greater upon the barometer read at the summit than upon that read at Station 2. In continuing the investigation for the purpose of learning more definitely the nature of the effect of the wind, we shall consequently restrict our attention to computations involving only Station 1, where the wind had greatest influence, and Stations 3 and 4, where its velocity was never great.

The next point to consider is the part played by the *direction* of the wind, for it has appeared by inspection of the record that some winds are more potent than others. In pursuance of this inquiry the hourly determinations of altitude for the eight June days were plotted upon section paper in such way that the horizontal scale represented heights and the vertical scale wind velocities. Each individual determination was indicated by a dot, and the color of each dot was made to show the corresponding direction of the wind. Displayed in this way, the determinations were seen to fall in two principal groups, the first of which included those associated with the north, northwest, and west winds, and the second those associated with the east, southeast, south, and southwest winds. The determinations corresponding to northeast winds were too few and too widely scattered to be confidently assigned to either group. A transcript from this plotting is given in Plate LXI, where the upper figure represents the northerly group and the lower the southerly. The determinations made during the existence of a calm appear in both figures, since the calm is the zero for all directions of wind. The vertical scale in each figure represents velocities of wind upon Station 1, in miles per hour; the horizontal scale represents computed altitudes, in feet, of Station 3 above Station 4.

The sympathy of the computed altitude with the velocity of northwesterly winds is exhibited in Figure 1 by the drifting of the upper dots to the left and of the lower dots to the right, while the absence of this sympathy in the case of the remaining group of winds is shown by the fact that in Figure 2 no one of the higher dots falls without the horizontal range of the determinations corresponding to a calm.

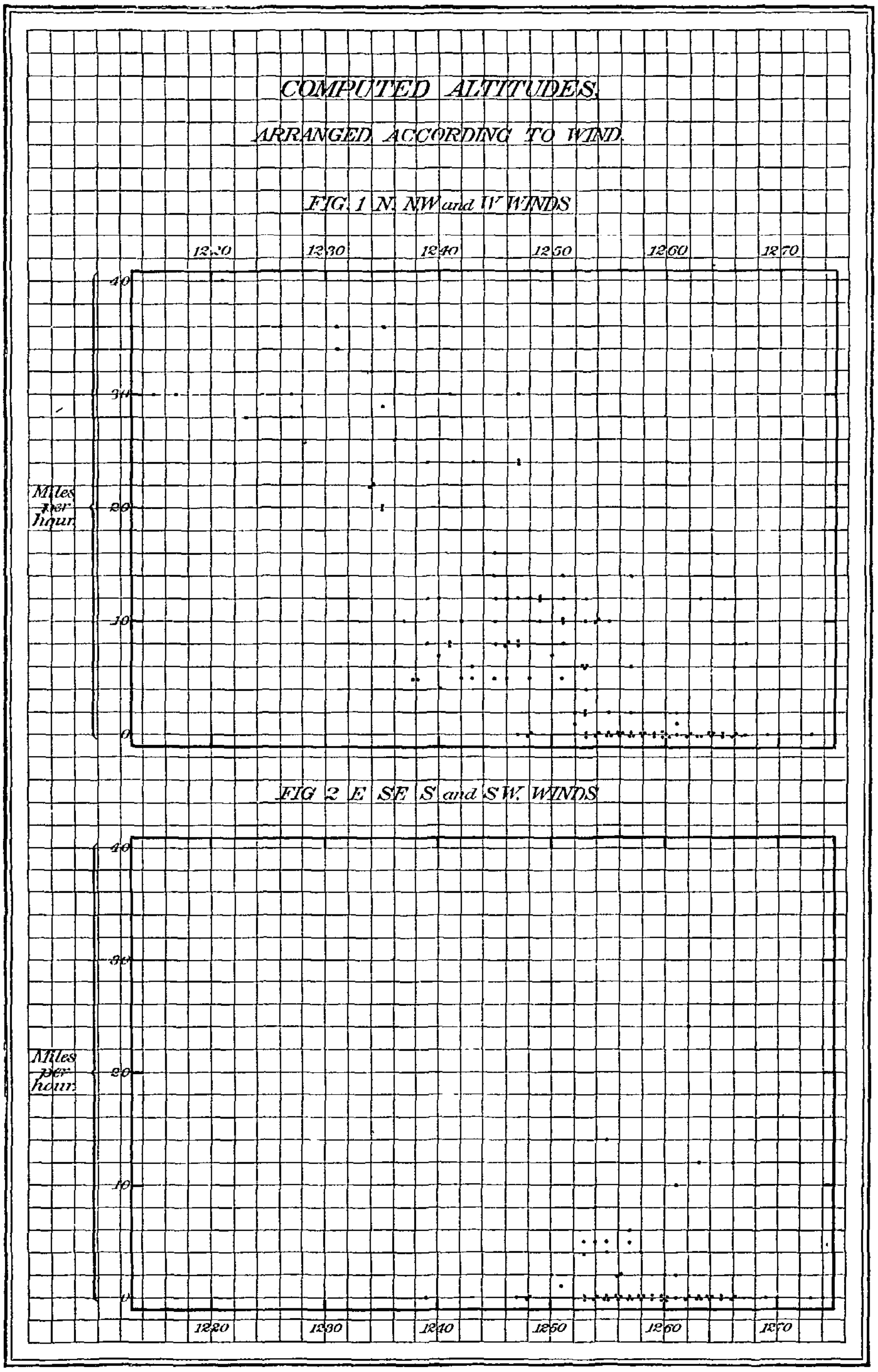
It happens, however, that during the eight days for which the hourly computations were made, there were no winds from the south or east comparable in force with the strongest winds from the northwest, so that the comparison exhibited by the plate is not entirely satisfactory. Indeed, the dots pertaining to the southerly group of winds really fall within the range of the dots pertaining to the northwesterly, and they are so few in number that the direction of their drift cannot be confidently asserted. To secure a more definite result a few additional computations were made, and the data for Table XXXIV were assembled.

TABLE XXXIV.

Relation of Computed Altitudes of Station 3, on Mount Washington, to the Direction of Wind at Station 1.

	Wind with Velocity of 20-30 Miles per Hour, from the—		No Wind			
			1,273	1,262	1,259	1,255
	N. W	S. W	1,272	1,262	1,258	1,255
			1,270	1,261	1,258	1,254
Computed Altitudes.	*Feet*	*Feet*	1,269	1,261	1,258	1,254
	1,260	1,267	1,267	1,261	1,258	1,253
	1,258	1,266	1,266	1,261	1,257	1,253
	1,247	1,265	1,266	1,260	1,257	1,253
	1,244	1,262	1,265	1,260	1,257	1,253
	1,243	1,259	1,265	1,260	1,257	1,252
	1,239	1,257	1,264	1,260	1,257	1,252
	1,236	1,255	1,264	1,260	1,256	1,252
	1,235	1,254	1,264	1,260	1,256	1,251
	1,235	1,252	1,264	1,260	1,256	1,250
	1,234	1,249	1,263	1,259	1,256	1,248
	1,234	1,249	1,263	1,259	1,256	1,248
	1,228	1,249	1,263	1,259	1,255	1,248
	1,227	1,241	1,262	1,259	1,255	1,247
	1,221					1,246
Mean..	1,239±2	1,256±2	1,258 5±0.5			

The first column contains heights selected from the eight-day series of determinations, and includes all the values of the altitude of Station 3 determined during the prevalence on Station 1 of a wind from the northwest with a velocity from 20 to 30 miles per hour. To obtain the corresponding quantities in the second column the entire record for the month was searched, and a similar computation of altitude was made for each hour at which the wind upon Station 1 was from the southwest and had a velocity of 20 to 30 miles. The third column, which is divided on account of its length into four parts, contains all those determina-


COMPUTED ALTITUDES.
ARRANGED ACCORDING TO WIND.
FIG. 1 N. NW and W. WINDS.
1220
1230
1240
1250
1260
1270
Miles per hour
40
30
20
10
0
FIG. 2 E. SE. S. and S.W. WINDS.
40
30
20
10
0
Miles per hour
1220
1230
1240
1250
1260
1270

tions of the eight-day series made when the wind on Station 1 did not exceed 2 miles per hour. The first column represents, by 14 examples, the effect of a 25-mile wind from the northwest; the second column, by 13 examples, the effect of a 25-mile wind from the southwest; the third column, by 69 examples, the influence of a calm. For facility of comparison the numbers in each column are arranged in numerical order. Comparing first the northwest wind with the calm, it will be perceived that the mean of the determinations affected by the former is 19½ feet less than the mean of the determinations affected by the latter. That this difference is not accidental is attested, first, by the fact that the probable errors of the two determinations are comparatively very small, and, second, by the fact that the two series of numbers do not greatly overlap. Only a single determination with northwest wind is greater than the mean of those with no wind, and there is no determination of the no-wind series so small as the mean of those with northwest wind. The influence of the northwest wind is therefore clearly revealed.

Comparing now the southwest wind with the calm, we find that the means of the two corresponding series of determinations differ from each other by 2½ feet only, an amount which is accounted for by their probable errors—that is to say, the determinations approach each other within the range of their uncertainties. We cannot affirm, therefore, that the southwest wind exerts any influence upon the determination of altitude. If it does exert any it certainly is slight as compared with that of the northwest wind.

We need not extend the comparison, for the precise influence of individual winds at the given station at the given time is not a matter of present importance. It is sufficient to have established the fact that not all winds exerted the same influence, but that direction, as well as velocity, was concerned in the perturbations of the barometer.

Having ascertained that the observations at Station 1 were more influenced by wind than those at Station 2, and that the northwest was one of the more potent winds at Station 1, we now proceed to seek a quantitative expression for the influence of that wind. For this purpose it is desirable to contrast the strongest winds with a calm. The record for the entire month has accordingly been searched and two series have been selected, the first characterized by winds with velocities from 50 to 56 miles per hour, the second by winds with velocities from 60 to 68 miles. The first series numbers ten, the second seven. For each hour of each series the altitude of Station 3 has been computed, as in the last example; and the resulting determinations will be found in the second and third columns of Table XXXV. The first column of the table repeats from the preceding table the numbers corresponding to a calm.

TABLE XXXV.

Relation of Computed Altitudes of Station 3, Mount Washington, to the Velocity of the Northwest Wind at Station 1.

	Reported Velocity of Wind, in Miles per Hour								
	0 to 2.							50 to 56.	60 to 68.
Computed Altitudes.	1, 273	1, 264	1, 261	1, 259	1, 257	1, 255	1, 252	1, 234	1, 218
	1, 272	1, 264	1, 261	1, 259	1, 257	1, 255	1, 252	1, 231	1, 216
	1, 270	1, 264	1, 261	1, 259	1, 257	1, 255	1, 251	1, 230	1, 214
	1, 269	1, 263	1, 260	1, 259	1, 257	1, 254	1, 250	1, 229	1, 207
	1, 267	1, 263	1, 260	1, 259	1, 256	1, 254	1, 248	1, 226	1, 205
	1, 266	1, 263	1, 260	1, 258	1, 256	1, 253	1, 248	1, 226	1, 192
	1, 266	1, 262	1, 260	1, 258	1, 256	1, 253	1, 248	1, 225	1, 185
	1, 265	1, 262	1, 260	1, 258	1, 256	1, 253	1, 247	1, 223	
	1, 265	1, 262	1, 260	1, 258	1, 256	1, 253	1, 246	1, 223	
	1, 264	1, 261	1, 260	1, 257	1, 255	1, 252		1, 221	
Mean.	1, 258 5±0. 5							1, 226. 8±0. 8	1, 205. 3±3. 2

The series of numbers in the three columns are mutually exclusive. The altitudes computed during a calm, range from 1,273 to 1,246 feet; those during the prevalence of a 50-mile wind, from 1,234 to 1,221; those during the prevalence of a 60-mile wind, from 1,218 to 1,185. This phenomenon cannot be referred to temporary conditions or other accidents. The observations represented by the first series are scattered through eight days; those affording the 50-mile series of altitudes, through a period of five days. Only the observations for the 60-mile series are grouped closely together in the record.

The same mutual exclusiveness is indicated by the probable errors of the means, which it will be seen are very small as compared to the differences between the means. The mean altitude determination affected by the 50-mile winds is 31.7 feet smaller than that affected by a calm, and the probable error of this difference is only ± 1 foot; while that associated with the 60 mile winds is 53.2 feet smaller, with a probable error of ± 3.2 feet.

It remains to compare the dynamic equivalents of these errors in computed altitude with the pressures of the corresponding winds, and to accomplish this we shall estimate each in terms of the mercurial inch.

The measurement of the wind on Mount Washington was made by means of a cup-anemometer, an instrument recording the velocity of a set of cups revolved by the wind. Theoretically, the velocity of the wind is three times that of the cups, and in the velocities reported by the Signal Service the factor 3 was used in the reduction. It has been more recently ascertained by Dohrandt, however, that in practice the revolution of the cups is more rapid, and that the proper factor for such an instrument as that used on Mount Washington is 2.4 instead of 3*.

* Repertorium fur Meteorologie. Memoir No. 5, 1878. Bestimmung der Anemometer-Constanten, von F. Dohrandt.

The recorded velocities are therefore too great and need to be reduced twenty per cent. After making this allowance, the mean velocity of wind corresponding to the second column of Table XXXV is found to be 41.6, and that corresponding to the third column 50.2 miles. The equivalent pressures, expressed in inches of the mercurial column, are .122 and .177. These numbers appear in Table XXXVI.

Assuming, as we certainly are warranted to do, that the synchronous variations in the computed altitude of Station 3 are due to perturbations of the barometer at Station 1, we proceed to ascertain the nature and amount of those perturbations. It is needless to detail the computation, which can be readily inferred from the part played by the pressure at Station 1 in the computation of altitude. Suffice it to say that the change in the barometric pressure at Station 1 necessary to produce the observed variation in the determined altitude of Station 3 is .078 inch in the case of the weaker wind and .132 inch in the case of the stronger. The nature of this change is a depression—that is to say, in order to account for the diminution in the computed altitude we must assume that the barometer was relatively low during the prevalence of the stronger winds. The effect of the wind was therefore to diminish the tension in the observatory at Station 1, and not to increase it.

Comparing now the deduced depression of the barometer with the coincident pressure of the wind, we find that it approaches the latter in amount but does not equal it. In the case of the less violent wind, the barometric depression is 64 per cent of the barometric column expressing the force of the wind, and in the case of the more violent it is 75 per cent. (See Table XXXVI.)

TABLE XXXVI.

Comparison of the Pressures of High Northwest Winds on Mount Washington with the Coincident Depressions of the Barometer.

	Series I	Series II	Series III.
Number of observations	69	10	7
Mean velocity of wind (recorded) in miles per hour	0	52.0	62 7
Mean velocity of wind (deduced) in miles per hour	0	41.6	50 2
Pressure of wind, expressed in barometric inches .. (A)	0	122	.177
Computed altitude of Station 3 (mean), in feet	1258.5±0.5	1226.8±0.8	1205.3±3.2
Error in computed altitude caused by wind, in feet	0	— 31 7	— 53 2
Equivalent depression of barometer on Station 1......(B)	0	078	132
Ratio of barometric depression (B) to synchronous pressure of wind (A)	....	64	.75

It has been shown by Hagemann by a series of ingenious experiments that the power of suction exerted by the wind in blowing over an aperture approximates closely, under favorable conditions, to the force of the wind; and there appears warrant for his conclusion that the quantitative limit to its exhausting power is equal to its horizontal pressure.* We may therefore conclude that in referring the hypsometric error under consideration to the local influence of wind upon the tension of the air in the observatory, we are appealing to a cause which is quantitatively sufficient, and our demonstration is thus rendered as complete as it could be without actually visiting the observatory and examining and experimenting upon its apertures. This indeed is impracticable, first, because the observatory now in use upon Mount Washington is not the one used during the month of June, 1873, and, second, because the records of the Signal Office fail to show precisely what building was occupied at that time. It is probable, however, that the building actually used stood upon the northwest side of the absolute summit of the mountain, so that of the winds rushing past it those from the northwest had an upward tendency, while some others had not. During the prevalence of a high wind there can be little doubt that the principal opening in the building was the chimney, and if the orifice of that was turned upward, a strong draft would be created by a wind tending obliquely upward. There is a fair presumption, therefore, that the northwest winds communicated their influence to the barometer of the observatory by means of the draft of the chimney.

The result of our inquiry was not in the least anticipated, but it is none the less valuable. It gives us an additional reason for assigning a low weight to all hypsometric determinations made by means of the barometer during the prevalence of a high wind, and it directs attention to the importance of devising means for the elimination of this particular wind influence, not only from the data for hypsometry, but from meteorologic data in general. The discussion of such corrective means would be out of place here, since it pertains in no wise to the new hypsometric method, but a brief consideration will be given to it in a note at the end of the paper.

The facility afforded by the new formula in the discussion of series of observations, and the fact that it has here led to the detection of a systematic error of observation, testify to the soundness of the principles upon which it is founded and encourage the belief that it will find a sphere of usefulness outside its special hypsometric province.

We now return to the main subject of this section—the consideration of the possible advantage to be gained by increasing the number of base stations from two to three. Having learned that the observations previously used to test the matter were to a certain extent vitiated by the local influence of winds, we now repeat the test with the aid of a selected series of well conditioned observations. In the first place, we reject from the eight-day series in June all those hours at which the wind at any one of the four stations equaled or exceeded a velocity of ten miles per hour; and from the observations made at the remaining

* Annuaire pour l'année 1876 de l'Institut Meteorologique Danois "Sur les anemometres," par G. A Hagemann.

74 hours compute the height of Station 2 by the method with a double base, and again by the method with a triple base. The rejection of the observations dominated by wind increases the mean of the determinations of height from 2,828 feet to 2,836 feet, and it diminishes the average deviation of individual determinations by the aid of two base stations from 11.8 to 7.7 feet. It diminishes also the average deviation of determinations by the aid of three bases from 9.4 feet to 7.8 feet. It therefore improves the harmony among themselves of the individual determinations by either method; but it removes at the same time the apparent advantage of the method with three bases, for the selected observations give no better result with three bases than with two.

TABLE XXXVII.

Altitude Determinations on Mount Washington, from Individual Observations made when the Velocity of Wind was Less than Ten Miles per Hour.

Method of Computation.	Height of Station 2 above Station 4, Mean of 74 Determinations	Average Deviation of individual Determinations from Mean.
	Feet.	*Feet*
By Double Base (Stations 1 and 4)	2835. 5	7 7
By Triple Base (Stations 1, 3, and 4)	2836. 2	7 8

To continue the comparison, a selection has been made from the thirty days of June, 1873, of those ten days on which the wind at Station 1 on Mount Washington was least, and the altitude of Station 2 was computed by the two methods for those days. The results are displayed in Table XXXVIII, and are still less favorable to the triple base, the mean residual being increased by its use from 4.9 to 6.5.

TABLE XXXVIII.

Altitude Determinations at Mount Washington from Daily Means of Pressure Observations. The Ten Days of June, 1873, exhibiting the Lowest Mean Velocity of Wind.

Date.	Height of Station 2 above Station 4, computed from—			
	Stations 1 and 4		Stations 1, 3, and 4	
	Altitude.	Residual	Altitude	Residual.
	Feet	*Feet.*	*Feet*	*Feet*
June 8	2, 825 6	— 6. 7	2, 834. 8	+ 2, 6
9	2, 831 3	— 1 0	2, 841 9	+ 9 7
13	2, 830 2	— 2 1	2, 838 7	+ 6 5
14	2, 839 4	+ 7 1	2, 846 0	+ 13 8
22	2, 822 6	— 9 7	2, 821 2	— 11 0
23	2, 837. 3	+ 5 0	2, 827 5	— 4 7
24	2, 838 8	+ 6 5	2, 831. 8	— 0 4
25	2, 837 5	+ 5 2	2, 829 5	— 2 7
26	2, 827 1	— 5 2	2, 826 2	— 6 0
29	2, 833 2	+ 0 9	2, 824 6	— 7 6
Mean	2, 832. 3	4 9	2, 832 2	6 5

These two tests are indeed inconclusive, by reason of the brevity of the series of observations upon which they are based, but they serve to suggest that the error which in the first group of tests appeared to have been eliminated by the introduction of the third base, may have been, in whole or in part, that caused by the pressure of the wind; and they certainly give no warrant for the belief that with properly conditioned observations the employment of three base stations will afford a higher degree of precision than the employment of two. It should be said, however, that the Mount Washington series of observations, although the best available for the discussion of this question, are not the best conceivable, and it is not impossible that a more exhaustive treatment of the subject may at some future time vindicate the utility of the triple base.

5. BETTER FORM FOR THERMIC TERM.

In the construction of the new hypsometric formula, it was postulated that the vertical change of density dependent upon temperature and moisture is uniform at all altitudes, but we have no reason to believe that this assumed law of distribution is true. Indeed, we are assured that it does not obtain in any specific case, so that it is only in general averages that it can possibly represent the actual facts.

There are no present means of testing it, but it is easy to project a system of observations which would serve to illuminate the subject. If a string of meteorologic stations, as many as five in number, were established upon a steep mountain slope in such way that their local conditions were closely similar except in the matter of altitude, while their altitudes formed a uniform series, the discussion of their observations would accomplish the desired result. The pressure differences of the successive stations, taken in connection with the known differences of altitude, would afford the densities of the several segments of the total atmospheric column, and would enable the law of their succession to be developed.

The same string of stations would serve to determine the constant of the formula and would afford material for the satisfactory discussion of diurnal and annual periodicity in hypsometry by the new method.

If the essential incompetence of the postulated law of density variation were demonstrated by such an investigation, it would become necessary to give a different form to the thermic term of the formula, but at present there appears no ground for the suggestion of a change.

6. GENERAL PROVISION FOR NON-PERIODIC GRADIENT.

The atmospheric inequalities affecting barometric hypsometry may be broadly classified as vertical and horizontal. The vertical inequalities, or the variations of density in the local vertical column, are the sole objects of consideration alike in the new hypsometric method and in what we have called the ordinary and the empiric methods. The horizontal inequalities, which consist chiefly of gradients,—annual, perennial, and non-periodic or cyclonic,—are not considered by any formula in use. The only manner in which hypsometry practically attempts to avoid their influence is by using the means of long series of observations, and the advantages of this procedure cannot be reaped by ordinary geographic surveys, which are unable to make a great number of observations, or even more than a single observation, at each new station. The only general device adapted to the use of the geographer is the one deriving corrections for gradient errors by means of plotted isobars, and this involves the employment of so many auxiliary base stations that it can rarely, if ever, be employed with economy when the entire expense of the stations has to be borne by the geographic work. The great development of meteorologic work, however, which has followed and is following the success of meteorologists in the prediction of storms, promises to afford the geographer, in many places, and at no distant day, the data necessary for the determination of gradients; and it is pertinent to inquire how he can employ them to the best advantage.

It is quite conceivable that a comprehensive formula could be devised in which every observed element affecting the determination of altitude would find place, and through which the result would be evolved by a single complex process; but it is probably better, as it certainly is simpler, to treat the vertical and horizontal factors separately. In the judgment of the writer the vertical factor should be treated by a hypsometric formula, properly speaking, whether that of the new method or of the ordinary; but before this is done the horizontal factor should be treated for the purpose of correcting the barometric data intended for use in the hypsometric computation.

It is desirable that the stations used in determining gradient do not differ greatly among themselves in altitude. Let us first suppose them to have the same altitude, and let us further suppose (assuming the use of the new method) that they include among their number one of the base stations of the hypsometric pair. To ascertain the gradients at any moment we have merely to subtract the barometer reading at the hypsometric base station from each of the simultaneous readings at the auxiliary stations, and we obtain in the remainders the relative gradients of the several auxiliary stations. Plotting these upon a map we are enabled to draw lines of equal gradient (isobars) referred to the hypsometric base station as a zero. The relative gradient of the new station is then seen by reference to the position of the station on the map, and its amount, applied with the proper sign as a correction to the reading, prepares the latter for use in the hypsometric formula.

Let us now suppose that the auxiliary stations, as would usually occur, differ somewhat in altitude from the hypsometric base station with which they are compared, and that these differences are known. The relative gradient cannot now be ascertained by simple subtraction, but must be reached by a computation involving an allowance for the density of the atmosphere. Assuming that the density conditions are similar throughout the entire district, the principles upon which the new formula is based readily afford the means of making this computation.

Assume, for convenience, that that base station of the hypsometric pair which approximates in height to the auxiliary stations is the lower of the two. Represent by G the relative gradient of an auxiliary station, by h the reading of the barometer at that station, and by H the same reading after correction for gradient.

$$G = h - H.$$

Then, by the formula,—Equation (7)—

$$A = B \frac{\log l - \log H}{\log l - \log u} + \frac{A\,(B - A)}{D}$$

whence, by transformation—

$$H = \log^{-1}\left[\log l - \frac{AD - A\,(B - A)}{BD}\,(\log l - \log u)\right]$$

and by substitution—

$$G = h - \log^{-1}\left[\log l - \frac{AD - A\,(B - A)}{BD}\,(\log l - \log u)\right] \quad (22)$$

In this equation, B is the known difference in altitude between the hypsometric pair of bases, and A is the known difference in altitude between the lower base station and one of the auxiliary bases. The expression $\frac{AD - A\,(B - A)}{BD}$ is therefore constant for each auxiliary base; and in each specific case the gradient (G) is a function merely of the simultaneous barometer readings at the upper and lower base stations and at the auxiliary station. When the number of observations is great, the labor involved in the computation of the second term of the second member (H) can be abridged by the construction of a simple table.

The relative gradients of the various auxiliary stations having been thus derived, the procedure is the same as in the preceding case.

Of the practical value of the plan here proposed for determining the gradient errors of the barometer readings at the auxiliary stations, the writer is unable to judge. Like every other hypsometric device, its utility can only be demonstrated by the practical test; and like every other device, it is liable to encounter practical difficulties which cannot be foreseen. It is here developed, merely as the logical consequence of the general principle underlying the new formula—the principle which warrants the determination of the density of a column of air by a direct measurement of the density of a neighboring column of known height.

It is the belief of the writer that the perfect elimination of the influence of cyclonic gradients from hypsometry is impossible, for the reason that different systems of gradient exist simultaneously at different altitudes. However thoroughly the system of gradients in a given horizontal plane may be determined, there seems no possible method by which to deduce from it the gradient system of a higher plane, and unless this can be done a considerable element of error must always remain.

The satisfactory determination of the systems of gradient which succeed each other in mountainous districts is an unsolved problem in meteorology to which a great deal of attention has been devoted. The formula embodied in equation (22) is adapted, so far as form goes, to its solution, but there is no immediate opportunity to test it, and in the face of so many failures it would be rash to anticipate its practical success. It is barely possible, however, that it may afford trustworthy results in a somewhat larger field than that to which hypsometry would assign it,—that it may find a meteorologic as well as a hypsometric use.

7. SPECIAL PROVISION FOR NON-PERIODIC GRADIENT.

There is a special case, arising not unfrequently in geographic work, in which it is possible to escape a large gradient error by the aid of a single outlying base station. Let us suppose that a pair of hypsometric base stations (U L of the diagram) are in use, and that by their aid the altitudes of new stations in their vicinity are being determined. Let us suppose, further, that a second piece of geographic work is in progress, which demands the measuring of the altitudes of a group of new stations in the locality S N—so remote from the pair of base stations that large gradients will usually intervene, but not so remote as to cause great disparity in other meteorologic conditions. Within the interior districts of the United States these limitations would apply to distances from 100 to 300 miles.

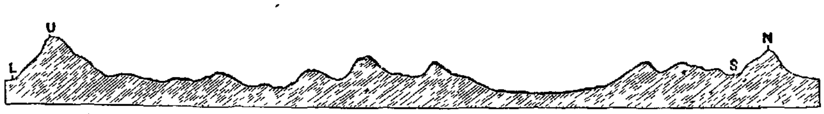


FIG. 31.—Ideal Land-Profile, to illustrate the use of an Outlying Base Station

The special procedure proposed for such a case is as follows: Establish a base station at S in the midst of the distant group of new stations, and conduct there a series of observations for so long a time as observations are made at new stations in the vicinity. In selecting the site for the outlying base station,—it is better, when feasible, to approximate it in altitude to the new stations, its vertical relation to the main pair of base stations being comparatively unimportant. If its altitude is not otherwise known, it can be computed by reference to the principal base stations, using either the entire series of synchronous observations or such a selection from them as may be indicated by the variations of wind during the period. In the computation of the new stations, refer each of them to the outlying base station, but employ the measurement of density afforded by the simultaneous observations at the pair of principal base stations.

A modification of the general formula adapts it to the special case:

Let n stand for the barometer reading at a new station of the outlying group. Represent by r the synchronous reading at the outlying base station. Call R the height of the outlying base station (S) above the lower base (L) of the pair, and A′ the height of the new station (N) above the outlying base (S). Give to l, u, B, and D the same significations as before. It is needless to repeat here the various steps by which the special formula is deduced, for the reasoning is identical with that for the derivation of the formula on page 442. We therefore write at once—

$$A' = B\frac{\log r - \log n}{\log l - \log u} + \frac{A'\left[(B - 2R) - A'\right]}{D} \quad . \quad . \quad . \quad . \quad (23)$$

In the application of this formula the table published at the end of this paper can be used, with this difference only, that in place of B as an argument the quantity B—2 R must be substituted.

In any application of the more general system for the elimination of gradients, outlined in the preceding section, it will frequently occur that the new station is situated so near to one of the auxiliary stations that the gradient referrible to the intervening distance is inconsiderable. In every such case the formula just given can be employed with economy of labor and without prejudice to precision.

8. SUMMARY.

Our search has not resulted in the discovery of an immediately practicable way of improving the new formula, but it has served to indicate a line of investigation which promises to advance the subject.

If ever a string of thoroughly equipped stations shall be established upon a steep mountain slope and maintained for a sufficient term, it is probable that the discussion of their observations will afford a new and better value for the constant of the new formula; and it is possible that it may so far define the law of the vertical distribution of thermic density that the form of the thermic term of the formula will need to be changed. It may also dictate the introduction of a factor dependent on the season of year, and it may possibly demonstrate the advantage of employing three base stations in the vertical series instead of two.

Such a discussion could not fail to throw light upon the relation of diurnal curves of pressure to altitude, and by so doing it might indicate some manner of avoiding the hypsometric errors which have a daily period.

It is believed that in general all corrections for atmospheric gradient should be applied to the barometric data previous to the introduction of the latter into the hypsometric formula; but it has been pointed out that in a certain class of cases gradient errors can be avoided by a modification of the general hypsometric method, with a corresponding modification of the formula. The modified formula (23) is in point of fact of a more general nature than the one proposed for ordinary use (7), for in it the new line is made independent of the vertical base, whereas the latter requires an extremity of the new line to coincide with an extremity of the vertical base.

It has been discovered that wind may attain importance as an unfavorable condition of observation, and the necessity for investigating its influence upon the indication of the barometer has been pointed out. The harmony of a series of altitude determinations upon the flanks of Mount Washington was increased about 40 per cent by the rejection of those based on observations made during the prevalence of winds.

The harmony of the Mount Washington determinations after the elimination of this disturbing factor, is indeed so conspicuous as to suggest that the hypsometric method has in this case almost eradicated the errors incident to abnormal atmospheric inequality,—little remaining besides the errors incident to the making of the observations. To test this matter recourse has been had to the mathematical theory of probabilities, and an attempt has been made to ascertain, first, the probable error of barometric instrumentation and the probable error of a single hypsometric determination at Mount Washington as dependent upon instrumentation; and second, the probable error proper of the same determination as deduced from residuals.

The probable error of barometric instrumentation may be defined to be that deviation from the proper or indicative height of the mercurial column which is most likely to be incurred in making an observation. It includes the errors dependent on the imperfection of the scale of the instrument, on imperfect correction for the capillarity of the tube, on the inaccuracy of the adjustments that have to be made by the observer before the reading, on the inaccuracy of the reading itself, and on the inaccuracy of the determination of the temperature of the instrument. If one has a long series of independent observations or measurements of the same quantity, he is enabled, by the application of a simple mathematical formula, to deduce the probable error of a single measurement. In the use of a single barometer such a series is not obtained, because the quantity measured—the pressure of the atmosphere—is variable, and in a series of observations it is impossible to discriminate between small errors of observation and small changes of atmospheric pressure. But when two barometers are placed side by side and are subjected to a series of synchronous observations, the differences between the readings taken in pairs constitute a series of measurements from which it is possible to deduce the probable error of instrumentation.

The writer has made six determinations—two from a series of comparative readings made in connection with the Mount Washington observations and published on page 534 of the Report of the Chief Signal Officer for 1873, and four from series contained in the barometric records of the Geological Survey. The series published by the Signal Officer were made by the same observers who occupied the four stations on Mount Washington, and with the same instruments, and would furnish the best possible criterion of the accuracy of that work if they were sufficiently extended. One of them, however, contains only five comparative readings of three barometers, and the other seven comparative readings of three barometers; and these data are too scant to afford a trustworthy estimate of the probable error. The following is a summary of the results:

Series	Number of Comparisons.	Deduced Probable Error of a Single Reading.
1 (Signal Service)	10	± .0030 inch.
2 (Signal Service)....	14	± .0030 inch.
3 (Geological Survey).......	56	± .0041 inch
4 (Geological Survey)	79	± 0032 inch
5 (Geological Survey)	100	± .0014 inch
6 (Geological Survey)	100	± .0023 inch
	Weighted Mean	± .0027 inch.

Each series of comparisons by the Geological Survey was carried through a period of several days, during which time the barometer rose or fell one or more tenths of an inch, so that different parts of the scale and tube were brought into use. The series of observations by the Signal Service observers were each made within an hour's time, and exhibit small barometric ranges. The test in the former case was therefore somewhat more rigorous, and there is no reason for presuming that a longer series of observations by the Signal Service observers would have afforded a smaller probable error of instrumentation. In assigning to each of their readings an error of ±.0027 inch (the general or weighted mean of all the determinations) we seem in no danger of underrating the precision of their work.

In the computation of altitude the errors of observation at the different stations affect the result by different amounts, and these amounts depend upon the relative and absolute altitudes of the stations. We shall not describe these relations, but merely mention that they have been taken into consideration. Taking due account of them, the assumed error of instrumentation at the several stations gives 3.8 feet as the probable error of a single determination of the altitude of Station 2 above Station 4, and 3.4 feet as the probable error of a determination of Station 3.

The individual determinations of altitude constitute a series of measurements of a constant quantity, and yield to the simple application of the mathematical formula the probable error of a single determination. Seventy-four determinations of Station 2, made at hours when the velocity of the wind did not exceed 10 miles per hour at any station, yield 6.8 feet as the probable error of a single determination. Sixty-nine measurements of the height of Station 3, made at hours when the wind upon Station 1 did not exceed 2 miles per hour, give 3.7 feet for the probable error of a single determination.

Combining these results, it appears that the probable error of a determination of Station 2, made by the new hypsometric method under favorable conditions as regards wind, is 6.8 feet, and that 3.8 feet may be assigned to instrumentation. The remaining error, which must be assigned to other causes, is expressed by $\sqrt{(6.8)^2-(3.8)^2}=\pm 5.6$ feet. The corresponding error of the determination of Station 3 is $\pm$ 3.7 feet, of which $\pm$ 3.4 feet is assignable to instrumentation, and only $\pm$ 1.5 feet to other causes.

It would be hazardous to pin our faith to these figures and affirm that the new hypsometric method has determined the height of a station with such precision that the uneliminated errors due to atmospheric inequality affect the result by less than 2 feet, but it may safely be said that barometric hypsometry has been brought to such a stage that the influence of errors of instrumentation is distinctly appreciable in the result; and there is full warrant for the declaration that observations designed for the future refinement of hypsometric method must themselves be of the highest grade. The employment of inferior or of untested instruments, of observatories badly located, or of unskillful or untrustworthy observers, would suffice to nullify any attempt which might be made to give the science of barometric hypsometry a better experimental basis.

CHAPTER V.

LIMITATIONS TO UTILITY.

The new hypsometric method is not of universal application. It is not indeed subject to local restrictions like the empiric, but there are certain conditions under which its employment is impracticable, and certain others under which it is disadvantageous. The majority of these would occur to the geographer at once, but there are some which might not, and it is proper to enumerate them all for the sake of avoiding any possible misapprehension. There are, moreover, certain conditions which restrict the use of the barometer by whatever method, and for the sake of symmetry these will be included in the list.

A. *The* barometer *will not be employed:*

(1) *When the demand for precision is beyond its competence.* It is admitted by all barometricians that there is a degree of precision attainable by other instruments to which the barometer can never hope to reach. In the nature of things there is a limit to its powers, and although the apparent position of that limit may be modified by refinements in method, it can never be abolished. The present essay is an attempt to crowd it slightly backward, but is so far from removing it altogether that it serves rather to confirm or reassert its permanence. For such engineering works as canals and railroads the barometer can serve no useful purpose except in reconnaissance.

(2) *When its precision can be equaled at less expense.* The better class of modern geographic work is performed by means of observations made at stations which are intervisible, and in proportion as the demands for accuracy increase, and more is attempted in the delineation of details, the interspaces between the stations occupied by the topographer are progressively diminished. The topographer is able to compute the relative height of all points visible to him from any station, provided their distances become known, by measuring the angles of elevation or depression which they subtend; and since other stations of his system are always included among the points of observation, he is able in this manner to carry through his field a connected system of altitude determinations. If the stations are widely separated, such determinations of altitude are of little value by reason of the errors introduced by atmospheric refraction, but if the stations are near together, the determinations may have a high degree of precision. When, therefore, in the progress of geographic refinement the stations of the topographer approach so near to each other that the precision of the measurement of

altitudes by angulation becomes equal to the precision obtainable by means of the barometer, barometric hypsometry receives at once a formidable competitor. Indeed it encounters an invincible antagonist, for the expense of reading vertical angles, when it is performed as a mere accessory to the general work of the topographer, is notably less than the expense of transporting and observing barometers,—to say nothing of the expense of maintaining base stations. The most thorough geographic work will therefore dispense altogether with the barometer.

B. *The* new method *will not be used:*

(3) *When sites for the necessary base stations are not available.* The method demands that its two base stations shall be upon a steep slope, and that their difference in altitude shall not be unduly small. The first demand is dictated by the importance of avoiding gradient errors; the second by two independent considerations. In the first place, the air column whose weight and density are determined by the observations at these stations, is necessarily composed in part of the layer adjacent to the earth's surface, which is abnormally affected by the sun's heat and undergoes rapid changes, and in part of the upper and more general portion of the atmosphere, which changes more slowly. It is the density of the latter which it is important to know, and the greater the height of the column weighed the smaller is the influence of its abnormal superficial factor. Theoretically, a very short column would give no better indication of the density factor of the atmosphere than do the measurements of temperature and humidity heretofore customarily depended on. The second consideration arises from the unavoidable errors of observation. These depend upon the instruments and the observers, and are independent of the height of the air column. They consequently affect the measurement of the density of a short column in greater ratio than that of a tall column.

No definite limit can be assigned to the admissible interval between the base stations, because it must vary with circumstances. If the new stations are all in the immediate vicinity of the base stations, and fall between them in point of altitude, the requirements are not so great as when the new stations are widely scattered. It may be said without qualification, however, that a region in which the slopes are all gentle is unsuited to the employment of the new method, and can be best served by the "ordinary" method.

(4) *When the demand for precision is not beyond the capacity of a cheaper method.* The class of cases debarred by this limitation is large, for it includes every reconnaissance made as a preliminary to more exact work,—whether of a general geographic nature or for some such special purpose as the construction of a railroad.

(5) *When the unavoidable errors from gradient are great.* Non periodic or cyclonic gradient is a function of horizontal distance. It depends, of course, upon many other things, but the *probable* hypsometric error arising from this source is always relatively great when the distance

between base and new stations is great, while it is comparatively unaffected by the vertical relations of base and new stations. The new hypsometric method and the "ordinary" compete only in the elimination of errors arising from inaccurate determinations of density, while they alike fail to remove gradient errors. When the new stations are near the base, gradient errors are inconsiderable, and the superior ability of the new method to contend with density errors renders its employment advantageous; but when the new stations are remote from the base, gradient errors become so large as to overwhelm those arising from imperfect determination of density, and then the accomplishment of the two methods is practically the same. If, therefore, all the new stations are remote from the locality selected for a base, no commensurate advantage can follow the employment of the more expensive method.

This consideration is enforced by the fact that errors arising from different sources are combined in the general result by means of their squares, and not by simple addition. Suppose, for example, that the computation of the altitude of a new station close to the bases has a probable error (depending on the vertical distribution of densities) of ± 15 feet when the ordinary method is employed, and of ± 10 feet by the new method. Suppose, further, that another new station is at such a distance that its computed altitude has a probable error due to gradient alone of ± 25 feet. Its total probable error by the ordinary method will then be ($\sqrt{(15)^2 + (25)^2} =$) ± 29 feet, while its total error by the new method will be ($\sqrt{(10)^2 + (25)^2} =$) ± 27 feet. The saving effected by the substitution of the new method for the old is 33 per cent in the case of the nearer new station, and only 7 per cent in the case of the more remote.

Here again no absolute rule can be laid down, for when the new stations differ greatly in altitude from that base to which they would be referred by either method (or, more simply, when the new lines are high), density errors are correspondingly great, and a comparatively large gradient error can be introduced without depriving the new method of its advantage.

(6) *When the new stations are few.* This limitation is connected purely with expense, and is not of universal application. It is perhaps rather an amplification of the fourth limitation. As a rule, the more elaborate and refined hypsometric methods can be economically employed only in surveys where many points are to be determined, so that the expense of equipping and maintaining base stations may be shared by a large number of new stations.

(7) *When the new station falls far without the vertical base.* The numerous comparative computations which have been made for testing the value of the new method have served to show that while it gives better determinations of points intermediate in height between the upper and lower bases, and of points a short distance above the upper base or below the lower, it nevertheless gives poorer determinations of points far

above the upper base or far below the lower. An attempt has been made, by discussing the available figures, to ascertain the limit at which the advantage of the new method ceases, but the results have not been accordant. It may be said in a general way, however, that when the vertical space separating the new station from the nearer base station is not more than one-half the vertical base line, the new method gives the better results, and that when the space separating the new station from the nearer base station is greater than the vertical base line, the better results are given by the "ordinary" method.

It follows from this, first, that when circumstances will permit, the upper and lower base stations should be so chosen as to include in their vertical interspace all or nearly all the proposed new stations. It follows, second, that when it is impracticable so to dispose the base stations that the new stations fall within the range of utility of the new method, there is no advantage in using more than one base station. It follows, third, that when two base stations have been used in field-work it will nevertheless be advisable in the case of some new stations to ignore the observations at the more remote base and perform the computation by the "ordinary" method.

It may appear to the reader that a system hemmed in by so many restrictions is practically useless; but the field remaining to the new method is in reality a broad one, including, unless the merits of the method are here overrated, the major part of the barometric hypsometry of the United States for the next decade. The reform was suggested by the needs of the geographic surveys conducted by the government during the past fifteen years in the mountainous region lying between the Great Plains and the Pacific Ocean, and it is especially adapted for use in such a region. The preliminary reconnaissances, which did not require the degree of precision it affords, have now been made, but the time has not yet arrived for that more elaborate geographic work which will dispense with the barometer altogether and employ only the theodolite and kindred instruments for the determination of its vertical element. For the present the barometer holds its place as the chief hypsometric instrument, and the principal work to which it is an accessory demands that it shall be so handled as to afford the highest practicable degree of precision.

CHAPTER VI.

THE WORK OF OTHERS.

In the preceding pages no attempt has been made to credit the founders and the numerous promoters of the science of barometric hypsometry with the ideas and principles derived from them. The citation of authorities has even been avoided, so far as possible, because the mention of a few among so many might seem to make an invidious distinction, while giving due credit to all would involve the full presentation of the history of the subject—a work for which the writer has neither time nor inclination. The reader who desires to know the successive steps by which the barometer has been brought to its present measure of utility can find his wishes fully met by consulting the works of Rühlmann, Whitney, Schreiber, and Cross.*

It is impossible, however, to pass without mention the work of those who have to some extent anticipated the hypsometric method forming the subject of this paper.

One of the leading and essential propositions of the paper is—to determine the condition of the atmosphere at the moment when a measurement of height is made, by means of the synchronous barometric measurement of a known height. This was first advanced by the writer at a meeting of the Philosophical Society of Washington, in May, 1877, at which time he supposed it to be novel. He has since learned that he was antedated in publication by no less than two hypsometers, while it is probable that a third also anticipated him in the conception of the idea. Nevertheless, the announcement of his method was not devoid of novelty, for he differed radically from his predecessors in his manner of developing and applying the idea.

The earliest investigator who has recorded his use of the principle is Plantamour. In his hypsometric method, a description of which has already been given, he recomputed the height of St. Bernard above Geneva at the instant of each observation upon which a computation of the height of a new station was based, and by comparing this computed height of St. Bernard with the known real height he obtained a

*Rühlmann's "Barometrischen Hohenmessungen," Leipsic, 1870.

Whitney's "Contributions to Barometric Hypsometry, 1874; Chapters I and III."

Schreiber's "Handbuch der barometrischen Hohenmessungen," Weimar, 1877; Chapter VIII.

Appalachia, vol. II, p. 201, May, 1881; Address on the "Barometric Measurement of Heights," by Charles R. Cross.

criterion for judging of the momentary condition of the atmosphere. His two base stations were so far apart that it was impossible to discriminate the effect of a false estimate of atmospheric density from the effect of gradient, and in his computations he assumed that his determination of density (that is, of temperature and humidity) was correct, and regarded the error of his computed height of St. Bernard as an indication of the effect of gradient alone. So regarding it, he proposed no plan for eliminating it, but simply used it as a means of giving weight to the synchronous determination of the required altitude as compared with other determinations of the same. It may seriously be doubted whether his assumption was warranted; but be that as it may, there can be no question that his weighting of individual determinations had a beneficial effect upon his ultimate result.

His method differs primarily from the one here advanced in that it used the redetermination of a known height to measure gradient only, while it is here used to measure density only. Density is by his method determined solely by means of thermometric and psychrometric observations, made simultaneously with those of the barometers and corrected by the aid of the mean errors of long series of observations.

A method of hypsometry proposed by Lieutenant William L. Marshall was first given to the world in 1877,* but appears to have been practiced by him for some years prior to that time. In the main it is the system of Williamson, but it includes a number of valuable innovations, the chief of which is the following:

Within the field of survey are established a pair of base stations, one high and the other low, but not widely separated horizontally. Their difference in altitude is either determined by some independent method or else from the means of the observations for the entire season. For each week of hypsometric work a special computation of their difference in altitude is made, in which the weekly means of the barometric, thermometric, and psychrometric observations at the two stations are employed. The standard difference in height is then divided by this computed difference, and the quotient is regarded as a correction factor. All barometric differences of altitude determined during the week in localities where the diurnal changes of temperature and other climatic characteristics are similar to those at the upper base station, are then multiplied by this factor, after having been computed from the observations of pressure, temperature, and humidity in the way prescribed by Williamson.

This system agrees with the one here advanced in using the rede-

* "United States Geological Surveys West of the 100th Meridian, in charge of First Lieut. George M. Wheeler, Vol. II. Astronomy and Barometric Hypsometry, Part II. Results in Barometric Hypsometry obtained during the years 1871, 1872, 1873, 1874, and 1875, reported by First Lieut. William L. Marshall, Corps of Engineers, U. S A. Washington, Government Printing Office, 1877." The novel element of his hypsometric system is described on pages 522 and 523 of the volume.

termination of a known height as a means of measuring the density of the atmosphere at a given moment. Its chief difference consists in the fact that instead of ignoring altogether the observations of temperature and moisture, it first introduces them into the computations, and then endeavors to counteract their vicious effect by a process of cancellation. The untrustworthiness of the thermometric and psychrometric determinations as indices of the density of the air column used in hypsometry is clearly pointed out by Lieutenant Marshall, and his weekly corrective factor was devised for the purpose of eliminating the errors to which they give rise. But he nevertheless admitted them into his computations, both of the altitude of the new station and of the height of the vertical base, and only sought to neutralize their ill effect in one case by balancing against it their ill effect in the other. Having once admitted them, there was perhaps no better mode of neutralizing the errors they caused; and it is probable that his device materially enhanced the accuracy of his hypsometric work.

It is a possible defect of his system that it takes no account of the fact pointed out by Plantamour and Whitney that the correction necessary at high altitudes is not the same as that required at low altitudes. So long as his correction factors are applied to the computed differences in level of base and new stations whose altitudes approximate respectively those of the upper and lower limits of his vertical base line, a good result is to be expected; but it is to be doubted whether the application can be extended to points differing greatly in height from the two stations limiting the vertical base.

In 1870, Dr. Richard Rühlmann, of Carlsruhe, published an elaborate memoir in which he reviewed the entire subject of barometric hypsometry. After describing the formulas and methods of others, he developed a formula and method of his own. His formula is a modification of that of Laplace, and represents the difference in level of two stations as a function of the observed atmospheric pressures, temperatures, and moistures at the two stations and of the latitudes of the stations. He differs from his predecessors chiefly in his manner of determining the atmospheric temperature. For this purpose he makes use of two stations whose difference in level is known, and from the observed pressures and moisture factors at these stations he computes the temperature of the intervening air column. The temperature thus derived he afterwards applies (by a special method to be described presently) in the computation of the unknown difference in level of two other stations. He thus agrees with the writer in rejecting the indications of the thermometer as a measure of atmospheric temperature, but differs from him in that he retains the observations of the psychrometer. With this exception he employs the same principle, for while the new method deduces the density of an air column of known height from a measurement of its weight, Rühlmann deduces the temperature of such a column from measurements of its weight and humidity. The new method then proceeds to apply the deduced density, in connection with observed pressure, to the computation of an altitude, and Rühlmann similarly proceeds to apply the deduced temperature, in connection with observations of pressure and humidity, to the computation of an altitude. The errors arising from false estimates of temperature so far outweigh those from false estimates of moisture that the practical difference between the two systems cannot be great, although theoretically the considerations leading to the rejection of the temperature observations apply with even greater force to the less veracious observations of humidity.

But while Rühlmann's method has thus, in principle, substantially anticipated the one here developed, it is applied by him in a very different manner. He gives no consideration whatever to single observations nor to a single pair of base stations, but says that a district of country in which his barometric method is to be applied must be furnished in advance with a large number of meteorologic base stations of which the latitudes, longitudes, and altitudes are known, and at which long series of observations have been made. The new stations must be occupied for the same period—a period so long that all minor inequalities incident to atmospheric changes will be eliminated by cancellation. With these elaborate data in hand, and making use only of the mean values, for each station, of the pressure and humidity, he proceeds as follows: First, he arranges the base stations in pairs, combining each one with every other one which differs from it considerably in altitude, and for each pair he computes, by the aid of their known heights and latitudes, and of the observed pressures and humidities, the mean temperature of the intervening air column. This temperature he ascribes to that point which is intermediate between the two stations both in distance and height. This series of computations gives him an estimate of the temperature of a large number of points in space, the positions of which are indicated by their latitudes, longitudes, and altitudes. He then assumes that the temperature of any point whatever in the district is equal to a certain factor, plus a second factor multiplied by the latitude of the point, plus a third factor multiplied by its longitude, plus a fourth factor multiplied by its altitude; and proceeds, by the aid of the individual temperatures already computed and by means of the method of least squares, to compute the values of these factors. Having computed them, he is furnished with a temperature formula by means of which he can compute the mean temperature of any point within the district. Taking now a pair of stations of which he wishes to determine the difference in altitude, he deduces from their known latitudes, their known longitudes, the known altitude of one, and the approximate altitude of the other, the latitude and longitude and approximate altitude of the point midway between them; and thus obtains, through the temperature formula, the mean temperature of the intervening air column.

This mean temperature enters his hypsometric formula in place of the mean of the thermometric readings, and the difference in altitude is then computed. If it differs notably from the approximate value given directly by the readings of the barometers, a second and more refined determination of the temperature is made, and the computation is repeated.

So far as the writer is aware, this cumbrous method has never been put in practice. It is quite inapplicable to general geographic work because it demands long series of observations, and if it has a field of utility it probably lies in the determination of the altitudes of meteorologic stations where observations are continuously made as a means of predicting the weather.

It thus appears that the precise ground covered by the new method has not before been occupied. Plantamour recomputed a known height for the purpose of ascertaining the temporary gradient. Marshall did the same thing for the purpose of ascertaining the temporary hypsometric error. Rühlmann did the same for the purpose of determining the local mean temperature. The writer only has performed the computation for the purpose of ascertaining the local and temporary mean density of the air column. Plantamour computed the altitude of his new station from the observed pressures, temperatures, and humidities (applying also empirical corrections), and used his coincident determination of a known height only as a criterion for judging whether the temporary meteorologic conditions were favorable. Marshall also computed the height of the new station by means of the observed pressures, temperatures, and humidities, and used his recomputation of a known height as a means of expunging the errors he had introduced. Rühlmann proposes to compute the height of the new station by means of the observed pressures and humidities, but substitutes for the observed temperatures a value derived from the recomputation of known heights. The present method only has altogether rejected observations of temperature and humidity and computed the height of the new station by the sole means of observed pressures.

Acknowledgments.—In the conduct of my investigation I have been greatly indebted to the courtesy and assistance of others. Professor J. D. Whitney and Colonel R. S. Williamson have afforded me the use of unpublished barometric records. General W. B. Hazen, Chief Signal Officer of the Army, has favored me with important data from the archives of the Weather Bureau, and the library of his office has been of the utmost service to me. I am indebted to my friends Professor Cleveland Abbe, Mr. M. H. Doolittle, Mr. Marcus Baker and Mr. H. A. Hazen for much kind counsel and assistance. The computations pertaining to the work, which were exceedingly onerous, have been performed at the expense of the Geological Survey by Mr. P. C. Warman, Mr. Paul Holman, and Mr. Albert L. Webster.

CHAPTER VII.

ON THE USE OF THE TABLE.

The barometric formula developed in Chapter II (Equation 17) is—

$$A = B\frac{\log l - \log n}{\log l - \log u} + \frac{A(B-A)}{490000}$$

in which

l is the atmospheric pressure (or the reading of the barometer) at the lower base station;

u is the pressure at the upper base station;

n is the pressure at the new station;

A is the height, in English feet, of the new station above the lower base station; and

B is the height, in feet, of the upper base station above the lower, or, in other words, is the height of the vertical base line.

The first term of the formula is otherwise designated by a,—

$$a = B\frac{\log l - \log n}{\log l - \log u}$$

and is called the *logarithmic term*, or *approximate difference in altitude;* the second, $\frac{A(B-A)}{490000}$, is called the *thermic term.*

B, l, u, and n are known quantities, and from them a is computed by the aid of logarithms. (See page 449.) The thermic term is obtained from the table (pages 556–561), with B and a as arguments.

In each page of the table the left-hand column contains the values of a, and the horizontal lines at the top and bottom margins give the values of B. The pages are arranged in pairs; the left hand of each pair includes the values of B from 1,000 to 5,000, and the right from 6,000 to 10,000. Each page has nine interpolation columns at the right, containing increments for the numbers in the columns at the left, to be used when B is not expressed in even thousands of feet.

The first pair of pages serve when a is negative, the second and third pairs when a is positive.

In the use of the table there arise three cases, which are illustrated by the following three examples. In the first the new station is intermediate between the two bases; in the second it is higher than the upper base; in the third it is lower than the lower base.

FIRST EXAMPLE.

(*New Station Intermediate.*)

What is the value of the thermic term when B = 4,000 and a = 1,200?

From the intersection of the line which contains + 1,200 as a value of a and the column headed 4,000, we obtain + 6.9, which is the required value of the thermic term.

SECOND EXAMPLE.

(*New Station Above Upper Base Station.*)

What is the value of the thermic term when B=3,600 and a=5,727?

Let us consider B as composed of 3,000 and 600, and a as composed of 5,700 and 27.

From the intersection of the line containing +5,700 as a value of a and the column headed 3,000 we obtain the correction . .	−30.9
To allow for the 600 we take from the intersection of the same line with the interpolation column headed 6	+ 6.8
To allow for the 27 we take from the column headed 3,000 the corrections corresponding to a=5,700 and a=5,800, subtract one from the other, divide the remainder by 100, and multiply the quotient by 27, thus:	
$\frac{30.9-32.6}{100} \times 27 =$	− 0.5
Adding, we obtain the total correction, or the value of the thermic term	−24.6

THIRD EXAMPLE.

(*New Station Below Lower Base Station.*)

What is the value of the thermic term when B=7,864 and a= −2,400?

Consider B as composed of 7,000, 800, 60, and 4.	
With B = 7,000 and a = −2,400, we obtain	−47.2
With 800, we obtain from the interpolation column	− 4.1
The interpolation element for 60 (one-tenth of that for 600) is .	− .3
The element for 4 is too small to note.	
The required value is the sum of these numbers	−51.6

SIGNS.

The formula and the table assume the origin of distances to be at the lower base station. The vertical distances of all higher points are affected by the plus sign, of lower points by the minus sign. The vertical base, B, is positive. A is positive when the new station is above the lower base station; negative when it is below. The value of the thermic term is positive when the new station is intermediate between the bases; negative when it is not intermediate. It is numerically additive to *a* when the new station is lower than the upper base station; subtractive when the new station is higher.

The interpolation elements are given the plus sign when the series of numbers to which they pertain is algebraically ascending; they are given the minus sign when it is descending. Thus, in the second example, 6.8 is made positive because the horizontal series in the table ascends from −30.9 to −19.5; while 0.5 is made negative because the vertical series descends from −30.9 to −32.6.

The computer who has to determine a large number of new stations by reference to a single pair of base stations can simplify his work by constructing a special table adapted to his particular value of B,—unless that value is measured by even thousands of feet. The special table will contain but two columns; one for values of *a*, and one for the corresponding values of the thermic correction. The latter can be simply derived, by the aid of the interpolation columns, from one of the columns of the printed table. The special table need not extend beyond the range of actual values for *a*, and ordinarily will be very short. In using it the value of *a* will be the only argument.

TABLE OF VALUES OF THERMIC TERM, $\frac{A\ (B-A)}{D}$, IN FEET.

a=Approximate Altitude, in Feet	B=Vertical Base, in Feet					Additional Hundreds of Feet.								
	1,000	2,000	3,000	4,000	5,000	1	2	3	4	5	6	7	8	9
— 5,000	—62.6	—73.2	—83.9	—94.6	—105.3	1.1	2.1	3.2	4.3	5.3	6.4	7.5	8.6	9.6
4,900	60.3	70.7	81.1	91.6	102.1	1.0	2.1	3.1	4.2	5.2	6.2	7.3	8.3	9.4
4,800	58.1	68.2	78.4	88.7	98.9	1.0	2.0	3.1	4.1	5.1	6.1	7.1	8.2	9.2
4,700	55.9	65.8	75.8	85.8	95.8	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
4,600	53.7	63.4	73.2	83.0	92.8	1.0	2.0	2.9	3.9	4.9	5.9	6.9	7.8	8.8
— 4,500	—51.6	—61.1	—70.6	—80.2	—89.8	1.0	1.9	2.9	3.8	4.8	5.7	6.7	7.6	8.6
4,400	49.5	58.8	68.1	77.5	86.9	0.9	1.9	2.8	3.7	4.7	5.6	6.5	7.5	8.4
4,300	47.5	56.5	65.6	74.8	84.0	0.9	1.8	2.7	3.6	4.6	5.5	6.4	7.3	8.2
4,200	45.5	54.3	63.2	72.1	81.1	0.9	1.8	2.7	3.6	4.5	5.3	6.2	7.1	8.0
4,100	43.5	52.1	60.8	69.5	78.3	0.9	1.7	2.6	3.5	4.4	5.2	6.1	7.0	7.8
— 4,000	—41.6	—50.0	—58.4	—66.9	—75.5	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.8	7.6
3,900	39.7	47.9	56.1	64.4	72.7	0.8	1.7	2.5	3.3	4.1	5.0	5.8	6.6	7.4
3,800	37.9	45.9	53.9	61.9	70.0	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2
3,700	36.1	43.9	51.7	59.5	67.4	0.8	1.6	2.3	3.1	3.9	4.7	5.5	6.3	7.0
3,600	34.4	41.9	49.5	57.1	64.8	0.8	1.5	2.3	3.0	3.8	4.6	5.3	6.1	6.8
— 3,500	—32.7	—40.0	—47.4	—54.8	—62.2	0.7	1.5	2.2	2.9	3.7	4.4	5.2	5.9	6.6
3,400	31.0	38.2	45.3	52.5	59.7	0.7	1.4	2.2	2.9	3.6	4.3	5.0	5.7	6.5
3,300	29.4	36.3	43.3	50.2	57.3	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3
3,200	27.8	34.6	41.2	48.0	54.8	0.7	1.3	2.0	2.7	3.4	4.1	4.7	5.4	6.1
3,100	26.3	32.8	39.3	45.9	52.4	0.7	1.3	2.0	2.6	3.3	3.9	4.6	5.2	5.9
— 3,000	—24.8	—31.1	—37.4	—43.8	—50.1	0.6	1.3	1.9	2.5	3.2	3.8	4.4	5.1	5.7
2,900	23.4	89.5	35.5	41.7	47.8	0.6	1.2	1.8	2.4	3.1	3.7	4.3	4.9	5.6
2,800	22.0	27.8	33.7	39.6	45.5	0.6	1.2	1.8	2.3	2.9	3.5	4.1	4.7	5.3
2,700	20.6	26.3	31.9	37.6	43.3	0.6	1.1	1.7	2.3	2.8	3.4	4.0	4.5	5.1
2,600	19.3	24.8	30.2	35.7	41.2	0.5	1.1	1.6	2.2	2.7	3.3	3.8	4.4	4.9
— 2,500	—18.1	—23.3	—28.5	—33.8	—39.1	0.5	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7
2,400	16.9	21.8	26.8	31.9	37.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
2,300	15.7	20.5	25.2	30.1	34.9	0.5	1.0	1.4	1.9	2.4	2.9	3.4	3.8	4.3
2,200	14.5	19.1	23.7	28.3	32.9	0.5	0.9	1.4	1.8	2.3	2.8	3.2	3.7	4.1
2,100	13.4	17.8	22.2	26.6	31.0	0.4	0.9	1.3	1.8	2.2	2.6	3.1	3.5	4.0
— 2,000	—12.4	—16.5	—20.7	—24.9	—29.1	0.4	0.8	1.3	1.7	2.1	2.5	2.9	3.3	3.8
1,900	11.3	15.3	19.3	23.2	27.2	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6
1,800	10.4	14.1	17.9	21.6	25.4	0.4	0.8	1.1	1.5	1.9	2.3	2.6	3.0	3.4
1,700	9.4	13.0	16.5	20.1	23.6	0.4	0.7	1.1	1.4	1.8	2.1	2.5	2.8	3.2
1,600	8.5	11.9	15.2	18.6	21.9	0.3	0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.0
— 1,500	— 7.7	—10.8	—13.9	—17.1	—20.2	0.3	0.6	0.9	1.2	1.6	1.9	2.2	2.5	2.8
1,400	6.9	9.8	12.7	15.6	18.6	0.3	0.6	0.9	1.2	1.5	1.8	2.0	2.3	2.6
1,300	6.1	8.8	11.5	14.2	17.0	0.3	0.5	0.8	1.1	1.4	1.6	1.9	2.2	2.4
1,200	5.4	7.9	10.4	12.9	15.4	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.2
1,100	4.7	7.0	9.3	11.6	13.9	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.8	2.1
— 1,000	— 4.1	— 6.2	— 8.2	—10.3	—12.4	0.2	0.4	0.6	0.8	1.0	1.2	1.5	1.7	1.9
900	3.5	5.4	7.2	9.1	11.0	0.2	0.4	0.6	0.8	0.9	1.1	1.3	1.5	1.7
800	2.9	4.6	6.2	7.9	9.6	0.2	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.5
700	2.4	3.9	5.3	6.8	8.2	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3
600	1.9	3.2	4.4	5.7	6.9	0.1	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.1
— 500	— 1.5	— 2.6	— 3.6	— 4.6	— 5.7	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
400	1.1	2.0	2.8	3.6	4.5	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8
300	0.8	1.4	2.0	2.7	3.3	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.6
200	0.5	0.9	1.3	1.7	2.1	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4
100	0.2	0.4	0.6	0.8	1.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
	1,000	2,000	3,000	4,000	5,000	1	2	3	4	5	6	7	8	9

TABLE OF VALUES OF THERMIC TERM, $\frac{A\ (B-A)}{D}$, IN FEET.

a=Approximate Altitude, in Feet	B=Vertical Base, in Feet					Additional Hundreds of Feet.								
	6,000	7,000	8,000	9,000	10,000	1	2	3	4	5	6	7	8	9
— 5,000	—116.1	—126.9	—137.7	—148.6	—159.6	1.1	2.2	3.3	4.3	5.4	6.5	7.6	8.7	9.8
4,900	112.7	123.3	133.9	144.6	155.3	1.1	2.1	3.2	4.3	5.3	6.4	7.5	8.5	9.6
4,800	109.3	119.7	130.1	140.5	151.1	1.0	2.1	3.1	4.2	5.2	6.3	7.3	8.4	9.4
4,700	106.0	116.1	126.3	136.5	146.8	1.0	2.0	3.1	4.1	5.1	6.1	7.1	8.2	9.2
4,600	102.7	112.6	122.6	132.6	142.7	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
— 4,500	— 99.5	—109.2	—119.0	—128.7	—138.6	1.0	1.9	2.9	3.9	4.9	5.9	6.8	7.8	8.8
4,400	96.3	105.8	115.3	124.9	134.5	1.0	1.9	2.9	3.8	4.8	5.7	6.7	7.6	8.6
4,300	93.2	102.4	111.8	121.1	130.5	0.9	1.9	2.8	3.7	4.7	5.6	6.5	7.5	8.4
4,200	90.1	89.1	108.2	117.3	126.5	0.9	1.8	2.7	3.6	4.5	5.5	6.4	7.3	8.2
4,100	87.1	95.9	104.7	113.6	122.5	0.9	1.8	2.7	3.5	4.4	5.3	6.2	7.1	8.0
— 4,000	— 84.1	— 92.7	—101.3	—109.9	—118.7	0.9	1.7	2.6	3.5	4.3	5.2	6.1	6.9	7.8
3,900	81.1	89.5	97.9	106.3	114.8	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.7	7.6
3,800	78.2	86.3	94.5	102.8	111.0	0.8	1.6	2.5	3.3	4.1	4.9	5.7	6.6	7.4
3,700	75.3	83.2	91.2	99.2	107.3	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2
3,600	72.5	80.2	88.0	95.7	103.6	0.8	1.6	2.3	3.1	3.9	4.7	5.4	6.2	7.0
— 3,500	— 69.7	— 77.2	— 84.7	— 92.3	— 99.9	0.8	1.5	2.3	3.0	3.8	4.5	5.3	6.0	6.8
3,400	67.0	74.3	81.6	88.9	96.3	0.7	1.5	2.2	2.9	3.7	4.4	5.1	5.9	6.6
3,300	64.3	71.4	78.4	85.6	92.7	0.7	1.4	2.1	2.8	3.5	4.3	5.0	5.7	6.4
3,200	61.6	68.5	75.4	82.3	89.2	0.7	1.4	2.1	2.8	3.4	4.1	4.8	5.5	6.2
3,100	59.0	65.7	72.3	79.0	85.7	0.7	1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0
— 3,000	— 56.5	— 62.9	— 69.3	— 75.8	— 82.3	0.6	1.3	1.9	2.6	3.2	3.9	4.5	5.2	5.8
2,900	54.0	60.1	66.4	72.6	78.9	0.6	1.2	1.9	2.5	3.1	3.7	4.4	5.0	5.6
2,800	51.5	57.4	63.5	69.5	75.6	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4
2,700	49.1	54.8	60.6	66.4	72.3	0.6	1.2	1.7	2.3	2.9	3.5	4.1	4.6	5.2
2,600	46.7	52.2	57.8	63.4	69.0	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.5	5.0
— 2,500	— 44.4	— 49.7	— 55.0	— 60.4	— 65.8	0.5	1.1	1.6	2.1	2.7	3.2	3.7	4.3	4.8
2,400	42.1	47.2	52.3	57.4	62.6	0.5	1.0	1.5	2.0	2.6	3.1	3.6	4.1	4.6
2,300	39.8	44.7	49.6	54.5	59.5	0.5	1.0	1.5	2.0	2.5	3.0	3.4	3.9	4.4
2,200	37.6	42.3	47.0	51.7	56.4	0.5	0.9	1.4	1.9	2.3	2.8	3.3	3.8	4.2
2,100	35.4	39.9	44.4	48.9	53.4	0.5	0.9	1.4	1.8	2.2	2.7	3.2	3.6	4.0
— 2,000	— 33.3	— 37.6	— 41.8	— 46.1	— 50.4	0.4	0.9	1.3	1.7	2.1	2.6	3.0	3.4	3.8
1,900	31.2	35.3	39.3	43.4	47.5	0.4	0.8	1.2	1.6	2.0	2.4	2.9	3.3	3.7
1,800	29.2	33.0	36.9	40.7	44.6	0.4	0.8	1.2	1.5	1.9	2.3	2.7	3.1	3.5
1,700	27.2	30.8	34.4	38.1	41.8	0.4	0.7	1.1	1.5	1.8	2.2	2.6	2.9	3.3
1,600	25.3	28.7	32.1	35.5	38.9	0.3	0.7	1.0	1.4	1.7	2.0	2.4	2.7	3.1
— 1,500	23.4	— 26.6	— 29.7	— 32.9	— 36.2	0.3	0.6	1.0	1.3	1.6	1.9	2.2	2.6	2.9
1,400	21.5	24.5	27.5	30.4	33.4	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7
1,300	19.7	22.5	25.2	28.0	30.8	0.3	0.6	0.8	1.1	1.4	1.7	1.9	2.2	2.5
1,200	17.9	20.5	23.0	25.6	28.1	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3
1,100	16.2	18.5	20.9	23.2	25.6	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1
— 1,000	— 14.5	— 16.6	— 18.7	— 20.9	— 23.0	0.2	0.4	0.6	0.8	1.1	1.3	1.5	1.7	1.9
900	12.9	14.8	16.7	18.6	20.5	0.2	0.4	0.6	0.8	0.9	1.1	1.3	1.5	1.7
800	11.3	13.0	14.7	16.3	18.0	0.2	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.5
700	9.7	11.2	12.7	14.1	15.6	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3
600	8.2	9.5	10.7	12.0	13.3	0.1	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.1
— 500	— 6.7	— 7.8	— 8.8	— 9.9	— 11.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
400	5.3	6.1	7.0	7.8	8.7	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8
300	3.9	4.5	5.2	5.8	6.4	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.6
200	2.6	3.0	3.4	3.8	4.3	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4
100	1.3	1.5	1.7	1.9	2.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
	6,000	7,000	8,000	9,000	10,000	1	2	3	4	5	6	7	8	9

TABLE OF VALUES OF THERMIC TERM, $\frac{A\,(B-A)}{D}$, IN FEET.

a = Approximate Altitude, in Feet.	B = Vertical Base, in Feet.					Additional Hundreds of Feet.								
	1,000	2,000	3,000	4,000	5,000	1	2	3	4	5	6	7	8	9
+ 100	+ 0.2	+ 0.4	+ 0.6	+ 0.8	+ 1.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
200	0.3	0.7	1.1	1.6	2.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4
300	0.4	1.0	1.6	2.3	2.9	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6
400	0.5	1.3	2.1	3.0	3.8	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.7
500	0.5	1.5	2.5	3.6	4.6	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
+ 600	+ 0.5	+ 1.7	+ 2.9	+ 4.2	+ 5.4	0.1	0.2	0.4	0.5	0.6	0.7	0.9	1.0	1.1
700	0.4	1.9	3.3	4.7	6.2	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3
800	0.3	2.0	3.6	5.2	6.9	0.2	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.5
900	0.2	2.0	3.9	5.7	7.6	0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7
1,000	0.0	2.0	4.1	6.2	8.2	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
+ 1,100	− 0.2	+ 2.0	+ 4.3	+ 6.5	+ 8.8	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0
1,200	0.4	1.9	4.4	6.9	9.4	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2
1,300	0.8	1.8	4.5	7.2	9.9	0.3	0.5	0.8	1.1	1.3	1.6	1.9	2.1	2.4
1,400	1.1	1.7	4.6	7.5	10.3	0.3	0.6	0.9	1.1	1.4	1.7	2.0	2.3	2.6
1,500	1.5	1.5	4.6	7.7	10.8	0.3	0.6	0.9	1.2	1.5	1.8	2.2	2.5	2.8
+ 1,600	− 2.0	+ 1.3	+ 4.6	+ 7.9	+11.2	0.3	0.7	1.0	1.3	1.6	2.0	2.3	2.6	3.0
1,700	2.4	1.0	4.5	8.0	11.5	0.3	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1
1,800	2.9	0.7	4.4	8.1	11.8	0.4	0.7	1.1	1.5	1.8	2.2	2.6	2.9	3.3
1,900	3.5	0.4	4.3	8.1	12.1	0.4	0.8	1.2	1.6	2.0	2.3	2.7	3.1	3.5
2,000	4.1	0.0	4.1	8.2	12.3	0.4	0.8	1.2	1.6	2.1	2.5	2.9	3.3	3.7
+ 2,100	− 4.7	− 0.4	+ 3.8	+ 8.1	+12.5	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.4	3.9
2,200	5.4	0.9	3.6	8.1	12.6	0.4	0.9	1.3	1.8	2.2	2.7	3.1	3.6	4.0
2,300	6.1	1.4	3.3	8.0	12.7	0.5	0.9	1.4	1.9	2.3	2.8	3.3	3.8	4.2
2,400	6.8	1.9	2.9	7.8	12.7	0.5	1.0	1.5	1.9	2.4	2.9	3.4	3.9	4.4
2,500	7.6	2.5	2.5	7.6	12.7	0.5	1.0	1.5	2.0	2.5	3.0	3.6	4.1	4.6
+ 2,600	− 8.4	− 3.2	+ 2.1	+ 7.4	+12.7	0.5	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7
2,700	9.3	3.8	1.6	7.1	12.7	0.5	1.1	1.6	2.2	2.7	3.3	3.8	4.4	4.9
2,800	10.2	4.5	1.1	6.8	12.6	0.6	1.1	1.7	2.3	2.8	3.4	4.0	4.6	5.1
2,900	11.1	5.3	0.6	6.5	12.4	0.6	1.2	1.8	2.3	2.9	3.5	4.1	4.7	5.3
3,000	12.1	6.1	0.0	6.1	12.2	0.6	1.2	1.8	2.4	3.0	3.6	4.3	4.9	5.5
+ 3,100	−13.2	− 6.9	− 0.6	+ 5.7	+12.0	0.6	1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.7
3,200	14.2	7.8	1.3	5.2	11.7	0.6	1.3	1.9	2.6	3.2	3.9	4.5	5.2	5.8
3,300	15.3	8.7	2.0	4.7	11.4	0.7	1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0
3,400	16.5	9.6	2.7	4.1	11.1	0.7	1.4	2.1	2.8	3.4	4.1	4.8	5.5	6.2
3,500	17.7	10.6	3.5	3.5	10.7	0.7	1.4	2.1	2.8	3.5	4.3	5.0	5.7	6.4
+ 3,600	−18.9	−11.6	− 4.4	+ 2.9	+10.2	0.7	1.5	2.2	2.9	3.6	4.4	5.1	5.8	6.5
3,700	20.1	12.7	5.2	2.2	9.7	0.7	1.5	2.2	3.0	3.7	4.5	5.2	6.0	6.7
3,800	21.4	13.8	6.1	1.5	9.2	0.8	1.5	2.3	3.1	3.8	4.6	5.4	6.1	6.9
3,900	22.8	14.9	7.1	0.8	8.7	0.8	1.6	2.4	3.1	3.9	4.7	5.5	6.3	7.1
4,000	24.2	16.1	8.1	0.0	8.1	0.8	1.6	2.4	3.2	4.0	4.8	5.7	6.5	7.3
+ 4,100	−25.6	−17.3	− 9.1	− 0.8	+ 7.5	0.8	1.7	2.5	3.3	4.1	5.0	5.8	6.6	7.4
4,200	27.0	18.6	10.2	1.7	6.8	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.8	7.6
4,300	28.5	19.9	11.3	2.6	6.1	0.9	1.7	2.6	3.5	4.3	5.2	6.1	6.9	7.8
4,400	30.1	21.3	12.4	3.6	5.3	0.9	1.8	2.7	3.5	4.4	5.3	6.2	7.1	8.0
4,500	31.6	22.6	13.6	4.6	4.5	0.9	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.1
+ 4,600	−33.2	−24.0	−14.8	− 5.6	+ 3.7	0.9	1.8	2.8	3.7	4.6	5.5	6.5	7.4	8.3
4,700	34.9	25.5	16.1	6.6	2.8	0.9	1.9	2.8	3.8	4.7	5.7	6.6	7.5	8.5
4,800	36.6	27.0	17.4	7.8	1.9	1.0	1.9	2.9	3.8	4.8	5.8	6.7	7.7	8.7
4,900	38.3	28.5	18.7	8.9	1.0	1.0	2.0	2.9	3.9	4.9	5.9	6.9	7.9	8.8
5,000	40.1	30.1	20.1	10.1	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
	1,000	2,000	3,000	4,000	5,000	1	2	3	4	5	6	7	8	9

TABLE OF VALUES OF THERMIC TERM, $\frac{A\,(B-A)}{D}$, IN FEET.

a = Approximate Altitude, in Feet.	B = Vertical Base, in Feet					Additional Hundreds of Feet								
	6,000	7,000	8,000	9,000	10,000	1	2	3	4	5	6	7	8	9
+ 100	+ 1.2	+ 1.4	+ 1.6	+ 1.8	+ 2.1	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2
200	2.4	2.8	3.2	3.6	4.1	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4
300	3.5	4.2	4.8	5.4	6.1	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6
400	4.6	5.5	6.3	7.1	8.0	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8
500	5.7	6.7	7.8	8.8	9.9	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
+ 600	+ 6.7	+ 7.9	+ 9.2	+10.4	+11.7	0.1	0.2	0.4	0.5	0.6	0.7	0.9	1.0	1.1
700	7.6	9.1	10.6	12.0	13.5	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3
800	8.6	10.2	11.9	13.6	15.3	0.2	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.5
900	9.4	11.3	13.2	15.1	17.0	0.2	0.4	0.6	0.8	0.9	1.1	1.3	1.5	1.7
1,000	10.3	12.4	14.5	16.6	18.7	0.2	0.4	0.6	0.8	1.0	1.3	1.5	1.7	1.9
+ 1,100	+11.1	+13.4	+15.7	+18.0	+20.3	0.2	0.5	0.7	0.9	1.1	1.4	1.6	1.8	2.1
1,200	11.8	14.3	16.9	19.4	21.9	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3
1,300	12.6	15.2	18.0	20.7	23.4	0.3	0.5	0.8	1.1	1.4	1.6	1.9	2.2	2.4
1,400	13.2	16.1	19.1	22.0	24.9	0.3	0.6	0.9	1.2	1.5	1.8	2.0	2.3	2.6
1,500	13.9	17.0	20.1	23.2	26.4	0.3	0.6	0.9	1.2	1.6	1.9	2.2	2.5	2.8
+ 1,600	+14.4	+17.8	+21.1	+24.4	+27.8	0.3	0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.0
1,700	15.0	18.5	22.1	25.6	29.2	0.4	0.7	1.1	1.4	1.8	2.1	2.5	2.8	3.2
1,800	15.5	19.2	23.0	26.7	30.5	0.4	0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.4
1,900	16.0	19.9	23.9	27.8	31.8	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6
2,000	16.4	20.5	24.7	28.8	33.1	0.4	0.8	1.3	1.7	2.1	2.5	2.9	3.3	3.8
+ 2,100	+16.8	+21.1	+25.5	+29.8	+34.3	0.4	0.9	1.3	1.7	2.2	2.6	3.1	3.5	3.9
2,200	17.1	21.7	26.2	30.8	35.4	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.7	4.1
2,300	17.4	22.2	26.9	31.7	36.5	0.5	1.0	1.4	1.9	2.4	2.9	3.3	3.8	4.3
2,400	17.7	22.6	27.6	32.6	37.6	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
2,500	17.9	23.0	28.2	33.4	38.7	0.5	1.0	1.6	2.1	2.6	3.1	3.6	4.2	4.7
+ 2,600	+18.1	+23.4	+28.8	+34.2	+39.7	0.5	1.1	1.6	2.2	2.7	3.2	3.8	4.3	4.9
2,700	18.2	23.8	29.4	35.0	40.6	0.6	1.1	1.7	2.2	2.8	3.4	3.9	4.5	5.0
2,800	18.3	24.1	29.9	35.7	41.5	0.6	1.2	1.7	2.3	2.9	3.5	4.1	4.6	5.2
2,900	18.4	24.3	30.3	36.3	42.4	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4
3,000	18.4	24.5	30.7	36.9	43.2	0.6	1.2	1.9	2.5	3.1	3.7	4.3	5.0	5.6
+ 3,100	+18.3	+24.7	+31.1	+37.5	+44.0	0.6	1.3	1.9	2.6	3.2	3.9	4.5	5.1	5.8
3,200	18.3	24.8	31.5	38.1	44.7	0.7	1.3	2.0	2.6	3.3	4.0	4.6	5.3	5.9
3,300	18.2	24.9	31.8	38.6	45.4	0.7	1.4	2.0	2.7	3.4	4.1	4.8	5.4	6.1
3,400	18.0	25.0	32.0	39.0	46.1	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3
3,500	17.8	25.0	32.2	39.4	46.7	0.7	1.4	2.2	2.9	3.6	4.3	5.1	5.8	6.5
+ 3,600	+17.6	+25.0	+32.4	+39.8	+47.3	0.7	1.5	2.2	3.0	3.7	4.5	5.2	5.9	6.7
3,700	17.3	24.9	32.5	40.1	47.8	0.8	1.5	2.3	3.0	3.8	4.6	5.3	6.1	6.9
3,800	17.0	24.8	32.6	40.4	48.3	0.8	1.6	2.3	3.1	3.9	4.7	5.5	6.3	7.0
3,900	16.7	24.6	32.6	40.7	48.8	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2
4,000	16.3	24.4	32.7	40.9	49.2	0.8	1.6	2.5	3.3	4.1	4.9	5.8	6.6	7.4
+ 4,100	+15.8	+24.2	+32.6	+41.1	+49.5	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.7	7.6
4,200	15.4	23.9	32.5	41.2	49.9	0.9	1.7	2.6	3.4	4.3	5.2	6.0	6.9	7.8
4,300	14.8	23.6	32.4	41.3	50.2	0.9	1.8	2.7	3.5	4.4	5.3	6.2	7.1	8.0
4,400	14.3	23.3	32.3	41.3	50.4	0.9	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.1
4,500	13.7	22.9	32.1	41.3	50.6	0.9	1.8	2.8	3.7	4.6	5.5	6.5	7.4	8.3
+ 4,600	+13.1	+22.4	+31.8	+41.3	+50.8	0.9	1.9	2.8	3.8	4.7	5.7	6.6	7.5	8.5
4,700	12.4	21.9	31.5	41.2	50.9	1.0	1.9	2.9	3.8	4.8	5.8	6.7	7.7	8.7
4,800	11.7	21.4	31.2	41.1	51.0	1.0	2.0	2.9	3.9	4.9	5.9	6.9	7.9	8.8
4,900	10.9	20.9	30.9	40.9	51.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
5,000	10.1	20.3	30.5	40.7	51.0	1.0	2.0	3.1	4.1	5.1	6.1	7.2	8.2	9.2
	6,000	7,000	8,000	9,000	10,000	1	2	3	4	5	6	7	8	9

TABLE OF VALUES OF THERMIC TERM, $\frac{A\,(B-A)}{D}$, IN FEET.

a = Approximate Altitude, in Feet.	B = Vertical Base, in Feet					Additional Hundreds of Feet								
	1,000	2,000	3,000	4,000	5,000	1	2	3	4	5	6	7	8	9
+ 5,100	− 41.9	− 31.7	− 21.5	− 11.3	− 1.0	1.0	2.0	3.1	4.1	5.1	6.1	7.2	8.2	9.2
5,200	43.7	33.4	23.0	12.6	2.1	1.0	2.1	3.1	4.2	5.2	6.2	7.3	8.3	9.4
5,300	45.6	35.1	24.5	13.9	3.2	1.1	2.1	3.2	4.2	5.3	6.4	7.4	8.5	9.5
5,400	47.5	36.8	26.0	15.2	4.3	1.1	2.2	3.2	4.3	5.4	6.5	7.6	8.6	9.7
5,500	49.5	38.6	27.6	16.6	5.5	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9
+ 5,600	− 51.5	− 40.4	− 29.2	− 18.0	− 6.8	1.1	2.2	3.4	4.5	5.6	6.7	7.8	9.0	10.1
5,700	53.5	42.2	30.9	19.5	8.0	1.1	2.3	3.4	4.6	5.7	6.8	8.0	9.1	10.3
5,800	55.6	44.1	32.6	21.0	9.3	1.2	2.3	3.5	4.6	5.8	6.9	8.1	9.3	10.4
5,900	57.7	46.0	34.3	22.5	10.7	1.2	2.4	3.5	4.7	5.9	7.0	8.2	9.4	10.6
6,000	59.9	48.0	36.1	24.1	12.1	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8
+ 6,100	− 62.1	− 50.0	− 37.9	− 25.7	− 13.5	1.2	2.4	3.7	4.9	6.1	7.3	8.5	9.8	10.9
6,200	64.3	52.0	39.7	27.4	15.0	1.2	2.5	3.7	4.9	6.2	7.4	8.6	9.9	11.1
6,300	66.6	54.1	41.6	29.1	16.5	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3
6,400	68.9	56.2	43.6	30.8	18.0	1.3	2.5	3.8	5.1	6.4	7.6	8.9	10.2	11.4
6,500	71.2	58.4	45.5	32.6	19.6	1.3	2.6	3.9	5.2	6.4	7.7	9.0	10.3	11.6
+ 6,600	− 73.6	− 60.6	− 47.5	− 34.4	− 21.2	1.3	2.6	3.9	5.2	6.5	7.9	9.2	10.5	11.8
6,700	76.0	62.8	49.6	36.2	22.9	1.3	2.6	4.0	5.3	6.6	8.0	9.3	10.6	12.0
6,800	78.5	65.1	51.7	38.1	24.6	1.3	2.7	4.0	5.4	6.7	8.1	9.4	10.8	12.1
6,900	81.0	67.4	53.8	− 40.1	26.3	1.4	2.7	4.1	5.5	6.8	8.2	9.6	11.0	12.3
7,000	83.5	69.7	55.9	42.0	28.1	1.4	2.8	4.2	5.5	6.9	8.3	9.7	11.1	12.5
+ 7,100	− 86.1	− 72.1	− 58.1	− 44.0	− 29.9	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6
7,200	88.7	74.5	60.3	46.1	31.7	1.4	2.8	4.3	5.7	7.1	8.5	10.0	11.4	12.8
7,300	91.3	77.0	62.6	48.1	33.6	1.4	2.9	4.3	5.8	7.2	8.6	10.1	11.5	13.0
7,400	94.0	79.5	64.9	50.3	35.5	1.5	2.9	4.4	5.8	7.3	8.8	10.2	11.7	13.2
7,500	96.7	82.0	67.2	52.4	37.5	1.5	3.0	4.4	5.9	7.4	8.9	10.4	11.8	13.3
+ 7,600	− 99.5	− 84.6	− 69.6	− 54.6	− 39.5	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5
7,700	102.3	87.2	72.0	56.8	41.6	1.5	3.0	4.6	6.1	7.6	9.1	10.6	12.1	13.7
7,800	105.1	89.8	74.5	59.1	43.7	1.5	3.1	4.6	6.1	7.7	9.2	10.7	12.3	13.8
7,900	108.0	92.5	77.0	61.4	45.8	1.6	3.1	4.7	6.2	7.8	9.3	10.9	12.4	14.0
8,000	110.9	95.2	79.5	63.8	47.9	1.6	3.1	4.7	6.3	7.9	9.4	11.0	12.6	14.2
+ 8,100	− 113.9	− 98.0	− 82.1	− 66.2	− 50.1	1.6	3.2	4.8	6.4	8.0	9.6	11.2	12.8	14.4
8,290	116.9	100.8	84.7	68.6	52.3	1.6	3.2	4.8	6.5	8.1	9.7	11.3	12.9	14.5
8,300	119.9	103.6	87.4	71.0	54.6	1.6	3.3	4.9	6.5	8.2	9.8	11.4	13.1	14.7
8,400	122.9	106.5	90.1	73.5	56.9	1.6	3.3	4.9	6.6	8.2	9.9	11.5	13.2	14.8
8,500	126.0	109.4	92.8	76.0	59.3	1.7	3.3	5.0	6.7	8.3	10.0	11.7	13.4	15.0
+ 8,600	− 129.2	− 112.4	− 95.5	− 78.6	− 61.7	1.7	3.4	5.1	6.7	8.4	10.1	11.8	13.5	15.2
8,700	132.3	115.4	98.3	81.2	64.1	1.7	3.4	5.1	6.8	8.5	10.2	11.9	13.6	15.3
8,800	135.5	118.4	101.2	83.9	66.5	1.7	3.4	5.2	6.9	8.6	10.3	12.1	13.8	15.5
8,900	138.8	121.4	104.1	86.6	69.0	1.7	3.5	5.2	7.0	8.7	10.5	12.2	14.0	15.7
9,000	142.1	124.5	107.0	89.3	71.6	1.8	3.5	5.3	7.0	8.8	10.6	12.3	14.1	15.9
+ 9,100	− 145.4	− 127.7	− 109.9	− 92.1	− 74.2	1.8	3.6	5.3	7.1	8.9	10.7	12.5	14.2	16.0
9,200	148.7	130.8	112.9	94.9	76.8	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2
9,300	152.1	134.0	115.9	97.7	79.4	1.8	3.6	5.4	7.3	9.1	10.9	12.7	14.5	16.4
9,400	155.6	137.3	119.0	100.6	82.1	1.8	3.7	5.5	7.4	9.2	11.0	12.9	14.7	16.6
9,500	159.0	140.6	122.1	103.5	84.8	1.9	3.7	5.6	7.4	9.3	11.1	13.0	14.8	16.7
+ 9,600	− 162.5	− 143.9	− 125.2	− 106.4	− 87.6	1.9	3.7	5.6	7.5	9.4	11.2	13.1	15.0	16.9
9,700	166.1	147.2	128.4	109.4	90.4	1.9	3.8	5.7	7.6	9.5	11.4	13.2	15.1	17.0
9,800	169.6	150.6	131.6	112.4	93.2	1.9	3.8	5.7	7.6	9.5	11.5	13.4	15.3	17.2
9,900	173.2	154.1	134.8	115.5	96.1	1.9	3.9	5.8	7.7	9.6	11.6	13.5	15.4	17.4
10,000	176.9	157.5	138.1	118.6	99.0	1.9	3.9	5.8	7.8	9.7	11.7	13.6	15.6	17.5
	1,000	2,000	3,000	4,000	5,000	1	2	3	4	5	6	7	8	9

TABLE OF VALUES OF THERMIC TERM, $\frac{A\,(B-A)}{D}$, IN FEET.

a = Approximate Altitude, in Feet.	B = Vertical Base, in Feet					Additional Hundreds of Feet.								
	6,000	7,000	8,000	9,000	10,000	1	2	3	4	5	6	7	8	9
+5,100	+9.3	+19.6	+30.1	+40.5	+51.0	1.0	2.1	3.1	4.2	5.2	6.3	7.3	8.3	9.4
5,200	8.4	19.0	29.6	40.2	50.9	1.1	2.1	3.2	4.2	5.3	6.4	7.4	8.5	9.6
5,300	7.5	18.3	29.1	39.9	50.8	1.1	2.2	3.2	4.3	5.4	6.5	7.6	8.7	9.7
5,400	6.6	17.5	28.5	39.5	50.6	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9
5,500	5.6	16.7	27.9	39.1	50.4	1.1	2.2	3.4	4.5	5.6	6.7	7.8	9.0	10.1
+5,600	+4.5	+15.9	+27.3	+38.7	+50.2	1.1	2.3	3.4	4.6	5.7	6.9	8.0	9.1	10.3
5,700	3.5	15.0	26.6	38.2	49.9	1.2	2.3	3.5	4.6	5.8	7.0	8.1	9.3	10.4
5,800	2.4	14.1	25.9	37.7	49.6	1.2	2.4	3.5	4.7	5.9	7.1	8.3	9.4	10.6
5,900	1.2	13.1	25.1	37.1	49.2	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8
6,000	0.0	12.1	24.3	36.5	48.8	1.2	2.4	3.7	4.9	6.1	7.3	8.5	9.8	11.0
+6,100	−1.2	+11.1	+23.5	+35.9	+48.3	1.2	2.5	3.7	4.9	6.2	7.4	8.7	9.9	11.2
6,200	2.5	10.0	22.6	35.2	47.8	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.1	11.3
6,300	3.8	8.9	21.7	34.5	47.3	1.3	2.6	3.8	5.1	6.4	7.7	8.9	10.2	11.5
6,400	5.2	7.7	20.7	33.7	46.8	1.3	2.6	3.9	5.2	6.5	7.8	9.1	10.4	11.7
6,500	6.6	6.5	19.7	32.9	46.1	1.3	2.6	3.9	5.3	6.6	7.9	9.2	10.5	11.9
+6,600	−8.0	+5.3	+18.7	+32.1	+45.5	1.3	2.7	4.0	5.4	6.7	8.0	9.4	10.7	12.0
6,700	9.4	4.0	17.6	31.2	44.8	1.4	2.7	4.1	5.4	6.8	8.1	9.5	10.8	12.2
6,800	10.9	2.7	16.5	30.3	44.1	1.4	2.7	4.1	5.5	6.9	8.2	9.6	11.0	12.4
6,900	12.5	1.4	15.3	29.3	43.3	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6
7,000	14.1	0.0	14.1	28.3	42.5	1.4	2.8	4.2	5.7	7.1	8.5	9.9	11.3	12.7
+7,100	−15.7	+1.5	+12.9	+27.2	+41.7	1.4	2.9	4.3	5.7	7.2	8.6	10.0	11.5	12.9
7,200	17.3	2.9	11.6	26.2	40.8	1.5	2.9	4.4	5.8	7.3	8.7	10.2	11.6	13.1
7,300	19.0	4.4	10.3	25.0	39.9	1.5	2.9	4.4	5.9	7.4	8.8	10.3	11.8	13.3
7,400	20.8	6.0	8.9	23.9	38.9	1.5	3.0	4.5	6.0	7.5	9.0	10.4	11.9	13.4
7,500	22.6	7.6	7.5	22.7	37.9	1.5	3.0	4.5	6.0	7.6	9.1	10.6	12.1	13.6
+7,600	−24.4	−9.2	+6.1	+21.4	+36.8	1.5	3.1	4.6	6.1	7.7	9.2	10.7	12.2	13.8
7,700	26.2	10.8	4.6	20.2	35.7	1.5	3.1	4.6	6.2	7.7	9.3	10.8	12.4	13.9
7,800	28.1	12.5	3.1	18.8	34.6	1.6	3.1	4.7	6.3	7.8	9.4	10.9	12.5	14.1
7,900	30.0	14.3	1.6	17.5	33.5	1.6	3.2	4.8	6.3	7.9	9.5	11.1	12.7	14.3
8,000	32.0	16.0	0.0	16.1	32.3	1.6	3.2	4.8	6.4	8.0	9.6	11.2	12.9	14.5
+8,100	−34.0	−17.8	−1.6	+14.7	+31.0	1.6	3.2	4.9	6.5	8.1	9.7	11.4	13.0	14.6
8,200	36.0	19.7	3.3	13.2	29.7	1.6	3.3	4.9	6.6	8.2	9.9	11.5	13.1	14.8
8,300	38.1	21.6	5.0	11.7	28.4	1.7	3.3	5.0	6.6	8.3	10.0	11.6	13.3	15.0
8,400	40.2	23.5	6.7	10.1	27.1	1.7	3.4	5.0	6.7	8.4	10.1	11.8	13.5	15.1
8,500	42.4	25.5	8.5	8.5	25.7	1.7	3.4	5.1	6.8	8.5	10.2	11.9	13.6	15.3
+8,600	−44.6	−27.5	−10.3	+6.9	+24.2	1.7	3.4	5.2	6.9	8.6	10.3	12.0	13.8	15.5
8,700	46.8	29.6	12.2	5.2	22.7	1.7	3.5	5.2	6.9	8.7	10.4	12.2	13.9	15.7
8,800	49.1	31.7	14.1	3.5	21.2	1.7	3.5	5.3	7.0	8.8	10.5	12.3	14.1	15.8
9,900	51.4	33.8	16.0	1.8	19.7	1.8	3.5	5.3	7.1	8.9	10.6	12.4	14.2	16.0
9,000	53.8	35.9	18.0	0.0	18.1	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2
+8,100	−56.2	−38.1	−20.0	−1.8	+16.4	1.8	3.6	5.4	7.3	9.1	10.9	12.7	14.5	16.3
9,200	58.6	40.4	22.1	3.7	14.8	1.8	3.7	5.5	7.3	9.2	11.0	12.8	14.7	16.5
9,300	61.0	42.7	24.2	5.6	13.1	1.9	3.7	5.6	7.4	9.3	11.1	13.0	14.8	16.7
9,400	63.5	45.0	26.3	7.5	11.3	1.9	3.7	5.6	7.5	9.3	11.2	13.1	15.0	16.8
9,500	66.1	47.3	28.4	9.5	9.5	1.9	3.8	5.7	7.6	9.4	11.3	13.2	15.1	17.0
+9,600	−68.7	−49.7	−30.6	−11.5	+7.7	1.9	3.8	5.7	7.6	9.5	11.5	13.4	15.3	17.2
9,700	71.3	52.1	32.9	13.6	5.8	1.9	3.8	5.8	7.7	9.6	11.6	13.5	15.4	17.3
9,800	73.9	54.6	35.2	15.7	3.9	1.9	3.9	5.8	7.8	9.7	11.7	13.6	15.6	17.5
9,900	76.6	57.1	37.5	17.8	2.0	2.0	3.9	5.9	7.9	9.8	11.8	13.8	15.7	17.7
10,000	79.4	59.6	39.8	20.0	0.0	2.0	4.0	6.0	7.9	9.9	11.9	13.9	15.9	17.9
	6,000	7,000	8,000	9,000	10,000	1	2	3	4	5	6	7	8	9

SUPPLEMENTARY NOTE

ON THE ELIMINATION OF THE INFLUENCE OF WIND PRESSURE FROM BAROMETRIC OBSERVATIONS.

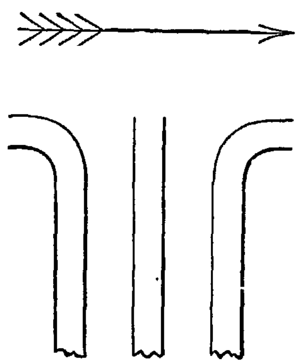
One result of the inquiry detailed in Chapter IV was the discovery that the pressure of the wind introduced a large error into the series of barometric observations made on Mount Washington in June, 1873. A northwest wind of 50 miles per hour, by drawing air out of the observatory (presumably through the chimney), caused the mercury in the barometer to stand .13 inch too low. Since the power of the wind to produce such effects is proportional, not to its simple velocity, but to the square of its velocity, it is evident that such a wind as the strongest observed at that station may utterly vitiate the record of the barometer. A wind with a velocity of 100 miles per hour would, under the same conditions, depress the barometer more than half an inch; and, after making every allowance for inaccuracy of velocity determinations, it cannot be doubted that that station is frequently subjected to a wind of that speed. In hypsometry, a barometric error of one half inch affects the computed height 500 feet. In the plotting of isobaric maps, such as are daily prepared by the Weather Bureau of the Army, it displaces five of the curves, putting them on the wrong side of the station where the error is incurred, and correspondingly distorting the contours of storms.

Not all winds had this effect at Mount Washington. Perhaps none do in the present observatory, for the building now occupied is not the one in use in June, 1873. But the danger certainly exists, and it is incurred by all stations subject to high winds. If any such errors occur, even though comparatively small, they cannot fail both to retard the development of the science of storms and to add to the uncertainty of meteorologic prediction. It is therefore important that the difficulty be thoroughly met. How shall this be done?

It is safe to say that it cannot be met by merely applying a correction to the reading of the barometer without attempting to control the conditions to which it is exposed. To make such a correction efficacious, we should need to know not simply the general influence of the wind upon the tension of the air in each room used as a meteorologic observatory, but the special influence of each particular wind, and this knowledge would be in the highest degree difficult to obtain. If we had some standard for comparison it would be possible to observe the actual errors at each observatory, and from them to construct a table of corrections applicable to the readings of the barometer; but while the wind blows, one barometer is as much a standard as another, since no room can be known to be exempt from the disturbing influence.

It follows that the conditions must be controlled. We must bring special apparatus to our aid and put the barometer in such relation to the wind that it will either record the normal pressure or else deviate from it by an ascertainable amount.

Three types of apparatus suggest themselves, each of which incloses the barometer in an air-tight case and connects the interior of the case with the outer air by means of a tube, the open end of which is made to assume a definite relation to the wind. If we exclude oblique positions from consideration, there are three relations which may be assumed by the tube. The aperture may be turned toward the wind (*a* in the diagram), it may be turned from the wind (*c*), or it may be directed at right angles to the course of the wind (*b*). It is evident that the wind will force air into the tube *a*, and thus increase the tension within the tube; it is evident that it will draw air out of the tube *c*, and thus diminish the tension within; and it has been shown by the experiments of Magius and Hagemann* that air is drawn also from the tube *b*, so as to produce a diminution of tension. The increase of tension in the tube *a* is equal to the horizontal force of the wind. Hagemann's experiments indicate that the decrease of tension in the tube *b* is likewise equal to the force of the wind, but his demonstration is indirect, and perhaps should not be accepted without further experiment. The tension in the tube *c* has not been investigated, but it is *a priori* probable that its deficiency as compared with the normal tension is equal to the excess produced in the tube *a*.



a *b* *c*

FIG 32.—Diagram showing Relations of Tube Apertures to Wind The Arrow points the Direction toward which the Wind is supposed to Blow.

The first suggested apparatus is as follows: Insulate a barometer from the air tension of the observatory, either by encasing the instrument or by encasing its cistern, and establish a communication with the outer air by means of a tube exposed to the wind in one of the three indicated ways. If the tube *b* is selected, it will need merely to be directed upward and so placed with reference to surrounding objects that it will be exposed to none but horizontal air currents. If *a* or *c* is used, it must be joined to a vane in such way as to maintain a constant relation to the direction of the wind. Whichever tube is employed, there must be placed near it an anemometer of some sort. If the tube *a* is used, the pressure indicated by the barometer will be greater than

* See reference on page 533.

the normal pressure; if *b* or *c* is used, it will be less than the normal; and in either case the correction necessary to be applied to the reading in order to deduce the normal pressure will be derivable from the velocity or pressure of the wind, as given by the anemometer.

The second suggested apparatus uses two barometers instead of one, and discards the anemometer. The barometers are independently inclosed. One of them is exposed to the wind by means of a tube of the form *a*, and gives a reading too high; the other is exposed to the wind by means of a tube like *b* or *c*, and gives a reading too low. The true reading, or the normal pressure, is evidently a function of the two abnormal readings, and is derivable from them.

The difference between the two readings depends upon the force of the wind, and may be made to serve as its measure. The second apparatus might therefore be used also as an anemometer.

In the third suggested apparatus a single barometer is made to communicate with the outer air by means of two or more apertures. Let us suppose that the tubes *a* and *c* are connected at bottom with a box which is otherwise closed. The wind forces the air into the box through the tube *a*, and draws it from the box through the tube *c*. The tendency of the inflowing air is to increase the tension in the box; the tendency of the outflowing air is to diminish it; and it is conceivable that the tubes can be so adjusted in size and form that the two influences shall neutralize each other, whatever the velocity of the wind, and leave a normal tension in the box. If this can be done, then a barometer put in communication with the box will record the normal atmospheric pressure, and its indication will require no correction.

Neither apparatus can be qualified for its work without a preliminary series of experiments, but there seems no reason to question that, with suitable details, either of them may be made to serve the purpose. A number of precautions and mechanical devices have occurred to the writer, which need not be described, because they will readily suggest themselves to any competent person who undertakes the experimentation necessary to the development of an apparatus.

It is to be observed that the third plan is the only one which promises any relief to the itinerary observer, and that the best relief it can possibly afford is but partial. And this leads to the further observation that the disturbing influence of the wind is two-fold, and that only one factor of it can be counteracted by apparatus. Besides the abnormal tensions communicated to apartments through apertures, there is another set of abnormal tensions, arising wherever the wind blows across an uneven surface. We may imagine that a level plain swept by a wind may sustain an equal pressure on every part, but if the continuity of the plain be interrupted by any projecting object, such as a hill or a house, an inequality of tension is produced. The atmospheric tension and pressure upon the windward side of the obstruction become abnormally great, and upon the lee side abnormally small. This is an inequality dependent upon locality, and cannot be corrected by mechanical appliances. Theoretically, there seems no way to avoid it except by the selection of localities for observation, and that selection is a matter of difficulty. A fixed observatory is itself an obstruction to the wind, and even if there are no other buildings in its vicinity it must be surrounded during a strong wind by a system of abnormal tensions. The mountain peak upon which the geographer has so frequently to read his barometer, and upon which he so often encounters a strong wind, is an obstruction of the most prominent kind. If he hangs his barometer on the windward side of the summit, he can be sure that his reading will be too high; if on the leeward side, that it will be too low; but there seems no possible way of selecting for observation a point subject to the normal pressure.

POSTSCRIPT ON GRAPHIC TABLE.

In the application of the table for the thermic correction, pages 556–561, a double interpolation is frequently necessary; and a double interpolation is always inconvenient. It is especially irksome in this case because the total value of the correction is so small as compared with the altitude it modifies. An attempt has therefore been made to avoid it by the construction of a graphic table, but the latter was not completed in time for the first edition of the volume. It is here added in Plate LXII, and a few words are necessary in explanation.

Vertical distances in the graphic table represent heights of base line, or values of B in the formula. Their origin or zero is at the base of the diagram. A horizontal line is drawn at each hundred feet, and a stronger line at each thousand feet. The thousand-feet marks are numbered at the right.

Horizontal distances represent values (in feet) of the approximate altitude—*a* of the formula—and each hundred feet is indicated by a vertical line. The zero line, or the origin of horizontal distances, is not at the margin of the diagram, but is between the middle and the right-hand margin, as indicated by the numbering at the bottom. Distances to the left of this line represent positive values of the approximate altitude, and distances to the right represent negative values thereof. The positive values run from 0 to 8,000 feet, the negative from 0 to 3,000 feet.

Upon this reticle of straight lines a system of curves is drawn, and each curve represents a value of the thermic correction or thermic term, $\frac{A\,(B-A)}{490000}$ of the formula. The curve which falls nearest to the zero line of approximate altitudes corresponds to a correction of ½ foot, the curve next it to a correction of 1½ feet, the third to 2½ feet, etc. For every point between the first and second curves the correction is greater than $\frac{1}{2}$ foot and less than $1\frac{1}{2}$ feet, or, if fractions are disregarded, it is 1 foot. So, for all points falling in the next space the correction is 2 feet, etc. The numbers on the upper and left hand margins apply to these spaces and show the values of the thermic correction corresponding to them. They are written opposite every fifth space, and the corresponding spaces are given a tint for convenience in tracing across the page.

EXAMPLE ILLUSTRATING USE OF TABLE.

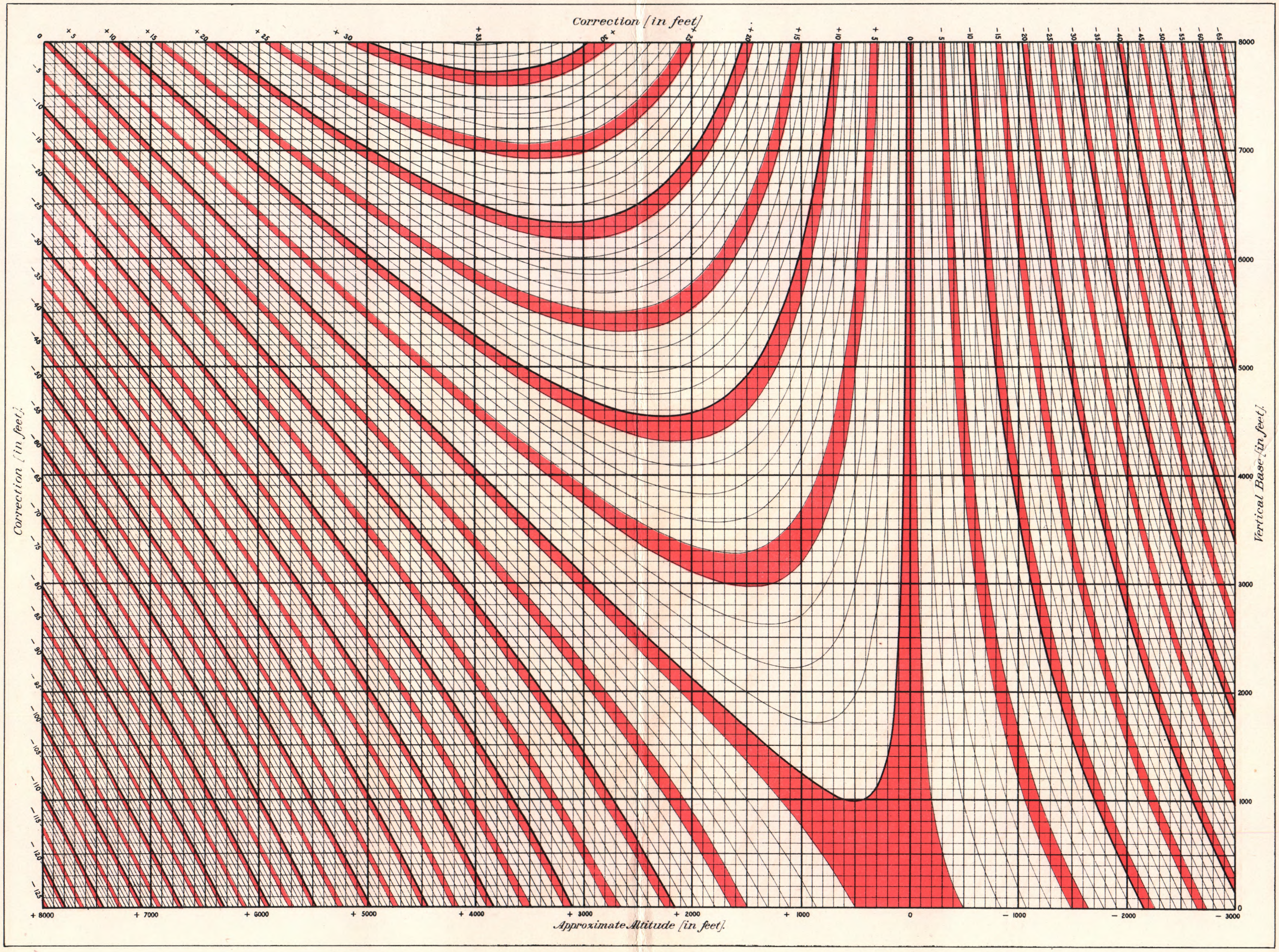
When B = 7,210 feet and $a = +2{,}570$ feet, required the value of the thermic correction.

First, find by the aid of the right-hand index the horizontal line corresponding to 7,200 feet, then from the index at the base the line corresponding to +2,600 feet. Trace them to their intersection. By inspection determine a point $\frac{1}{10}$ of the ruled square above this intersection and $\frac{3}{10}$ of the ruled square to the right of it. This point indicates the intersection of the undrawn lines representative of the arguments 7,210 feet and 2,570 feet. Note the relation of this point to the curved spaces; the space containing it is next to one of the tinted spaces. Tracing the tinted space in either direction to the margin of the diagram its index is found to be +25 feet, and the index of the space next it is therefore +24 feet—the desired thermic correction.

If this same example were solved by means of the table on page 559 the value 24.3 feet would be obtained, but the refinement implied by the definition of the tenths of a foot is a useless one, as has already been explained on page 450.

The computer who has to determine a large number of new stations by reference to a single pair of base stations, will find it advantageous to draw upon the graphic table a horizontal red line representative of his particular value of B. He will thus produce with a minimum of effort a one-argument table equivalent to that recommended on page 555.

This graphic table is in some sense an experiment. The idea, indeed, is not novel, but it has not been widely applied. It appears to the writer that a similar plan might advantageously be adopted for the tabulation of factors dependent upon two arguments whenever the arguments are large as compared with the tabulated factor; or rather, whenever the number of digits used to express each argument is large as compared with the number of digits used to express the dependent factor.



GRAPHIC TABLE FOR COMPUTATION OF THERMIC CORRECTION.

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