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OF THE

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TO THE

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BY

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DIRECTOR

IN TWO PARTS

PART II—ACCOMPANYING PAPERS

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UNITED STATES GEOLOGICAL SURVEY.

Part II.—ACCOMPANYING PAPERS.

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INTRODUCTION.

POTABLE WATERS IN THE HUMAN ECONOMY.

Human life depends on the utilization of potential energy stored up in a variety of substances which are consumed as food. These substances include minerals, such as water and salt, which are utilized alike by plants, lower animals, and mankind; vegetal products, comprising fruits and grains as well as leaves, roots, and sometimes stems, which are utilized alike by lower animals and mankind; and a variety of animal products, which are utilized by certain lower organisms as well as by mankind.

While mineral, vegetal, and animal substances yield food for living things, the food substances are not of like value and are not consumed in like proportions by different organisms. The prevailing plant foods are mineral substances which the plants assimilate and transform into higher compounds; excluding water, the prevailing foods of herbivorous animals are these higher compounds of the plant laboratory, which are assimilated and raised still higher; and, again excluding water, the prevailing foods of carnivorous and omnivorous animals are these compounds of the third order which are assimilated and thereby once more raised in the scale of differentiation. Thus, while certain food substances are common to all living things, others differ in degree of differentiation and so in the facility with which they may be assimilated and utilized in the higher stages of vital economy.

There is a differentiation of organisms running parallel with, and doubtless practically dependent on, the differentiation of foods; and viewed broadly the living things of the earth may be classified by the food substances utilized perhaps as justly as in any other way. Under this classification the lowest organisms are those whose food substances are mineral; a higher order includes those organisms whose food substances are predominantly mineral yet in part vegetal; and after several intermediate orders in which the proportion of more and more highly organized food substances varies yet progressively increases, man is found at the head of the series with a higher and more elaborate dietary than any other organism. The reciprocal character of the relation between the organism and its food is well illustrated in this culminating order of the organic series; for while the interdependence of animal and vegetal life began in earlier ages, while, indeed, as early as the Cretaceous of geologic history plant-fertilizing insects and seed-distributing birds initiated the development of fragrant flowers and sapid fruits, most of the foods of modern men are essentially products of human craft. The most useful grains, vegetables, and fruits are vegetal monstrosities, so far modified by cultivation that their original forms are unknown; so far transformed in habit that they can not exist without human aid; so far reconstructed in constitution that their vitality is expended in producing abnormal developments of tissue useless to the organisms themselves and useful only to mankind, for whose behoof they were transformed. And in like manner the chief sources of animal food—cattle, sheep, fowls, and swine—are so completely modified under human will as to be turned into biotic monstrosities, helpless without human aid, whose vitality is expended in producing tissue useless to themselves and useful only as food for mankind. Thus food substances represent a graded series, beginning with undifferentiated minerals and running up to the most highly differentiated animal compounds; and the living things of the earth, with man at their head, represent a parallel series which may be classified by the character of their food. With a single exception there is progressive diminution in the use of mineral foods in the series of organisms followed from the lowest to the highest, the exceptional substance being the mineral compound, H_2O, or water, which is consumed alike, and nearly always in a large proportion, by all living things.

Human foods are classified in a variety of ways. Thus they are frequently divided into liquids and solids, a division which is measurably indefinite for the reason that the nominal solids are always composed in part, generally in greater part, of water; but even under this classification it is commonly found that considerably more liquid than solid food is consumed. Classified chemically, foods are divided into (1) proteids, or nitrogenous substances, including the most highly differentiated among animal and vegetal compounds; (2) fats or non-nitrogenous substances, in which the proportion of hydrogen and oxygen is unlike that of water and which are second in the inverse order of complexity among animal and vegetal compounds; (3) carbohydrates (sometimes called amyloids) or nonnitrogenous compounds of carbon with hydrogen and oxygen in the proportions required to form water, i. e., relatively simple vegetal and animal compounds, standing third in the inverse order of differentiation; and (4) minerals, including water and various salts. This classification, too, is indefinite in that most articles of food embrace more than one and many embrace all of these constituents—indeed, the best dietary comprises all of these food classes, and none of the food articles in common use are free from the preponderant mineral constituent, water. Classified by function, human foods may be grouped as (1) nutrients, including meats, fruits, cereals, vegetables etc., whose substance is largely assimilated and absorbed into the system; (2) assimilants, including a variety of condiments which aid in assimilation; (3) paratriptics, or waste-preventers, including tea, coffee, wine and other alcoholic beverages, etc., which in some little understood way retard the waste of tissue and consequent dissipation of energy; and (4) diluents, which modify the consistency of solid foods and thereby facilitate assimilation, besides maintaining the water of the system and perhaps performing other functions. This classification also is indefinite, partly for the reason that many articles used as food perform different functions (e. g., milk is at once a nutrient and a diluent; beer at the same time a nutrient, a paratriptic, and a diluent, etc.); but, like the primary classification by degree of differentiation, the classification by physical condition, and the chemic classification, it indicates the low order of simple liquids among food substances.

So while water occupies the first place among foods in quantity it would appear to occupy a low, perhaps the lowest, place in quality.

The average human adult, in a condition of health and moderate activity, consumes daily about 4½ pounds of simple liquids and about 2½ pounds of nominally solid food, really consisting of about equal parts of water and solids, yet so intimately commingled as to demand common treatment; i. e., nearly two-thirds of the average human food is liquid, and barely more than one-third is more or less diluted solids. Now the character of the liquid food consumed by mankind varies from place to place and from time to time with many conditions; but under the social and other conditions obtaining in this country to-day by far the larger part of the liquid food is simple water; and accordingly it is fair to estimate that about one-half of the matter daily taken into the average American stomach is nominally pure water, drawn from spring or river, well or cistern, running brook or city hydrant.

The culinary condition of food substances in this country is not uniform. Most solids are cooked, and thereby any noxious germs or germ products that they may contain are destroyed; many fruits and nuts which are eaten raw are protected by epidermis or shell, so that the danger of contamination is reduced; most beverages are subjected to such treatment in manufacture or cooking as to destroy organic germs (which are now recognized as the cause of most diseases) and thereby rendered innocuous; but water is commonly consumed just as it comes from pump or hydrant, without germicidal treatment, without thought of poisons that may lurk within it. Accordingly, while water may constitute but half of the aliment, the danger of germ poisoning from this substance is, other things equal, much greater than the danger from all others combined.

Solid and liquid foods, even in the uncooked condition, are not alike in danger of contamination. Meats and other animal substances are highly complex compounds, and therefore, under the law of inverse relation between chemic complexity and stability, they are eminently unstable, so that decomposition is easily initiated and proceeds with great and cumulative rapidity; and in somewhat less degree the same is true of vegetal food substances. Hence, germs which are noxious alike to these substances and to the chemically similar substance of the human body can not long exist without making their presence known; and devices for cooking and preserving foods and systems of food inspection have been developed in order to protect human life from dangers growing out of organic poisons in solid food substances. But water is the common food of animal and plant, microbe and mankind; it is so stable chemically that microbes may exist within it in incalculable numbers without breaking it down or appreciably changing its character; and alone or in combination with other substances it is a favorite, or at least a suitable, medium for the growth and multiplication of germs noxious to mankind. Accordingly, the chance of organic poisoning by potable water is not simply that of the relative proportion of water and other foods, not even the greater probability going with the ratio of danger in raw water to that of cooked foods, but the very much greater probability growing out of the fact that water is a fit and favorite medium for the development of microbe life. This deduction from food character is fully sustained by medical records—indeed it is really an induction from medical observations traced backward, for the infection of typhoid and intermittent fevers and many other germ diseases is so commonly traceable to contaminated waters that the experienced practitioner called to combat such ills at once turns to the well, spring or cistern as the probable source of the disease.

In short, potable water occupies a prominent place in the human economy; it is preeminently *the* food substance of living things, and common to all from the highest to the lowest; it is the most abundantly consumed of all food substances, often more abundantly than all others combined; but at the same time there is a danger in its use much greater than in all other aliments. So it behooves men well to consider their water supply.

THE CONQUEST OF THE WATERS.

The land of eastern United States is sinking, and the ocean is encroaching on its purlieus. The encroachment has continued for uncounted ages, and the sea waters have backed into the lower reaches of the rivers, converting the valleys into estuaries; and thus the sinking of the land has given character to our coasts and thereby determined the rate and quality of settlement, of the subjugation of the land, and of the conquest of the waters for human weal. This physiographic change, one of the most notable on the globe, may not be neglected in considering the growth of the country.

The first American settlers were invaders of the domain of the red man; they came up from the sea in ships and found havens in the long, narrow, deep, forest-protected estuaries, and the returning mariners carried glowing accounts of fair lands and safe harbors, whereby other adventurers were attracted; and so the ships came up again and again into the deep bayed shores, and cargo after cargo of men and goods were debarked. Plymouth and Jamestown were early points of attack; but the invasion extended along the coast and up the broad estuaries traversing the coastal lowlands until the invaders displaced the aboriginal holders and claimed the land as their own. This was the first stage in the settlement of the country; and it is none the less real that it was not simultaneous from north and south and that it blended with the succeeding stage of internal pioneering.

In the first stage of settlement the invader drank from the fresh streams falling into ocean and estuary, and rejoiced in the sweetness of the waters. When later ships came the invaders, whether Puritans, Knickerbockers or Cavaliers, ascended the tidal canals into which the rivers had been transformed by the sinking of the land, scanning one shore or both for inflowing streams of fresh water; and as the stream mouths were taken by successive communities, or as seaward sites were found unavailable for various reasons, the vessels pushed farther and farther into the interior until they reached the cascades at the termini of the tidal canals; for while the coastwise land is sinking the interior is rising, and the zone of transition from downthrow to upthrow is marked by the line of cascades extending from the Hudson to and beyond the Roanoke (now known as the "fall line"), one of the most trenchant physical and cultural boundaries of the globe. Some settlers in New England, and a few farther southward, indeed, found natural springs; but most of the invaders sought simply for fresh water streams, and the settlements were located at their mouths. In this way the earliest centers of population were fixed, and hundreds of them have grown into towns, and some of them are become commercial marts.

So the dream of the invader of the American soil was a fresh water stream rippling over silvery sands or rushing over rocky bed; long before leaving the fatherland he dreamed by night and queried by day of the tempting flood, and ventured to face the frightsome main only when assured of the verity of the delectable waters in the fair land beyond.

At first the fresh brook water of the new found land was a grateful change from the stale cask water of the ships and even from the polluted streams and wells of the fatherland; and a refreshing expression was coined to indicate the fortunate condition of eastern America—it was said to be a "well-watered country," a land "watered" by many rivers and lesser streams; and the expression took root and followed emigration westward until even the erudite bookmakers came to describe the interior as "watered" rather than "drained" by numerous waterways.

The invaders commonly landed in fair weather, when the brooks were sweet and clear; but storms came and the waters were roiled, the huntsmen with their dogs pushed upstream and the waters were defiled, and anon the spume of marshes spilled into the brooks and the weaker folk fell ill of fevers. Thus little by little the waters of rivers and brooks dropped into disfavor; some sought to store and filter the capricious supply, but they were too few to make this profitable; some made cisterns for storing rain water, but with the limited appliances of primitive culture this involved great labor; and the second generation came to seek for springs and sometimes to dig wells.

So the first stage in the subjugation of the country was invasion by white men from foreign lands; and the first stage in the conquest of the waters began and ended with the beginning and ending of drinking directly from rivers and streams.

The invaders multiplied and the population of the coastwise country grew until the roving hunters on the outskirts found their ranges narrowed, until the farming folk found their acres too few for their families, and then began the stage of pioneering, in which the adventurous sons of hardy sires pushed into the western wilderness toward and finally over and beyond the mountains, slowly displacing the aboriginal landlords who lived on tithes in flesh and blood exacted from bestial tenantry. This was the stage of pioneering, the second stage in the subjugation of the country; and it is none the less real that it was not simultaneous from north to south, and that it merged into the preceding stage of invasion on the one hand and into the succeeding stage of actual settlement on the other hand—for the typical pioneer was a rover, and his race was but the flotsam borne on the breakers of the inflowing tide of population.

A clear cool spring bubbling from moss-covered rocks in a shady dell was the dream of the pioneer. Sleeping and waking, this vision haunted his brain as the brain of one of the first of his class was haunted by the dream of a fount of perpetual youth. From the mysterious sunset land rumors of game-filled woodlands, sparkling trout brooks, and laughing rivers floated away with the west wind and fanned into flame the home-seeking spirit smoldering in a thousand breasts; yet while the home-seeker spoke most of fertile fields and noisy mills and busy water craft, his brightest dreams were of conquest by gun and rod and ax, and the refreshing and health-giving spring was a feature in every picture, often the central feature, about which all others clustered. So the stalwart invader of the red man's domain looked first for a land to his liking and then sought among the hills and valleys for the clear cool spring of his dream; and when he found it, there his household gods were enshrined. His helpmeet shared his quest or soon followed; then children grew up, neighbors came, and the cabin became a house and later the nucleus of a settlement. In this way ten thousand settlements on both slopes of the Appalachian mountains and in the interior were located; and many hundreds of them have become towns and some of them great cities.

The pioneer accepted the spring as a gift of bountiful providence, or as the meed of patient search, to be enjoyed without profane scrutiny or ingrate question, and the origin of the water was a half-sacred mystery. Ignorant of the source of the crystal flood, he neglected the precaution necessary to preserve its purity, even to prolong its existence; so the fountain was sometimes polluted, often dried up—hundreds of cases of typhoid fever have been traced to the waters of erstwhile healthful springs, and half the springs known to the contemporaries of Daniel Boone and Davy Crockett have ceased to flow. The pioneer dreamed of the spring; his children cherished it until it dwindled away or poisoned their systems; his grandchildren sought the source of the waters, that the supply might be renewed and purified.

So the second stage in the subjugation of the country was that of pioneering; and the second stage in the conquest of the waters began with the search for natural springs and ended when the springs failed.

The pioneer enshrined his Lares and Penates beside the spring, and his followers sought other springs in the same and neighboring valleys, until every natural fountain of the woodland marked a household shrine; and when all were taken later comers crowded around the springs of the early comers and settlements grew up with a well-worn path connecting each house with a nucleal fountain. Yet, even when the springs were utilized to the full, the stream of settlement continued to flow and the pioneers were followed by men of stabler and less adventurous habit, who longed for vine and fig tree rather than gamy sports and flavors, and who sought real homes for themselves and their children. Then it was found that the uplands above the reach of the gurgling spring waters yielded more readily to the plow and produced more abundantly than the steep hillsides bounding the bosky dell, and gradually the sparse population of the pioneer stage spread over the divides and grew into a farming population; later, roads were made, forests were felled, towns were built, and all but the most intractable acres were put to the plow or turned into pasture. This was the stage of actual settlement and the beginning of agriculture, the third stage in the subjugation of the country; and it is none the less real that it was not simultaneous in all parts of the country and that it merged with the antecedent pioneering stage and the subsequent intensive stage.

With the increase in population and the felling of forests the flowing springs became too few and then shrank until a half dried up; so one and another of the settlers, and at last nearly all of the rural householders, were driven to well-digging. At first the failing spring was deepened, and the spring became a well; then other wells were located on sites whose moisture indicated the proximity of water; still later well sites were chosen at random, and some yielded bounteous supplies of cool, refreshing water, while others were barren. So well-digging went on apace until no homestead was complete without its well, until the son came to dream of the "old oaken bucket" as his sire dreamed of the clear, cool spring; and at length it came about that the water supply of the country was no longer taken from running brooks, no longer dipped from natural springs, but drawn from the artificial well.

The spirit of the pioneer who accepted the spring as a guerdon of the gods clung to his descendants, and some of them, groping blindly for better knowledge, invoked the aid of magic in locating their wells, and the plague of the wizard fell on the land; and from county to county, from settlement to settlement, from house to house, the craze of water-witching spread, deluding thousands and delaying knowledge. Blinded by the glitter of a phantasm, many settlers of the third generation knew even less of the source of the earth-given waters than the pioneer; so they, too, neglected the precautions necessary to preserve the purity and prolong the life of the crystal flood, and the wells were often polluted, sometimes dried up. But when the water wizard failed, and failed again and again until he fell into deserved contempt, when the physician traced the outbreak of typhoid fever to the well, and when the waters dried up in the long summer, many sons of the third generation profited by the experience of their ancestors and more wisely sought to renew and purify the water supply; and thus the nature of wells is becoming known.

So the third stage in the subjugation of the country was actual settlement, actual transformation of woodland and prairie into field and pasture, the appropriation of the land surface for human ends; and the second stage in the subjugation of the waters began with the substitution of artificial wells for natural springs and running brooks and, except in the cities, this stage is not yet ended.

Faculty is the child of exercise in mind as well as in body, in a people as well as in the individual, in the solidarity of terrestrial life as well as in the group of men. Now, so long as fertile and humid lands lay westward, the sons of the settlers sought new homes in the forests and plains of the interior and rested satisfied with a low grade of culture. In soil, as in social condition, their energies were directed toward half-subjugation of the new rather than toward complete subjugation of the old. So, on the Atlantic slope and over the broad interior, settlers multiplied and the population grew to a certain density varying from place to place with fertility of soil and local fashion, when the supposed excess flowed away westward; and the flux continued until nearly all of the fertile and humid lands of the interior, the subhumid lands of the foot slopes rising toward the Rocky mountains, and the fruitful valleys beyond, were transformed into fields. But when the available lands were taken, the energy born of exercise began to concentrate and seek higher levels, just as the pent-up waters of the walled spring rise; and the farmer boy ceased to dream of reclaiming the distant prairies, which needed only his presence to laugh into bountiful harvests, and sought conquest nearer home. So his hereditary vigor and enthusiasm found outlet first in better methods of farming through the employment of improved farm implements; and the improved implements involved manufacturing, which, in turn, led to the better utilization of forests and the opening of mines of coal and iron, and finally to the development of traffic and transportation; and all these interdependent activities increased cumulatively until human energy came to be expended largely in transforming not only the land surface, but the natural wealth of the forests above and of the earth beneath, until the power controlling the world came to be that of animals and running waters and of steam and electricity, utilized through the craft of the brain rather than the feebler craft of the human muscles.

This is the fourth stage in the subjugation of the country, the stage of intellectual control, in which not only the lands but all things that grow upon them and the resources that lie beneath are appropriated to human welfare; and the stage is none the less real that it is not everywhere simultaneous, but proceeds from nuclei or centers of activity springing into being from time to time and from place to place through the ferment of brain activity; nor is it the less real that it grades out of the earlier stage of subjugation of the surface alone.

The spring of the pioneer was pure and the surface well of the early settler was nearly as pure; but with the increase in settlement and with the manifold attendant transformations of natural conditions the earth beneath barns, houses, gardens, even fields, is gradually charged with noxious by-products of organic activity, and year by year these are washed deeper into the soil and eventually the poison finds its way into spring and well alike. Now in the spring the impurity is diluted and washed away in the flowing waters, while in the well it gathers as a grisly leaven which infects reservoir and contents and changes the healthful flood into festering filth, and curiously—and herein lies the greatest danger to drinkers of well water—as the filth increases the waters become pellucid, sparkling and even brilliant to the eye, sweet and palatably salt to the taste, so that the appetite of the habitual user craves the poison and rejects the pure. How far the surface wells of the country are already polluted no man may say; but certain it is that whole countrysides are annually swept by typhoid fever, that hundreds of towns and villages suffer outbreaks of the same disease every dry summer, and that each epidemic is traceable to the wells; and it may fairly be questioned whether every surface well in city or town is not a source of imminent danger, and whether any such well located hard by village house or country barn is safe. To-day the groaning sweep and creaking windlass, once beacons of health and the inspiration of the poet, have become signals of danger.

With development of manufacturing, water came to be used in large quantities and for many purposes; with the felling of forests and surface draining most springs failed, and with increasing density of population many wells were polluted or dried up and some rivers were defiled. Thus the problem of potable water supply grew into ever greater importance, and in different localities it was solved in different ways. Utilizing the wisdom inherited from their ancestors and growing out of their own observation, the men of the fourth generation sought potable waters in the deep lying strata of the earth, below the reach of surface contamination, and so artesian wells and deep pump wells were opened; where the underground structure was unfavorable for deep well supply, manufacturers or extensive agriculturists availed themselves of modern devices and made capacious cisterns in which the rain waters were stored; while the urban folk combined interests and forces and made reservoirs and constructed waterworks supplied from rivers, and sometimes adopted devices for filtering or otherwise purifying the waters. All of these solutions of the potable water problem are more or less satisfactory in different regions; and thus the prosaic and practical deep well with rattling windmill or coughing engine or wheezing gauge valves at its head, the underground cement-lined cistern of the North and the overground wood-staved and iron-hooped cistern of the South, both filled from carefully cleaned roofs, and the masonry dams diverting river waters into brickwork conduits and through elaborate filters and mains and hydrants to the very hand of the urban user, are all signs of the times and mark a fourth stage in the transformation of nature for human weal.

So the fourth stage in the subjugation of the country is that of complete utilization of natural resources residing in the soil, on the surface of the land, and in the underearth; and the fourth stage in the conquest of the waters began with the making of artesian fountains, or with the diversion of the rains and the control of the rivers, and will end only when the substitution of artificial processes for those of nature is completed.

The progress of civilization in this country may be measured in many ways, but in none more definitely than by the subjugation of the land and the conquest of the waters. The first stage was that of invasion from other lands when men lived largely on the products of the chase and the spoils of the sea, and, like the aboriginal landholders whom they displaced, drank from the running brooks; the second stage and generation was that of hardy pioneers who dreamed of clear, cool springs embowered in primeval forests, and who accepted the flowing water as a guerdon of the gods; in the third stage and generation men were lovers of home and the soil, and in transforming the soil to their uses destroyed the springs and became well-diggers, and this stage is not yet fully passed; in the fourth generation and stage, which is not yet fully come, men transform not only the soil but all nature, and by cooperation and the utilization of manufactured devices delve deep into the earth or divert the rains and rivers that they may enjoy to the full, without danger of poison, the simple mineral food on which all life depends.

THE SOURCES OF POTABLE WATERS.

The immediate sources of potable waters are (1) the rain water collected in cisterns or other reservoirs; (2) running brooks and rivers; (3) springs and wells supplied by ordinary ground water; and (4) deep wells and deep-seated springs supplied by phreatic water. But in the last three cases, as in the first, the ultimate source is the rain falling from the clouds.

While the primary source is the natural rainfall, potable waters are in all cases rendered available by certain natural agencies, or by artificial devices more or less closely simulating the natural agencies; and these agencies and devices give character to the immediate sources.

In the simplest case the waters are collected and stored in cisterns largely or wholly by means of artificial devices. The first device is a catchment area (or drainage basin) which is commonly an artificial roof, though it may be a tract of ground surface of suitable conformation, artifically protected from defilement. The second device is a system of waterways designed to collect the rain waters falling on the catchment area, and these waterways are commonly artificial eavestroughs, pipes, and conduits; but when the ground surface is employed as a catchment area, natural ravines may be utilized in lieu of a part of the artificial system. The third device, which is not essential to the collection of water for certain purposes, though it is absolutely essential to securing water of sufficient purity for potable uses, is a settling basin, or filter, or both combined, in which the water is strained of mechanical impurities taken up in catchment area and water pipes, and freed (either directly, or indirectly through long storage) from organic impurities gathered from roof or ground surface; and devices designed for this purpose in connection with cisterns are always artificial. The fourth device, which is not a prime requisite but which is requisite for a permanent water supply, is a reservoir of considerable dimensions in which the storm waters are kept against the season of drought; and most reservoirs designed for potable waters in this country are artificial cisterns.

In the second case in the order of complexity, potable waters are drawn from running brooks and rivers. In this case the primary source remains the rainfall, and the catchment area which serves as the agency for collecting the waters is the natural drainage basin of the waterway, while the settling-basin, or filter, is in some measure replaced by irregularities in the channel,[1] and the body of the stream serves as the reservoir. Now in this case only a part of the rainfall can be utilized; for while a portion of the storm water gathers into rills and rivulets and flows down the slopes and through the main waterways, another portion is absorbed by the porous soil to perform various functions in hydric economy. A fraction remains near the surface of the soil until drawn upward by capillarity and evaporated when the sunshine follows the rain; another fraction is consumed by the plants; while a third fraction percolates slowly downward and remains long at depths determined by the porosity of the soil, the frequency of rainfall, and other conditions, as a simple sheet of moisture known as "ground water;" or under certain conditions it passes into deep-lying strata and is conveyed long distances through subterranean channels or, more frequently, through inclined porous strata as "phreatic water;"[2] and the running brooks and rivers flowing on the surface are supplied only by that portion of the rainfall which flows off on the surface, together with that portion of the absorbed water which is given back through seepage and springs—commonly ground water, rarely phreatic water.

In the third case in the order of complexity, potable waters are drawn from ground-water springs or wells. Now, the ground-water surface is a somewhat indefinite one, and more or less variable in depth from storm to sun, from winter to summer; but in general it is a subterranean surface coinciding fairly with the land surface, save that it is somewhat smoother, its divides lower, its valleys shallower; and when the two surfaces intersect in the deeper valleys, the ground water exudes and perhaps gathers into subterranean streams, appearing in the bottoms or sides of the valley as springs; but in general each surface drainage basin or catchment area has a subterranean double to which the waters are conveyed by percolation vertically downward and along which they slowly move in obedience to gravity. The drainage basin of the land surface therefore constitutes a catchment basin; the porous soil and subsoil serve as an indefinite medium for collecting the waters, which sometimes form for themselves more definite subterranean channels, the whole constituting an agency for water transportation corresponding in function with the artificial system of eaves-troughs and pipes used in connection with the artificial catchment area; the slightly pervious soil and subsoil constitute an agency for freeing the water from impurities analogous in function to—and indeed the model for—the artificial filter; and open caverns, or saturated sand beds and other exceptional porous deposits, serve as natural reservoirs similar in function to artificial cisterns.

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[1] As set forth in some detail later, p. 33.

[2] This term was coined by Hay, in the course of the recent artesian and underflow investigation between the ninety-seventh meridian and the foothills of the Rocky mountains, as a convenient designation for "underground waters which can be, or which it is hoped may be, reached by wells or other subground works" Final Geological Report, etc., to the Secretary of Agriculture. Senate Ex. Doc. 41, part 3, Fifty-second Congress, first session, p. 8.

In the fourth and most complex case the waters rise from deep lying strata through natural or artificial openings, and are thus phreatic (called artesian when they flow from artificial openings). Now, in this case, too, there is a catchment area which is, however, only indirectly dependent on the surface configuration and may be remote from the well or spring; the deep lying cavern or porous stratum performs a function analogous to that of the artificial system of waterways used to connect artificial roofs and cisterns; and as in the case of ground water, either open caverns or saturated sand beds—nearly always the latter—replace the artificial reservoirs.

So, whatever the immediate source of potable waters, the ultimate source is the rain distilled from the clouds; and the waters are made available by four more or less clearly defined natural agencies, or four artificial devices of related function. The first of these is always the natural or artificial catchment area on which the waters fall; the second is always the artificial system of eavestroughs and pipes, or the natural drainage system of surface streams, or the natural system of subterranean drainage; the third is the artificial settling basin or filter, the natural pools of surface waterways, or the natural filter afforded by slightly pervious earth matter; and the fourth is always a reservoir whether in the form of artificial cistern, natural cavern, or natural mass of saturated sand or porous rock.

Of the four sources and modes of supply of potable waters, the first—that of cisterns—pertains chiefly to technology, yet is little understood and trenches upon applied geology so far as to demand treatment; the second—that of brooks and rivers—pertains largely to technology and is specially treated by municipalities and other corporations, and hence does not require extended technical discussion here; while the third and fourth sources and modes of supply pertain directly to geology and require somewhat extended treatment.

CISTERN WATER SUPPLY.

TYPES OF CISTERNS.

A considerable part of the population of the country take their drinking water from underground or overground cistern supplied from the storm water gathered on roofs. Both types of cistern possess merit, and both are, or may easily be made, safer than ordinary wells; yet certain elements of danger inhere in both.

UNDERGROUND CISTERNS.

In the northern and middle zones of eastern United States, underground cisterns prevail. The usual type of cistern is a simple excavation in the earth of suitable dimensions, floored and walled with brick or stone, and covered (except for the neck opening which serves as a manhole and accommodates the inflow and pump tubes) with an arched roof of the materials used for the walls; the entire interior being lined with a coating of hydraulic cement. In the northern zone at least the excavation is generally made sufficiently deep to permit the roof to be covered with a thickness of earth greater than the maximum depth of frost.

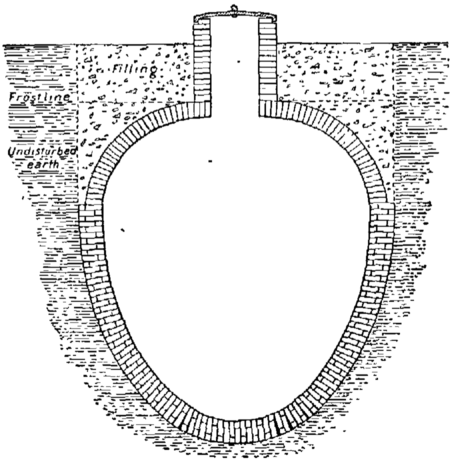

FIG. 1.—Cross-section of jug-shape cistern.

The size of the cistern depends, of course, on the service expected of it, and in some measure the form depends on the size. The ideal form of cistern is that of an egg with the small end downward. A common form in some districts is a modification of this, i. e., a jug shape, with sloping sides, flat or rounded bottom, and arched roof. A good example of the jug form, with rounded bottom, is shown in Fig 1. A cistern of any such form is, however, somewhat difficult to construct, and its contents, full or partly filled, difficult to determine.

A practical form of underground cistern, which well resists internal strains produced by its own contents and the external strains due to ground water under hydrostatic pressure, is a simple segment of a vertical cylinder, with hemispheric arched roof and inverted floor. Such a cistern is shown in section in Fig. 2.

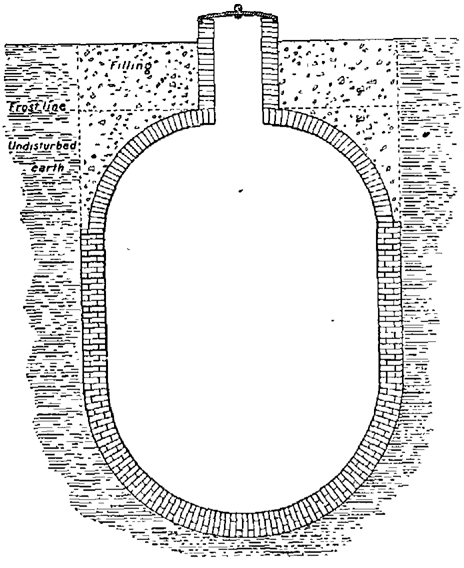

FIG. 2.—Cross-section of underground cistern of simple form.

The ideal type of cistern is modified in many ways: Thus, where building stone is abundant and brick expensive stone is frequently employed for the floor, walls, and roof and gives fairly satisfactory results. In fact stone is inferior to brick in cistern-making chiefly in that it is commonly used rough, thereby giving a liability to imperfect joints and to points and lines of weakness either in the main structure or in the lining.

Again, where the unconsolidated soil is thin and rests on firm and homogeneous rock the reservoir is sometimes excavated therein and the cement lining applied directly to the rock surface; an arched roof of brick or stone being constructed in the usual way. Where the rock is sufficiently solid and impervious this method is excellent, giving cisterns of great durability; it is objectionable when the rock is porous or penetrated by water-bearing seams, in which case considerable hydraulic pressure may be brought to bear upon a relatively thin wall of cement.

In regions of exceptional homogeneous subsoil or unconsolidated earth matter cisterns are sometimes made by simply excavating the earth and lining the bottom and sides of the excavation with cement applied directly to the earth; when the cistern is commonly roofed with wood, either lined with cement, tarred, charred, or in the natural condition. This method has given satisfactory results in the loess region of the Missouri and lower Mississippi rivers, and sometimes in glacial drift; but it is subject not only to the dangers common to rock cisterns but also to the danger of caving of the little coherent material of the walls.

The excellence of the underground cistern lies (1) in the protection of the waters from organic contamination within the carefully lined reservoir; (2) in the relatively uniform temperature of the water; and (3) in the certainty of supply—for while storms come at irregular intervals, and while precipitation varies somewhat from year to year, the average annual precipitation is so nearly uniform as to permit calculation of the dimensions of a cistern required to yield a given annual water supply.

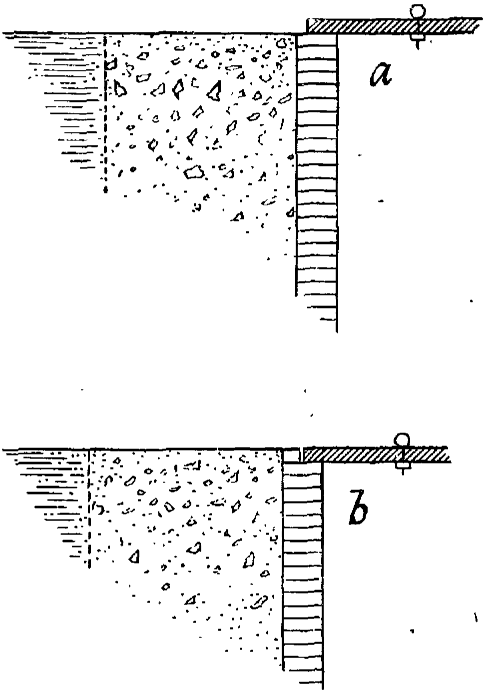

Fig 3.—Unsatisfactory arrangement of cistern cover.

The principal sources of danger residing in the cistern itself are (1) the admission of contaminated surface water; (2) direct contamination of the water through the use of unsuitable materials; and (3) cracking of the lining and consequent admission of contaminated ground water.

Surface water may be excluded by suitable construction of the neck of the cistern and by carrying it above the reach of the highest local floods. Frequently the neck of a cistern is made to terminate flush with a cemented floor, and is closed only by a wooden cover laid flat on the surface or a cover of wood or iron or terra cotta fitting into a rabbet or depression, as shown in Fig. 3. Such an arrangement is unsatisfactory and a source of danger. Commonly little care is taken to raise the floor above the reach of storm floods or spilled liquids; and even when this precaution is taken dust and other solid matter finds its way under the edge of the cover and into the cistern. The neck should always be carried to a height of at least several inches above the floor and the cover should have an outer flange fitting on the outside of the neck or on the outside of a rabbet made to receive it, as shown in Fig. 1. Equal care in fitting should be bestowed on the pump, which commonly passes through an aperture in the cover. The best material for the cover is terra-cotta ware; the next best iron. If wood is used the interior should be painted with tar or coated with pitch, and it should be frequently examined for fungoid growths and cleaned or renewed.

The direct contamination of cistern waters through materials used in construction is commonly from wood used for roofs and sometimes for walls. Wood should never be used for cistern walls. If the materials in which the excavation is made are such as to require cribbing, wooden cribbing may of course be employed, but it should either be removed on walling or should be thoroughly and completely lined by a water-tight wall of brick or stone laid in hydraulic cement. The use of wooden cistern roofs is also to be deprecated, except, perhaps, when used simply as a support for a lining of cement, which should join and form a unit with the lining of the walls. It is true that wood kept constantly moist endures much longer than when subjected to alternations from wet to dry, commonly longer even than when kept thoroughly dry; but, nevertheless, decomposition begins sooner or later, and certain of the products are poisonous; and, moreover, fungi and other minute organisms are liable to infest wood, hastening decomposition and multiplying the poison.

The chief source of danger in cisterns is cracking of bottom, walls, or roof, and consequent leakage or admission of contaminated water. The cracks are most frequently formed in the bottom; first, because the bottom is carelessly made level, when the floor and lining form a plane which is more easily deformed and broken by external pressure than the curved surfaces of walls and roofs; and second, because most builders neglect the "creep" of more or less plastic earth materials which causes the bottom slowly to bulge upward. Moreover, it is a besetting sin of the cistern-maker not to floor the cistern at all, even when the sides are properly walled, but simply to line it with a thin coating of hydraulic cement. The "creep" of clay beds and even of shale is well known in mines in which the pressure is removed from the portion of the stratum lying immediately beneath the drift and conveyed to the portion lying beneath the side walls; when, partly through the elastic expansion of the materials of the stratum, but chiefly through an actual viscous movement of the shale or other rock from both sides, the floor of the drift slowly rises and in some cases eventually fills the opening. Now commonly the depth of cisterns is limited, and hence this element of "creep" is much less important than in mines, but it is always to be anticipated; its tendency is to bulge the bottom upward as shown in Fig. 4, and thus to break the floor or crack the cement lining This element of danger is to be guarded against by constructing the floor of the cistern in the form of an inverted arch, as shown in Fig. 2; or, if this is impracticable, by making the floor so thick and strong as to resist not only the "creep" of materials, but also to compensate for the relative weakness of the plane structure as against the curved structure of walls and roof. It should be noted that the most destructive stress to which the cistern is subjected is commonly that due to external hydrostatic pressure of the ground water.

Cracking of walls and roofs can be guarded against only by the use of good materials in sufficient quantity, and by careful construction. It is to be remembered, particularly when water-bearing seams are encountered in the excavation, that the external water may have considerable "head" or hydrostatic pressure, and when the water in the cistern is low considerable strength of wall may be required to resist this pressure. In some instances, however, the external pressure is less than the internal pressure when the cistern is full.

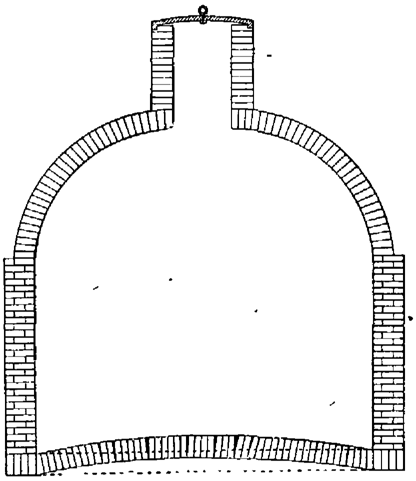
FIG. 4.—Cracking of cistern bottom by "creep."

Rupture of walls or cracking of cement in sides or bottom is sometimes due to the simple weight of water within the reservoir either (1) when the material in which the excavation is made is heterogenous or incoherent, or (2) when the walls are of inadequate strength. These sources of danger are always to be foreseen and provided against by the use of suitable materials and proper construction.

A serious source of danger in the higher latitudes is expansion and contraction and consequent cracking of the roof through frost action. This evil is best prevented by sinking the reservoir to such depth as to lie beneath the reach of frost; but when this is impracticable the danger may measurably be avoided by use of nonconducting materials, by exceptional strength of roof and thickness of cement, or perhaps by the use of a cement made slightly elastic by the introduction of a fibrous material; or, when asphalt is found available for closed cisterns, by the employment of this somewhat elastic cement.

A self-evident source of contamination is living things, such as frogs, tadpoles, fish, larvæ of mosquitos or other insects, water plants, etc.;

and dead animals or plants are rank poison, their presence demanding the immediate emptying and disinfecting of the cistern.

OVERGROUND CISTERNS.

On the Gulf slope, and to some extent on the southern Atlantic slope and in the Mississippi valley, overground wooden cisterns prevail. The chief advantage of this type of cistern lies in its economy; the overground cistern is commonly employed where brick, stone, and cement are expensive, and where, moreover, contaminated "ground water" is exceptionally abundant (e. g., in and about New Orleans), rendering protection therefrom unusually difficult and costly.

Commonly the overground cistern is simply a large, strong, wood-staved cask, tapering upward like an old fashioned churn or fish kit, hooped with iron and floored with a strong bottom fitted into a deep chamfer, the floor commonly requiring the support of external crossbeams. Such cisterns should always be covered in order to cut off evaporation and prevent the admission of germ-bearing dust; if of moderate size a movable cover with an external flange fitting over the top will suffice, but if large the cover should be permanently attached and provided with a manhole. The permanent cover may either rest on the ends of the staves and be attached thereto by screws or strapbolts, as shown in Fig. 5, or it may be chamfered in like the head of an ordinary cask, when apertures should be provided for the escape of water accumulating within the chine. The manhole may be circular or square, with a neck (a hoop, if circular) rising higher than the tops of the staves or other obstruction to the run-off of rain water; and the cover should have an outer flange fitted on or rabbeted into the neck. All joints should be pitched or tarred, and the entire interior should be treated with pitch or other preservative; good results are obtained by charring, though perhaps the best treatment for the interior is coating with silicate of soda or "liquid glass." The exterior should be thoroughly and frequently painted.

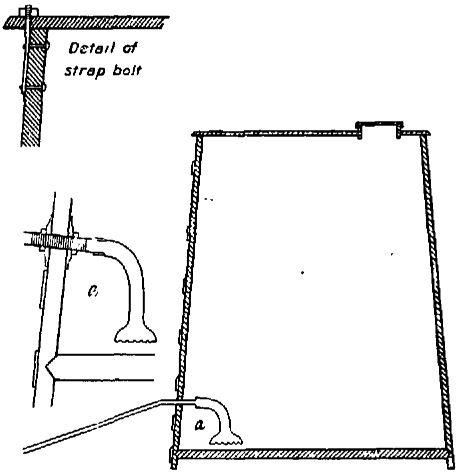

FIG. 5.—Section of overground wooden cistern.

Various kinds of wood are used for overground cisterns. The desiderata are (1) freedom from ill taste; (2) durability; and (3) the minimum contraction on drying and consequent freedom from warping. On the whole, cypress is probably the most satisfactory material. The chief source of danger inhering in the overground wooden cistern is contamination of the water from the wood itself, and this is to be prevented only by constant attention to the cover and upper walls of the cistern and by drawing off the water and recharring or recoating the entire interior at intervals of a few years, or whenever the water becomes in the least degree foul. It may be observed that the existence of so-called "water lice" or any other visible organisms in the water affords sufficient warrant for its condemnation; for while the organisms themselves may not be injurious to the system, and while, as frequently held, they tend measurably to purify the water by consuming minute organisms and organic products, their occurrence always indicates the presence of organic impurities, without which, indeed, they could not live.

The wooden overground cistern can hardly be accepted as a sign of the times like the carefully designed underground cistern or the artesian well; it stands rather for the third stage in the conquest of the waters represented by the ground-water well in more favorably conditioned regions. At best the wooden cistern is a primitive affair which is bound to be supplanted by more trustworthy and wholesome devices. It is, indeed, probable that the rain-supplied reservoir will long remain in use in the regions in which overground cisterns now prevail; but it is eminently desirable that some better material should be used in its construction. Probably the best substitute for the easily destructible germ supporting wooden staves and headings will be found to be terra-cotta boards or, perhaps, groups of hollow hexagonal prisms of the same material. There is an extensive area in western Kentucky and Tennessee, northern Mississippi, northern Florida, and parts of Georgia and Alabama in which the lower part of the Lafayette formation contains immense beds of fine siliceous clay, sometimes known locally as kaolin or pipe clay. This material is admirably suited for the manufacture of so-called terra-cotta in boards, tiles, cylinders, prisms, and other forms, and, indeed, is already in use for such purposes. The deposit is one of the most extensive in the world and is bound to be utilized at no distant day, and no better use can be made of the abundant and excellent material than in purifying the water supply of southern United States.

ARTIFICIAL CATCHMENT AREAS.

Both underground and overground cisterns are commonly supplied by rain water caught on artificial roofs and collected in gutters and conveyed through pipes directly to the reservoir, or preferably to a filter chamber communicating therewith. Now, the character of cistern water is measurably determined by the materials of the roof on which it is collected. The prevailing roofing material used at the present time is wood, generally in the form of shingles; probably next in extent of use follows metal, usually tin or iron, generally painted; and last in the order of use come slates and tiles. The chief advantage of wood as a material for roofing lies in its cheapness and, if the structure roofed is temporary, consequent economy. It is objectionable from the hygienic point of view in that unless frequently cleaned or painted the shingles become covered with fungi, lichens, and mosses which eventually cover the greater part of the roof, and in that the wood, howsoever durable or carefully treated, progressively decays. The vegetal growth and decay, and the breaking down of the wood, yield a certain amount of mechanical sediment as well as abundant organic impurities, which are washed from the shingles and are liable to find their way into the cistern. Accordingly, the use of shingle roofs as catchment areas for cisterns can not be recommended, and unless special pains are taken to prevent contamination is strongly to be deprecated.

Metal roofs are preferable to shingle roofs partly in that they may be laid flatter, thereby economizing material. They are preferable also hygienically in that they are much less liable to support organic growths. They are, however, in some measure objectionable in that they readily oxidize, when the oxides are carried into the cistern and affect its contents; the oxides of lead and zinc sometimes used in galvanizing iron or in soldering tin and other materials being especially deleterious. Simple iron oxides are less injurious and, indeed, sometimes beneficial.

Slate roofs are in general nearly as little liable to vegetal growth as metal, and slates are, moreover, practically free from danger of contamination through metallic oxides. Accordingly, slate is an acceptable material for roofs used as catchment areas for cisterns. Glazed tiles are, however, preferable to slates by virtue of their greater freedom from organic growth; indeed, the ideal roof for use in connection with cistern water supply is one of glazed tiles.

Both wooden and metal roofs are frequently painted. If renewed from time to time the paint diminishes the danger from organic growth on wooden roofs and from oxidation on metallic roofs; but the paint itself is gradually worn off under the action of the weather and the beating of the raindrops, and a part is washed into the cistern, either as inert sediment or an active metallic agent, which may be poison to the human stomach, the oxides of lead, which are largely used to give body to mineral paints, being especially injurious.

All roofs, whatever their material, are liable to fouling in a variety of ways. Where coal is used as fuel, and to some extent even where wood is burnt, soot and ashes accumulate during the hours and days of sunshine, and when the storm comes they are carried into the cistern. While these are, perhaps, the least objectionable impurities (soot being even superior to charcoal as a deodorant and disinfectant), they are liable to discolor the water and to affect its flavor. Dust also constantly accumulates on roofs in the intervals between storms, to be swept down the eavestroughs and pipes when the storm begins; and dust is one of the most effective vehicles for the transportation of microbes and spores. Still more dangerous is the pollution of roofs by cats and domestic or semidomesticated birds, chiefly pigeons, while the most dangerous pest of all is the English sparrow, which not only defiles the roof but nests in and constantly befouls eavestroughs and water pipes. From the point of view of sanitary water supply, cats and pigeons are nuisances and the sparrow is a scourge.

The danger of contamination of cistern water inhering in the conditions of roofs can not, perhaps, be completely removed, but it may be greatly diminished by care and attention. Every roof should be of the best available material and should be cleaned artificially from time to time; and, moreover, the system of pipes connecting roof and cistern should be so arranged as to permit the diversion of the first waters of the storm until roof and eaves troughs and pipes are thoroughly washed.

The catchment area required to supply a given household may easily be computed from (1) the number of persons to be supplied, (2) the daily allowance per capita, (3) the rainfall in the district contemplated, and (4) the frequency of rainfall sufficient to fill the cistern.

The consumption of water in cities and suburban districts has steadily increased for many years. The average consumption for domestic purposes, including drinking, is more frequently over than under 20 gallons per day for each person, but this figure is fair as a basis for computation. When the cistern water is used only for drinking and cooking this allowance may be much reduced, even to a tenth in extreme cases. On the other hand, when stables are supplied, or if water is used freely for baths and closets or in gardens, the allowance should be much increased, even to ten times the average amount.

The rainfall and its distribution throughout the season vary in different districts. The accompanying table, compiled by Mr. Cyrus C. Babb, Secretary of the National Geographic Society, shows the mean rainfall by months in five representative cities of eastern United States:

Average rainfall for 18 years.

Stations.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct	Nov.	Dec.	Annual.
Portland, Me......	3.57	3.62	3.28	3.15	3.03	3.36	3.80	3.76	2.85	3.85	3.89	3.39	41.55
Boston, Mass......	4.56	3.88	4.49	3.95	3.30	3.58	3.57	4.26	2.72	4.12	4.86	3.50	46.79
Philadelphia, Pa..	3.42	3.29	3.21	3.01	2.99	3.50	4.36	4.80	3.20	2.90	3.08	2.75	40.51
Washington, D C.	3.41	3.26	4.21	2.95	3.48	4.10	4.52	4.38	3.71	3.15	2.85	3.11	43.43
Augusta, Ga......	4.63	3.71	5.39	4.01	3.34	4.42	4.77	4.63	3.40	2.55	3.49	3.86	48.20

The roof area required to yield a given supply with any rainfall may be determined from the following table, also kindly computed by Mr. Babb. It should be observed that where water is collected from ordinary roofs for drinking purposes a considerable allowance should be made for the washing of roof and pipes by the first waters of the storm, an element always important, and especially so when storms are light and frequent.

Quantity of water collected on given roof areas from 500 square feet to 10,000 square feet, with given rainfall from 0.5 inch to 5 inches.

Roof area.	0″.5	1″.	1″.5.	2″.	2″.5.	3″.	3″.5.	4″.	5″.
500	155.84	311.69	467.5	623.38	779	935.06	1.091	1,246.7	1,558
1,000	311.69	623.37	935.1	1,246.7	1,558	1,870.13	2.182	2,493	3,116
1,500	467.53	935.06	1,402.6	1,870.12	2,338	2,805.2	3,273	3,740	4,676
2,000	623.38	1,246.75	1,870.1	2,493.50	3,117	3,740	4,363	4,987	6,234
2,500	779.22	1,558.44	2,337.7	3,116.88	3,896	4,675	5,454	6,234	7,792
3,000	935.06	1,870.13	2,805.2	3,740 26	4,675	5,610	6,545	7,481	9,350
3.500	1,090.91	2,181 82	3,272.7	4,363.6	5,455	6,545	7,636	8,727	10,910
4,000	1,246.75	2.493.50	3,740.2	4,987	6,234	7,480	8,727	9,974	12,468
5,000	1,558.44	3,117	4,675	6,234	7,792	9,350	10,908	11.467	15,584
6,000	1,870	3,740	5,610	7,481	9,351	11,220	13,091	13,961	18,702
7,000	2.182	4,364	6,545	8,727	10.909	13,090	15,272	16,454	21,818
8,000	2,494	4,987	7,480	9,974	12,468	14,961	17,454	18,948	24,936
9,000	2,805	5,610	8,416	11,220	14,026	16,831	19,636	21,441	28,052
10,000	3,117	6,234	9,351	12,468	15,585	18,701	21,818	24,935	31,170

EAVESTROUGHS AND WATER PIPES.

In early days eavestroughs, and even the system of pipes by which the roof water was conveyed to the cistern, were commonly of wood, and the water was liable to contamination thereby just as from the wooden roofs. Of late years metallic troughs and pipes are commonly used, and while they are superior hygienically to wood there is a danger of contamination through oxidation of the metal itself and of the solder and paint used in connection therewith. Eavestroughs and water pipes are sometimes made of terra-cotta ware or tiling, and the use of this material is to be commended in the strongest terms, particularly in connection with roofs of tiles or slates.

A common source of danger in eavestroughs and water pipes is found in depressions due to bad designing or workmanship, or to subsequent sagging, by which pools are formed in which the storm water accumulates and lies until it is swept away by the succeeding storm or, slowly evaporated. Such pools are particularly objectionable in wooden waterways. Insects flock into them to dwell or drown; birds have recourse to them for drinking and for the insects gathered about them; spores are caught and develop into noisome scum and fungoid growths along the margin, and thus the contents of the pool are quickly converted into reeking filth, a mass of organic poison which too often accumulates only to be washed into the cistern by the next storm. In metallic pipes the organic action soon developes acids which attack the metal and add the poison of metallic oxides, but in such cases the evil soon works its own cure, in that the pipe is oxidized through, forming a leak which must be stopped else the water supply is lost. No system of water pipes should ever be designed or constructed or accepted from the builder that does not show a decided fall in every part, and the pipes and particularly the eavestroughs should be inspected from time to time, and whenever a sag is found it should be remedied at once.

A considerable part of the danger of contamination of cistern waters from roofs and water pipes may be removed by suitable devices for diverting the earlier storm waters until both roof and pipes are washed. The earliest storm water is itself less pure than that which comes later; for it collects from the lower strata of the air a variety of impurities in the form of dust, smoke, carbonic acid, etc. Then the early waters wash the roof and pipes, collecting thereby a series of mechanical, chemic, and organic impurities which should not be given entrance to the reservoir for potable waters. Accordingly the cistern should never have direct and permanent connection with the roof; but the pipes should be so arranged as readily to be disconnected from the cistern and turned into a waste pipe.

Moreover, it is important that the waste-pipe connection should be habitually maintained, automatically or otherwise, except when the storm waters are deemed sufficiently pure to be admitted into the cistern; and the waters of slight storms and the early waters of all storms should be excluded from the cistern for such time as to permit the thorough washing of roof and pipes.

A common defect in systems of water pipes connecting roofs and cisterns is inadequate capacity. Usually little attention is given to the relation of roof slope and area to size and slope of eavestrough; consequently while the trough may suffice to carry the waters of the light summer shower, it overflows during the heavier shower and allows most of the waters from the storm to run to waste. The serious nature of this defect becomes evident in view of the considerations just mentioned. It is bootless to provide water pipes to carry only the product of light showers when this product is turned into the waste pipe; it is the product of the great storm which quickly washes the roof and then runs pure that it is most desirable to preserve and convey into the reservoir. Accordingly, care should be taken to make eavestroughs and water pipes amply large; if there is any doubt as to the capacity of the former, their slope should be increased to augment their carrying capacity to the desired amount.

FILTERS AND RELATED DEVICES.

So many are the ways in which the relatively pure waters falling from the clouds are contaminated on roofs and in water pipes that despite the utmost care cisterns connected directly with roofs are certain to be polluted sooner or later; and if the pollution be that most pervading and insidious of all poisons, germ-bearing organic matter, it will rapidly develop until the entire body of water and the walls by which it is confined will reek with poison. Accordingly, whatsoever the materials of which roofs, eavestroughs, and water pipes are made, whatsoever care is exercised to prevent contamination, no cistern should be used as a source of potable water supply without the further protection afforded by a filter.

Filters used in connection with municipal or other water supply in which the ground surface serves as a catchment basin are commonly designed to serve several purposes, e. g., (1) to exclude the floating débris, (2) to remove mechanical sediment pushed forward along the stream bottom or held in suspension, and (3) to exclude or destroy organic impurities. Accordingly in such cases it is usual to employ a number of devices including (1) grates or strainers, (2) mechanical filters or settling basins, or both, and (3) devices for securing protection against organic matter. The rain waters collected on roofs or other artificial catchment areas, however, carry little mechanical sediment, and simpler filtering devices suffice.

In most cases the first requisite is a grating or strainer designed to catch leaves, twigs, and other débris that may be blown upon the roof or swept into the eavestroughs during the storm. Such a device is especially necessary when insufficient care is given to diverting the early storm water until the roof and pipes are washed; for in that case there is additional débris of birds' nests and other inter-storm accumulations to be removed. A simple grating, or preferably a strong wire sieve, placed in an enlargement of the pipe immediately below the waste gate, and provided with a movable cover or door, will commonly be found sufficient.

The most important requisite, which is, indeed, absolutely essential to the purification of water taken from ordinary roofs, is a filter for organic matter, which may be so designed as to exclude also any mechanical sediment that may pass the grating. This may consist of alternating layers of gravel, sand, and charcoal, or of a single layer of each of these materials so arranged that the water passes first through the gravel, next through the sand, and last through the charcoal. Other devices are sometimes used with satisfactory results. The Spencer filter, which has been "used in England with great success in connection with sand filtration," employs in lieu of charcoal "the crushed grains of the carbide of iron prepared by roasting red hematite ore mixed with equal parts of sawdust in an iron retort." This material is mixed with the "sand of the lower sand strata of a sand filter and its office is to decompose the organic matters in solution in the water. The carbide is said to perform this office thoroughly several years in succession without renewal."[1]

While this device is especially adapted to use on a large scale in connection with municipal water supply, and has, indeed, been adopted in several of the cities of Great Britain, it is also well suited for use in a small way in connection with cisterns for domestic supply. Another device recently patented in England, but not yet introduced in this country, would seem to be specially applicable for use in connection with household cisterns. This is the Atkins filter, which is designed chiefly or solely for the removal of organic impurities. It consists essentially of charcoal plates, usually a foot square and 3 inches thick, and so firm that their surfaces when foul can be scraped

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[1] Hydraulic and Water Supply Engineering, by J. T. Fanning, 1890, p. 534.

clean. The plates are set in frames as panes of glass are set in the sash, and so arranged that the water must percolate through them in passing from the filter chamber to the main reservoir.[1]

The filter should be so arranged as to be easily accessible for cleaning or renewal, and the conduit opening into the cistern should be provided with a valve or gate, in order that the inflow may be shut off in case of accident to the filter. Various arrangements for filtering have been devised: Thus, the cistern is sometimes divided by a partition into two portions, connected through the filter, the inflow pipe communicating with one compartment, the pump or outflow pipe communicating with the other. Sometimes, also, two cisterns are placed side by side and similarly connected. A more satisfactory arrangement on the whole, however, is a combination of cistern and filter chamber in such manner that the contents of the latter will flow into the larger reservoir through the charcoal plates or other device for filtering. In capacity the filter chamber should suffice to contain the water collected from a single storm; it should be protected from contamination by a manhole cover, etc., like the main cistern; and the filter should be so arranged as to permit inspection of either side. Such a filter chamber should be floored and roofed and lined precisely like the cistern, and provided with a waste or overflow pipe to prevent the water from flowing over the top of the filter, and the conduit opening into the main cistern should always be supplied with a shut-off gate. A filter chamber of this character may be made to perform the functions also of a settling basin by carrying the inverted arch forming the bottom below the level of the filter; and the sediment accumulating in the lower part of the bottom should be removed from time to time.

Filters should be used also in connection with overground cisterns. A simple and evident modification of the filter chamber just described may advantageously be employed.

Various expedients may be used temporarily for the clarification and purification of cistern waters. The most trustworthy is boiling, and no cistern water in which the least trace of organic matter, living or dead, can be detected by the eye, or in which the least trace of foulness can be detected by tongue or nostrils, should ever be used without boiling. Mechanical sediment, which is commonly finely divided clay or mud, may be precipitated by alum when a portion of the organic impurity is commonly carried down at the same time. A saturated solution of alum used in the proportion of 1 part of solution to 50,000 parts of water may be employed for the purpose. The perchloride of iron, in the proportion of 3 or 4 parts by weight to 100,000 parts of water, is especially useful for the precipitation of organic impurities in water, and it has been found by repeated experiments in England and Holland that ordinary iron in the form of filings, turnings, or scraps is a useful purifying agent. All such devices, however, are to be regarded

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[1] Op. cit., p. 535.

only as temporary expedients, makeshift substitutes for the more trustworthy plan of preventing contamination.

To palates accustomed to the water of springs and wells, cistern water is frequently insipid, particularly after long standing. Commonly the staleness and ill flavor of cistern water is due to impurities of such character as to warrant condemnation or demand boiling, but in some cases the difficulty may be remedied by aeration. Many users of cisterns find that the waters are aerated in a satisfactory manner by the use of a chain pump in which the return pipe is fitted to the valves or buckets so that air is pumped into the cistern in quantity equal to that of the water pumped out.

STREAM WATER SUPPLY.

ECONOMIC CONDITIONS.

In the first stage in the conquest of the waters, the invaders of the red man's domain stooped to quaff from running brooks and dipped water from rivers for domestic uses; but this primitive mode of water supply soon passed away. The waters of running streams are roiled by storms and run dry in droughts, while in populous districts they are contaminated in a multitude of ways. Accordingly stream water can not be made available for drinking and domestic uses without elaborate and costly devices for purification and storage.

The devices for purifying and storing stream waters for drinking and domestic purposes usually comprise a reservoir, which may serve as a settling basin, and some arrangement for filtering; and in addition there are commonly required a dam across the stream yielding the supply, together with intake gates and conduits connecting the stream with the reservoir, and also a system of mains and lesser pipes designed to convey water from the reservoir to the points at which it is needed. Commonly these devices are too extensive and expensive for individual means and can not, accordingly, be installed until the population becomes so dense that individual interests may be united and waterworks constructed for the common use. So a practical requisite for stream water supply is a dense population of united interests. This condition is fulfilled in various parts of the world, and public water supply has been found feasible by municipalities in all civilized countries.

Cooperative water supply from streams, demanding as it does the construction of expensive works, involves a direct or indirect water tax which, like all other institutions designed to distribute benefits, is strenuously opposed by certain individuals and classes. Moreover, there is an undercurrent of opposition to water taxes growing out of the hereditary sentiment that potable water, like the air, like the waters of open ocean, like the land under primitive social conditions, is common property and should be free to all; and for these and perhaps other reasons the installation of waterworks and the imposition of water taxes has been in the past and is bound to be in the future vigorously opposed in every community, municipality, and state; and this ultra-conservative opposition is a condition which has to be faced whensoever and wheresoever it is proposed to improve the common water supply at the common cost.

Few partisan policies are more prejudicial to human interests than opposition to water taxation. Half the food taken into the human stomach is water, and two-thirds of the preventable disease of modern times arises from the use of impure water. So individuals, communities, municipalities, and states are directly or indirectly taxed, and exorbitantly taxed, in order that individuals may enjoy the inalienable right of consuming poison. Hospitals are maintained, cemeteries are laid out and beautified, and undertakers are supported in consequence of the use of impure water; men and women who should be in the bloom of health are made invalids, children are cut off at the dawn of life, and the aged and infirm are daily swept away by reason of the poison in potable waters; and the average life and working period of man in every country is materially shortened by defective water supply. No municipality or other community can evade certain imposts which grow out of the relations of men among each other and to their environment, and, laying sentiment aside, the questions which communities have to decide are: Is it cheaper to maintain waterworks than hospitals and cemeteries, and is the water tax less burdensome than the impost of the undertaker?

The practical question as to the amount of water tax which a given community is able to bear can not be decided in the abstract by reason of the multiplicity of local and perhaps temporary considerations. The general proposition may indeed be laid down, that no tax is too heavy which secures the health and happiness of the community through permanent immunity from disease; and if the city, town, or village is so unfortunately located that pure water is not obtainable, it should, in common humanity, as well as in the interests of national progress, be abandoned. Practically, however, there is probably no city, town, or populous village in eastern United States which can not secure a trustworthy supply of potable water by collecting the rainfall on artificial roofs or in artificially protected drainage basins, provided natural streams are not obtainable; and so the maximum limit of cost for stream-fed waterworks may be fixed at the minimum cost of rain-fed reservoirs.

The practical question as to the size of town or village required to warrant public water supply is also too complex for solution in general terms, since it depends on a wide variety of local and variable conditions: The character of the population and industries pursued; the cost of waterworks and the tax involved; the character and cost of the present supply, and the preventable death rate depending thereon—all these and many other conditions have to be weighed in solving the problem as to the expediency of public water supply in city, town, village, or smaller community. In general it may be said that a function of every incorporated city or town should be the supervision and control of water supply; for in this case, as in many others, the thought of the majority is directed elsewhere, so that the few must at least take the lead in thinking for the many. In general it may be said, too, that any community burdened by disease or handicapped by a high death rate is large enough to consider the question of public water supply and to secure pure water in one way or another; and in a desperate case it should be remembered that the actual value of potable water in the human economy, estimated in terms of the quantity consumed, in terms of the beneficence of purity and maleficence of impurity, in terms of physical and mental work determined thereby, or estimated in any other comprehensive way, is fully equal to that of all other foods combined.

So the artificial control of stream waters for common use may be recommended in the strongest terms, and no reasonable per capita tax should be allowed to stand in the way of instituting systems of waterworks. This conclusion indeed flows from the logic of events in the settlement of this and other countries, as clearly as from considerations respecting the source and conditions of potable waters in general. Public water supply has long been a subject of municipal legislation and in some cases of legislation by states, and institutions for water supply have grown up in spite of vigorous opposition and have spread wherever men are gathered in such numbers as to profit by cooperation; and this righteous tendency, which has proved stronger than creed or platform or party in the past, is bound to continue until not only the greater cities but the lesser towns and villages are supplied with pure drinking water at the common cost.

NATURAL CONDITIONS.

Viewed as sources of potable waters, rivers and smaller streams may be arbitrarily separated into three intergrading classes, viz, (1) storm-fed streams, (2) spring-fed streams, and (3) composite streams.

Streams of the first class serve simply to carry off that portion of the storm water (including the melted snow fall) which is not absorbed into the earth to be consumed by plants or to form ground or phreatic water. Such streams divide into secondary and again into tertiary tributaries, and eventually spread out in fan-like assemblages of rills into which the sheet of fresh-fallen storm water quickly divides; and in humid regions, like eastern United States, streams of this class are nearly always more or less swollen by reason of storms in some part of the drainage basin, though in protracted droughts they run dry. Thus each rain-fed stream represents the accumulation of the storm waters of a definite drainage basin bounded by divides. It is subject to freshets and great floods produced by vernal snow melting and by heavy storms, particularly when the storms succeed each other in time and place throughout the basin in such order that the floods of all tributaries reach the lower river at the same time. Such rivers, moreover, commonly carry considerable quantities of sediment, for the falling raindrops, by their impact, dislodge particles of soil and these are carried down the slopes, along the rain-formed rills, and into the ravines and brooks, where a part are deposited by the water, while another part is swept into the lower river. Moreover, such surface streams transport considerable quantities of organic matter swept from the living and dislodged from the decaying vegetation by which the drainage basin is mantled. These characters of surface streams affect their value as sources of supply for potable waters.

The second class of streams is supplied by springs, which may be either of the ground water or of the phreatic type; and they are always less liable to freshets than rain-fed streams, practically uniform in volume when fed by phreatic water. While such streams commonly convey beneficial or injurious mineral salts in greater or less quantity, they usually convey little mechanical sediment derived from the breaking up of the soil and the corrasion of channels; and, in general, they are much freer from organic impurities than rain-fed streams. These qualities affect the value of spring-fed streams and in general the inherent value of spring-fed streams as sources of potable waters.

The third type of stream is supplied in part by storm waters and in part from the outflow of springs, and in general their characteristics are intermediate between those of the distinctive types. Most of the rivers of eastern United States belong to the composite type.

Not only the channels of streams but the valleys in which they run, the hills by which they are bounded, and indeed the entire surface represents the secular work of streams, and there is thus a marvelously harmonious interrelation of parts in each drainage basin. In general the slope of the surface of the stream, or the fall, increases from the lower river to the heads of the tributary streams and confluent brooks, diminishing again toward the divides over the narrow zone representing the sheet of water accumulated during the storm, the zone over which the fresh-fallen rain water flows as a sheet or in ill-differentiated rills too small to form channels. Thus the profile of the waterway from the head of the brook to the mouth of the river is commonly a flattened curve, concave toward the sky, the degree of curvature depending on a variety of conditions, of which one of the most important is the increasing volume of the stream. This curved profile exemplifies the *law of water profiles*,[1] and the degree of curvature affects the rate of deposition of mechanical sediment borne in the stream, and thus the value of the stream as a source of potable waters.

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[1] Defined in detail in the Eleventh Annual Report of the U. S. Geological Survey, 1891, p. 246.

The general law of water profiles is affected and measurably antagonized by a subordinate law (the *law of varigradation*),[1] under which the curved stream profile is broken up into alternating pools and rapids. These alternations of relatively still and relatively rapid water are initiated by a variety of causes and conditions, and exert an important influence on the work of the stream in excavating its channel and in fashioning its drainage basin; and they exercise a decided influence on the deposition of matter transported by the stream, and are thus of exceeding consequence in streams used as sources of potable waters.

The rate of stream flow in general depends on slope or declivity; and in general (1) the amount of matter transported in the waters and (2) the activity of the stream in cutting its channel and fashioning its drainage basin depend on the rate of flow and so on the declivity. Other conditions also affect the rate at which sediment is conveyed; i. e., the muddiness of waters. One of these is time distribution of the rainfall. Nearly all of the work of streams in transporting sediment and corrading channels is performed during or in consequence of storms; and other things equal, it may be said that the activity of stream work diminishes with uniformity in precipitation and increases with variable precipitation and culminates where (as in the arid regions of the United States) the precipitation occurs chiefly in infrequent storms. This law finds expression in topographic configuration: Other things equal, regions and districts of gentle slopes and soft contours are regions of uniformly distributed rainfall; other things equal, regions of steep slopes and rugged contours are regions not simply of limited precipitation, as certain masters have held, but of rare storms. Again, the activity of stream work depends on the character of vegetation. When rain falls on a forest the drops are intercepted, and the water percolates slowly down branches and trunk, or drips gently from the leaves, so that the force of the fall is broken, and, moreover, the ground surface is further protected by a carpet of fallen leaves and moss; while on the prairieland the raindrops are not intercepted, but beat in full violence on the unprotected soil, which is thereby broken up, triturated, and in part carried down the slopes and into the river. Thus, other things equal, the activity of storm work is greater on the prairie than in the forest, and this law, too, finds expression in topographic configuration; for the more active storm waters and streams of the prairie carve the hills into flatter slopes, the waterways into flatter curves, than in the woodland, and there is thus developed a characteristic topography of prairieland and a characteristic topography of woodland which may be distinguished at a glance. All of these conditions affecting the flow of streams and the transportation of sediment therein have an important bearing on the utility of streams as sources of potable waters.

The natural conditions affecting stream water supply are so many and so varied as to render it inexpedient to solve the problem of public

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[1] Op. cit., p.269.

water supply from this source in the abstract; but they serve to indicate changes and limitations of stream-water supply in concrete cases. Thus it may be said in general that spring-fed streams are superior to storm-fed streams as sources of potable waters; that streams of moderate declivity or gentle (but not too slight) fall are in general superior to streams of high declivity; that other things equal, those streams which are most completely broken up into alternating pools and rapids under the law of varigradation are preferable to streams whose profiles are more uniform; that streams collecting in forest-protected areas are in general freer from freshets and sediment than prairie streams or streams in cultivated districts; and that in general streams are more serviceable as sources of potable waters in regions of uniform precipitation than in regions of variable rainfall.

CULTURAL CONDITIONS.

In thinly settled districts the problem of stream-water supply involves consideration only of economic and natural conditions; but the population of eastern United States has already reached such density and such general distribution as to compel consideration of conditions growing out of settlement and industries. The most important cultural conditions are those growing out of (1) cultivation of the soil; (2) the sewerage of cities; (3) the by-products of manufactures; and (4) the waste of mining.

Cultivation of the soil affects materially the volume, rate of flow, and quality of stream water. In regions of high relief agriculturists sometimes endeavor to diminish the rate of run-off of storm waters, either to prevent erosion or to store up ground water against droughts, as in many of the southern states in which contour cultivation has been extensively adopted to serve one or both of these purposes. In regions of low relief, on the other hand, agriculturists resort to open ditches, under drainage, and other devices to hasten the run-off and diminish the ground water, thereby increasing the volume of the stream supply from their acres. But whether the streams are increased or diminished the general effect of agriculture is to increase the transportation of sediment; the plow relieves the beating raindrop of half its task, while the harrow and drill provide rills for the storm water, and the triturated soil is borne off more rapidly than in a state of nature, so that in general agriculture makes muddy streams. But whether mechanical débris is added or not, the effect of cultivation of the soil is to increase the organic impurities; fertilizers are partly absorbed into the ground water to reappear at lower levels, partly washed down the slopes; the annual crop with its enormous waste of root, stalk, leaf, and flower is a more abundant source of organic débris than the natural flora; and, moreover, domestic animals and fowls and even man himself are constantly contributing to the land and eventually in part to the streams vast quantities of poisonous by-products of the animal mechanism. So the cultivation of the soil materially affects the value of the stream as a source of potable waters throughout most of the area of eastern United States.

Most cities and many smaller towns secure or seek to secure cleanliness and consequent health by systems of sewerage; and commonly the sewage is conveyed into a neighboring river or on adjacent lands sloping away from the city, to be gradually collected by the waters and conveyed toward the domiciles of their downstream neighbors. In this way the waters of all large rivers are polluted in greater or less degree; sometimes even an important waterway, like the Ohio, is transformed into a great sewer throughout most of its course; and but few rivers, like the Potomac, remain on which the settlements are so few as not to jeopardize the lives of dwellers on the lower reaches compelled to drink of their waters. The contamination of river water by sewage is of great importance in its bearing on the question of stream water supply.

In most cities manufacturing is carried on, and in most manufactories considerable quantities of more or less noxious by-products are formed, and in general these are conveyed either directly or through the sewerage system into the neighboring waterway or on slopes leading thereto. Thus the question of the pollution of rivers through the by-products of manufacturing is connected with that of pollution by ordinary sewage and is of serious import.

Mines and quarries, notably the vast coal mines of the Appalachian region in eastern United States, yields enormous quantities of rock matter, of which a part is thrown into neighboring streams or on tributary surfaces, so as eventually to affect the running waters. A part of the material is organically inert mineral débris, which only adds to the mechanical sediment transported by the streams; but a part comprises mineral salts and various unstable mineral compounds, sometimes of organic origin, which pass into solution, and in some cases befoul and poison the waters. Thus certain mining operations and the disposition of the waste products of mines materially affect the value of the running waters of eastern United States as sources of potable waters.

It is to be observed that to some extent the effects produced on running waters by cultural conditions are compensatory; thus, there is a highly suggestive reciprocal relation between mechanical sediment and organic impurity, evidenced by the facts that sewage is an efficacious precipitant of mechanical sediment and that clay or mud in sufficient volume appears to throw down sewage and other suspended or dissolved organic matter. Thus the mechanical sediment conveyed from plowed lands and the waste heaps of mines into the running streams measurably counteracts the poison of organic matter from farm, factory, and sewer. This inverse relation between chemic and organic impurity is one of the conditions affecting the value of running streams as sources of potable waters.

TECHNICAL CONDITIONS.

Commonly a system of waterworks designed to take its supply from a river or smaller stream requires for its construction a special engineering survey and the construction of dam, intake gates, gauges, conduits, and perhaps other devices which can be successfully installed only under the direction of a hydraulic engineer. Until within a decade it was commonly necessary also to make more or less detailed surveys of the entire area of the drainage basin, designed to show the character of slopes, the presence, absence, or state of vegetal growth, the extent of cultivation, the declivity of the stream and the danger of freshets, the location and probable influence of cities, manufactories, and mines, and in other ways to ascertain the natural and cultural conditions entering into the problem of water supply in the concrete case. During the past decade, however, such progress has been made in the subjugation of the country for human ends that the labor and expense of such general surveys may be spared in many parts of the country.

The U. S. Geological Survey has executed extensive topographic surveys in most of the states and territories; and in the eastern half of the country these surveys are on a sufficiently large scale to meet the general requirements of engineers entrusted with the installation of waterworks. The surveys are made commonly on a scale of 1: 62,500, or about a mile to the inch. They show the configuration of the land, the slopes of streams, the location of lakes and large springs, the distribution of forests; together with roads, railways, cities, towns, villages, and in some cases farmhouses. Several states, acting independently or in cooperation with the national bureau, have made like surveys and published maps of similar character.

Within recent years the operations of the U. S. Signal Service have been extended over a large part of the country, and careful measures have been made of precipitation in the form of rain and snow, so that in almost every district in eastern United States the amount and character of the precipitation may be determined from the published reports of that bureau. Furthermore, the same bureau has instituted a series of hydrographic studies and has established a system of gauging rivers and recording floods, and from this work average natural conditions affecting stream-water supply have been determined and the results of the determinations made public in official reports; and many states maintain weather bureaus or meteorologic offices of related function, either independently or in cooperation with the Signal Service. The Geological Survey has also made extended researches into the hydrography of the country, with the view of ascertaining the extent, character, and frequency of floods in various rivers, and with the view also of determining for various districts what proportion of the rainfall flows off in surface streams and what proportion is absorbed by the earth to be consumed by plants or perhaps to reappear later in the form of springs.

These researches on the part of the General Government and the wealthier states represent the wholesale method of acquiring knowledge for the public benefit; observations are made by trained men working under definite plans and in accordance with the best known methods; and the results of the work are far more economical and trustworthy than those secured through sporadic effort. Such wholesale reseaches are preeminently characteristic of the fourth stage in the subjugation of the land for the benefit of human kind. While they are so new that they can hardly be regarded as more than well under way, the results are already of great value; hundreds of cities and towns are to-day in a position to install systems of water supply without the cost of preliminary surveys, and hundreds more are in a position to estimate approximately the cost of public waterworks, and thereby to determine the expediency of cooperative water supply without expensive preliminary examinations.

After the solution of the general problem of water supply there always remains a variety of local and perhaps temporary conditions, giving origin to minor problems which can be solved only by the hydraulic engineer or other technical expert. Similar problems have arisen in various municipalities in different parts of the world, and the experience acquired in solving them has been recorded and crystallized in the art of hydraulic engineering and in a variety of devices and appliances for use in connection with public water supply. So, while such problems are not susceptible of general solution, the present draws on the past for the power of solving them cheaply and well.

In brief, while the problems growing out of the technical conditions affecting stream-water supply are too complex and too varied for general solution, recent progress in scientific work has furnished many of the essential data in such form as greatly to facilitate local solutions, and thus the question of public waterworks no longer remains mysterious and forbidding, no longer transcends the ken of the intelligent citizen, but has become so simple and tangible as to bring cooperative water supply for the common good within the reach of all.

GROUND WATER SUPPLY.

ACCUMULATION OF GROUND WATER.

When the rain distills from the clouds and falls on the land a part flows away in the form of surface streams and another part is drank by the thirsty soil. Of this part a fraction is consumed by plants, but the remainder percolates downward through the soil and subsoil and perhaps into bed rock, where it may either remain as simple moisture or, if the substructure is favorable, may flow away through porous strata or in open channels. Immediately after the rain the wettest layer of the earth may be the soil; but as evaporation proceeds at the surface and as percolation proceeds below in obedience to gravity the layer or couche of maximum wetness gradually sinks at an ever-decreasing rate until it is overtaken by the similar couche of moisture derived from a later storm. In this way there is eventualy formed a fairly constant layer or couche of moisture at a depth below the surface determined by a variety of conditions, including the slope of the land, and thus the rate of run-off, the porosity of the soil and subsoil, and the frequency of storms. The moisture of this couche or layer is known, colloquially and technically, as "ground water." Ordinary wells are supplied from this layer; many springs flow from it; in sandy tracts perforated pipes—the so-called drive wells—are forced into the earth until they encounter the couche when they are quickly filled, and the water may be pumped out; and when a great earthquake comes, like that of New Madrid in 1811–'13, or that of Charleston in 1886, the shaken earth particles settle into closer contact, and, being heavier than the moisture filling the interstices, squeeze out the water and force it to the surface under hydrostatic pressure so great that the sod may be rent by gushing fountains rising to the height of trees and sweeping out tons of sand to mark for a century the site of the catastrophe. Ordinarily the ground water stream is simply a layer of moisture in permeable soil or rock; yet the disseminated water flows in obedience to gravity, making its way slowly through the interstices of the earth matter just as water exudes from the solid charcoal plates of an Atkins filter.

Commonly the ground water layer is indefinite; the upper limit is simply one of degree of moisture and can only arbitrarily be drawn, perhaps at the horizon at which the moisture is sufficiently abundant to exude more rapidly than evaporation can carry it away, and the lower limit is often more indefinite and of less practical interest. Moreover, the upper limit at least is a variable one, rising with storms and falling with droughts, and so changing from season to season. Yet, albeit indefinite and variable, the ground water layer always forms a surface; and this surface is in general fairly uniform in depth throughout each drainage basin, and thus conforms approximately to the land surface, so that the land surface of each drainage system has a subterranean double which imitates the major features of its model.

Thus in humid lands like eastern United States there is an aqueous circulation within the earth as well as on its surface; that portion of the waters of a given storm absorbed by the earth may exceed the portion which flows away on the surface, and this absorbed water lies long in the earth and a fraction of it at least accumulates in a slowly moving layer of moisture, maintaining approximate parallelism with the surface; and it commonly lies so near the surface as to be intersected by the deeper valleys and is often reached by shallow wells. This layer is within reach of surface contamination; so while it furnished nectar for the pioneer it distils hemlock for his descendants.

GROUND WATER SPRINGS AND WELLS.

While the ground water surface conforms fairly to the superjacent land surface, and while every surface drainage basin has its subterranean double, there is a difference in individuality of the surfaces; the land surface rises into higher and sharper crests and sinks into deeper and sharper ravines than the ground water surface, and accordingly when the land surface is exceptionally rugged it sometimes happens that its deeper ravines intersect the ground water couche when the moisture exudes in the bottom or trickles down the sides of the ravine. This intersection of land surface and moisture surface most commonly occurs when the latter is raised by persistent rains, and is the explanation of the long-continued but gradually decreasing flow of temporary streams as summer advances or as the drought is prolonged. Now, when the ground water horizon is permanently above the level of a surface stream the moisture exuding from the porous rock matter gradually opens passages or channels extending into the hills, and these passages prolong themselves and bifurcate after the fashion of surface streams until they are gradually formed into subterranean waterways with tributaries flowing in from right and left and to some extent from above and below, but all marking approximately the horizon of ground water; and in this way there may be developed a subterranean drainage system, simulating, albeit in vague and variable fashion, the surface drainage system; and the embouchure of the subterranean stream is a spring.

So the ordinary spring, which was accepted as a mysterious dispensation by the pioneer, really derives its supply from the rains which supply also the surface streams of the same drainage basin. When the hills are deforested a larger proportion of the stream water runs off in freshets and a less proportion percolates into the earth, so that the ground water level is lowered and the spring dwindles or fails; so, too, when the land surface is polluted with noxious fertilizers, or when stables or shambles are located on the slopes above the spring, its waters are polluted; and while the percolating waters may be partly purified in their slow passage through the porous soil and subsoil some part of the poison often remains, and the spring, once a source of health and strength, becomes a menace to life.

It follows that the spring fed by a ground water couche is unworthy of trust as a source of potable water. Half the springs of this character known to the pioneers have dried up, and half the remainder have dwindled to the point of failure, and most of the remainder are weakened. Moreover, the ground water spring, like the surface stream, is liable to local contamination. The waters are not distilled from the depths of the earth, but are accumulated rainfall, often gathered within rifle shot; and while the poison in the spring is diluted in the flowing waters, enough may and often does remain to work mischief—for scores of cases of typhoid and other fevers in different parts of the country have been traced to formerly healthful springs.

The ordinary well is simply an artificial spring of limited flow, and in the laws of its supply, in its evanescence or permanence, in the danger of contamination, it is very like the natural spring gurgling cheerily in the shady dell. Commonly the well is simply a reservoir excavated in the ground water horizon forming the subterranean double of the surface drainage basin; and commonly the reservoir is filled by the exuding moisture from the pervious subsoil, so that, when little used, the water marks the ground water level, though it may easily be pumped out. If the subsoil is exceptionally porous the exuding moisture may gradually open passages through which the water percolates, or even streams, into the reservoir, when the well is a strong one, competent to supply stock as well as human consumers. But, whether weak or strong the ground water well depends for its supply on the rain falling in its immediate vicinity, and thus the supply waxes and wanes with the wetness and dryness of the season and fails when the neighboring hills are deforested. Moreover, the waters are liable to pollution by local poisons coming from ill-used fertilizers, ill-placed barnyards, ill-designed outhouses. The spring of the pioneer was pure and the ground water well of the early settler was nearly as pure, but with increasing population, and with the development of agriculture and manufacturing, and the growth of cities, the very earth is gradually charged with the noxious by-products of organic activity, and year by year these are washed deeper and deeper into the soil, and eventually pervade the ground water horizon. The poison finds its way into spring and well alike; and while in the spring it is in part diluted and washed away, it gathers in the well as a grisly leaven, infecting the reservoir and its contents until the erstwhile healthful flood is changed into noisome filth.

Thus the ground water well, once a source of health and a mark of progress in the subjugation of the land, has in most sections outlived its usefulness and become a source of disease and a mark of social sloth and decadence. How far the ground water wells of the country are already polluted no man may say; but certain it is that whole countrysides are annually swept by typhoid fever, that hundreds of towns and villages suffer outbreaks of the same disease during every dry summer, and that each epidemic is traceable to wells; and while it would be hasty to condemn all wells indiscriminately, it is not too much to say that every well within city limits is a menace to health and should constantly be looked on with distrust, and that every farm well located hard by stable or barnyard is a legitimate object of suspicion

The pioneer dreamed of the clear, cool spring gurgling from moss-grown rocks in the depths of the dell; the farmer boy dreamed of the picturesque well sweep or creaking windlass and "the moss-covered bucket that hung in the well;" but both dreams have faded; for the spring is dried up and in the well lurks a poison sweeter than poppies, deadlier than nightshade.

PHREATIC WATER SUPPLY.

ACCUMULATION OF PHREATIC WATER.

When the rain falls from the clouds and a part is taken up by the thirsty soil, the behavior of the absorbed water depends on the texture and structure of subsoil and bed rock. If soil, subsoil, and bed rock are homogeneous in texture a simple sheet or couche of ground water is formed, but if the subsoil or bed rock is composed of layers of varying porosity, and if these layers are inclined, then the water circulates the more freely in the open textured layers and slowly finds its way down the slope in obedience to gravity. In this way the varying texture of the strata comes to be represented by varying moisture, and each porous bed becomes a phreatic horizon which is measurably independent of surface drainage and closely dependent on structure.

Then, whenever such a porous bed is intercepted by a deep ravine, the waters exude and may gradually form a subterranean channel with tributary channels dividing into seepage passages, and eventually a complete subterranean drainage system; and the embouchure is a spring. The waters of such a spring may come from long distances, and if the distant margin of the inclined porous stratum opens to sun and storm well up among the hills or on the mountain sides the waters may have a strong "head" and gush forth in a natural fountain.

In some cases the inclined porous strata carry the imprisoned waters to considerable depths in the earth, often far below sea level. When the temperature of the water is raised by the proper terrestrial heat, so that if they find or by their increased solvent action make for themselves a passage through the superincumbent less pervious strata, they may appear at the surface as thermal springs; and in this case the waters are commonly charged with mineral salts dissolved by reason of the pressure or the heat of the waters, when they are known as "mineral springs." There are other cases in which the phreatic waters are carried down the inclined strata to fractures (faults) or abrupt flexures in the strata, when they rise to the surface; and if, as frequently happens in mountainous regions, the fault or flexure is undergoing movement (either uniform or spasmodic) and the rocks are thereby heated by friction, the temperature of the water is raised and warm springs are formed which may not come from profound depths; and these thermal springs, like those of deeper origin, may be charged with mineral salts.

In general phreatic waters exist simply as moisture, like that forming the ground water couche, permeating porous beds of sandstone and other rocks; but when limestone or other soluble rocks are permeated by ground water or phreatic water the material is gradually dissolved along the more pervious lines, and subterranean channels are formed; and these may gradually be enlarged into great channels ever lengthening and bifurcating until the hills are honeycombed with caverns and pitted with sinks, and in some cases (as in the Bluegrass region of Kentucky) subterranean streams take the place of surface drainage, and sometimes these streams burst forth, Juno like, in full-sized rivers, such as the elfin Silver spring of Florida and the enchanting Oklawaha river in which its shining waters are slowly darkened.

So when the subterranean structure and texture are favorable the rain water absorbed by the earth is carried long distances and to profound depths in subterranean drainage systems which are largely independent of surface configuration. Such are the phreatic waters of the country which supply most thermal springs, most mineral springs, all artesian wells, and many deep pump wells; and, in general, the course of the phreatic water from the time of its absorption into the soil to the time of its reappearance in spring or deep well is so long and devious that the mechanical and organic impurities with which it may at first be infected are almost certainly eliminated. Thus the phreatic moisture of the earth is generally a trustworthy source for the supply of potable waters.

THERMO-MINERAL SPRINGS.

Some mineral springs are cold and some thermal springs are not abundantly charged with mineral matters in solution, yet in general there is an intimate connection between the thermal condition and the mineral condition; accordingly it is usually inexpedient to separate spring waters into distinct thermal and mineral classes, and for most purposes they may be combined as thermo-mineral waters. In general such waters become impregnated with mineral salts in consequence of the increase in chemic activity due to pressure or augmented temperature, or both combined.

The thermo-mineral character displayed by the phreatic waters appearing in certain springs is produced by a variety of conditions. The prevailing causes are two, viz, (1) contact with rocks heated by faulting, flexure, or other diastrophic movements, or by volcanism; and (2) contact with deep-lying strata whose temperature is raised only by proper terrestrial heat. Accordingly springs of the first class are commonly confined to mountainous regions or regions of volcanic activity, while those of the second class are found in regions of plain surface and simple structure. The first class of springs is accordingly represented by the White Sulphur springs of Virginia, the Warm spring near Asheville, North Carolina, and the Hot springs of Arkansas. The same general class is represented also by many springs distinguished rather for the mineral condition than the thermal condition of the waters, such as those of Saratoga. The second class of thermo-mineral springs is represented by the deep-seated springs of Florida, of which most are thermal and practically all mineral-bearing.

The thermo-mineral springs of eastern United States are of great and ever-increasing importance as sources of potable waters, for not only the increase in population, but the gradual pollution and abandonment of waters obtained in more primative ways tends constantly to increase their consumption. Various conditions are, however, combining to regulate and control the distribution of such waters by private enterprises. For this reason and for the further reason that extended publications on the mineral springs of the United States have recently appeared, the thermo-mineral springs of eastern United States do not seem to demand a detailed discussion in this place. They are more fully treated in the following memoir by Dr. A. C. Peale.

ARTESIAN WELLS.

Artesian wells (so named from the province of Artois, in France, in which wells of this character were first extensively employed in the present stage in the development of civilization) are usually simple bores tapping deep-seated strata saturated with phreatic water; when, if the tapped stratum is sufficiently porous and the head adequate, the water flows out at the surface. The success of artesian boring depends on a variety of conditions more or less closely analogous to those covering thermo-mineral springs.

In the inverse order of their importance, the requisites for artesian flow of water are, (1) conditions of structure, (2) conditions of texture, and (3) conditions of supply. The most favorable structural condition is an arrangement of the strata in the form of a basin, as in the French province of Artois. The rain water falling on the rim of such a basin percolates through the strata to its center, and there rises through natural or artificial openings to a height depending on the difference in altitude between the area of supply (or catchment area) and the head of the well; but the basin structure is not absolutely essential, and artesian flows are obtained from uniformly inclined strata (such as those constituting the Atlantic coastal plain) when the catchment area is elevated considerably above the wellhead, or when the strata either diminish in permeability in the direction of inclination or extend far beyond the point of outlet, i. e., textural and other conditions may combine with structure to produce flow where structure alone is unfavorable. The most favorable textural condition is found when the porous stratum extends from the catchment area to the part of the basin, trough, or moncline tapped by the drill, and is overlain (excepting in the catchment area) by an impervious stratum. This condition, like the last, is not absolutely essential to artesian flow, since all rocks are more or less pervious, and if the difference in altitude between the catchment area and wellhead is sufficient a slight flow may be obtained almost anywhere; but it is essential to abundant flow, and even to the slightest flow, unless other conditions are exceptionably favorable. The most favorable condition of supply is found where a porous formation rises from beneath less porous strata and forms the surface over a broad area. It should be borne in mind that on nearly all parts of the land the annual aggregate volume of rainfall largely exceeds the aggregate volume of river flow; that a considerable part of the rainfall not carried directly into the sea by the rivers finds its way thither more slowly by percolation through the rocks in the form of phreatic water; and that in consequence the strata of the earth—at least below the reach of surface evaporation—are more or less completely saturated. Even in desert regions a part of the rain drank by the thirsty sands during each rare storm reappears in springs, or may be reached by artesian borings to form oases, at lower levels. In short, while the condition of supply is the essential and primary one, it is a fact that the supply is adequate in nearly all parts of the earth, and that artesian flow or its failure are usually determined by local conditions of structure and texture.

Artesian waters, like the naturally escaping phreatic waters, are frequently thermal and also more or less abundantly charged with minerals. The thermal condition, if sufficiently decided, may be utilized, e. g., the warm waters of deep artesian wells may be employed for heating conservatories or residences, as is done to some extent in Florida. The minerals held in solution are sometimes beneficial, sometimes injurious to the human system; and in most sections some wells at least yield waters whose minerals are not so unwholesome as to warrant the condemnation of the water for drinking.

On the whole, artesian wells are to be regarded as a trustworthy source of potable water over large areas in eastern United States. The areas include districts in New England, New York, northern New Jersey, Pennsylvania, western Maryland, West Virginia, eastern Tennesseeand Kentucky, northwestern Georgia, and northeastern Alabama, in all of which the phreatic waters represent sublocal rainfall, and in which, with proper precautions, the waters accumulated under local conditions of texture and structure may be considered wholesome. There is another vast area in which artesian waters may be obtained either generally or under favorable local conditions (e. g., in valleys, but not on hilltops), embracing southeastern Minnesota, southern Wisconsin, about half of Iowa, extensive tracts in Illinois, parts of northern Missouri, and some portions of Michigan and Indiana. Throughout this district the waters are slightly thermal and in general exceptionally free from mineral salts, being derived from the extensive sand beds of the Potsdam and St. Peter formations. This district grades southeastward into an extensive area, including portions of the southern peninsula of Michigan, much of Ohio, and parts of Indiana, Connecticut, and Tennessee, in which artesian water may be reached under fair or strong head, but in which the water is commonly too salt for drinking purposes and is sometimes charged with a variety of mineral constituents. The most extensive area of artesian water supply in eastern United States includes the greater part of the coastal plain fringing the Atlantic and Gulf coasts in a belt from 50 to 250 miles broad. In this district strong flows of water are reached at various depths, e. g., 300 to 700 feet on the New Jersey coast, 400 to 1,000 feet on the eastern shore of Maryland, 1,000 to 1,200 feet in eastern Virginia, about 2,000 feet as well as at lesser depths at Charleston, at different depths up to 1,200 feet at Jacksonville and St. Augustine, and at more variable depths and with somewhat less trustworthy results on the Gulf coast. The waters in general are sufficiently pure for drinking purposes without precipitation of the mineral salts, and are thermal in moderate degree only. Further westward there is a vast area throughout much of which artesian supply is possible, including a large part of the great plains in a zone stretching from the international boundary to the Gulf of Mexico, about 97° to 100° west longitude.

There are many districts in eastern United States in which artesian water supply is not and never will be possible, by reason of unfavorable conditions of structure and texture. Perhaps the most extensive of these is the Piedmont area of crystalline rocks stretching parallel with the Atlantic coast between the coastal plain and the Appalachian mountains from New York into Georgia and Alabama.

The general conditions of artesian well supply in the coastal plain of the United States have been set forth in considerable detail in the Seventh Annual Report of the U. S. Geological Survey, pages 640–646, and the requisite and qualifying conditions of artesian wells, considered in general, were discussed at length by Prof. T. C. Chamberlin in the Sixth Annual Report, pages 125–173.

DEEP PUMP WELLS.

A considerable portion of the phreatic water of eastern United States never reappears at the surface, but is partly consumed in mineral combinations in the depths, partly carried directly into the ocean through seepage and springs. There are unquestionably numerous submarine springs in the Atlantic ocean off the coast of Florida, of which some are so large as to send up strong columns of fresh water to the surface. Now, the phreatic water conveyed into the ocean in these ways is lost to mankind. A part of this supply will eventually be utilized by tapping the water-bearing strata at new points, when, even if the water does not flow at the surface, it will be found to rise within easy pumping distance. Moreover, the principal artesian districts of eastern United States are so conditioned that the waters rise but little above the surface, even when the borings are made in valleys. In such cases the aggregate volume of water may be increased and the water supply

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OF THE

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INTRODUCTION.

Aside from the geological interest attached to the subject of mineral waters the facts that within the limits of the United States there are between 8,000 and 10,000 mineral springs, and that the waters from nearly 300 are annually placed upon the market to the extent of over 21,000,000 gallons, at a valuation of nearly $5,000,000, show plainly that the subject is also one of considerable economic importance. That this importance is an increasing one is evident when a comparison of these figures is made with the figures for 1883, the first year they were compiled. The production then was 7,529,423 gallons, with a valuation of $1,119,603, and the total number of springs known to be utilized for commercial purposes was only 189.

Dr. John Bell was one of the first to write about the mineral springs of the United States, and when he made his list of them in 1831 he enumerated 21 in all. To-day the list of commercially used waters drawn from our mineral springs is nine times greater than the total number then known.

When individual localities are considered and comparisons are made between the present conditions and those of a relatively few years ago the same advance in importance and interest is evident. At Saratoga Springs, for instance, a place that has given its name to many mineral spring resorts from one end of the country to the other, 40 springs have been discovered in addition to the High Rock spring, which, first known to white people in 1767, had been known and utilized for its medicinal virtues long before that by the aboriginal inhabitants of the country. In Saratoga to-day we have a spa that rivals the best in Europe, where attention has been devoted to the subject of mineral waters for centuries. In Virginia and West Virginia, also, which together now have at least 150 known mineral springs, there were in 1831 only 7 springs catalogued. Of these the Bath Mineral spring, now Berkeley Springs, named after the celebrated English watering place, was known and slightly improved as a resort in 1777;

and the Greenbrier White Sulphur Springs, generally known simply as the "White Sulphur Springs," date their first improvement from the year 1778. These places are the prototypes of mineral spring resorts now found in almost every State of the Union.

Much remains, however, to be done before the scientific use of our mineral waters can be defined with that careful regard to their chemical composition and their therapeutic value which is so much to be desired.

HISTORY.

Inasmuch as the history of our country reaches back only to a comparatively recent date the written history of its mineral springs must of necessity also be a rather short one. Although many of our best known mineral waters were known to the Indians from earliest times, and traditions of their virtues were transmitted to their white successors, the time of the latter was too much occupied to allow of much attention being paid to them.

The history of mineral springs in general, however, dates from the most remote periods. The Egyptians, Arabians, Mohammedans, Greeks, Romans, and, in fact, all nations, have used mineral waters for medicinal purposes from time immemorial. Hippocrates, Aristotle, Herodotus, and even Homer wrote of them; temples dedicated to Æsculapius, the god of medicine, were erected near them; and they were made the sites of hospitals, medical schools, baths, and resorts for the diversion of the sick.

Pliny, in his Natural History, says of these waters: "They spring wholesome from the earth on every side, and in a thousand lands, the cold, the hot, the hot and cold together, as at Tarbellum (Dax), in Aquitania, or in the Pyrenees, where they are separated only by a small interval, or yet the warm and tepid, announcing relief to the sick, and flowing from the earth only for man, of all living things."

For five centuries mineral waters were almost the only medicines used in Rome. In their conquests of northern and western Europe the Romans sought the springs of the countries, and in the names Acqui, Aix or Aachen, Dax, etc., derived from the Latin *aqua*, we have testimony of the former celebrity of these towns as watering places. The reputation of many of them has descended to our own time. Among the Romans warm bathing was indulged in to excess, and at one time there were 800 thermæ in Rome. Many traces of these ancient Roman baths remain. They were buildings of great architectural beauty, grand and magnificent, adorned with statuary and mosaics, and among them the baths of Diocletian and the baths of Caracalla were the most celebrated.

In our practical day we have shorn the springs of the superstitions of the ancients, and the busy habits of modern times do not permit us to spend the time and elaborate preparation upon the bath that was bestowed upon it in the luxurious days of imperial Rome. Although we no longer depend upon hearsay as to the efficacy of springs in the cure of disease, but have chemists analyze the waters, still the period of true scientific investigation of their properties reaches back only a few hundred years, and the therapeutic study, especially in our own country, will require many more years of patient labor.

The first work upon the quality and use of water that was printed in America treats of it from a therapeutical standpoint. It is entitled: The Curiosities of Common Water, or the Advantages thereof in Curing Cholera, Intemperance, and other Maladies, by John Smith, C. M. It was reprinted at Boston, Massachusetts, from the London edition of 1712, for Joseph Edwards, at the corner shop on the north side of Town House, in 1725. It calls special attention to the excellency of water as a drink, and enumerates its therapeutical attributes as follows: "It cures gout and hypochondriac melancholy; it benefits gravel and stone in the bladder; it makes the child grow strong in the womb, and increases the mother's milk; it stays hunger; for there was a certain crack-brained man who, at Leyden, when Dr. Carr resided in that university, pretended he could fast as long as Christ did; and it was found that he held out the term of forty days without eating any food, only he drank water and smoked tobacco." "Water is also of great use to strengthen weak children; it prevents swelling from bruises, sickness of the stomach, shortness of breath, and vomiting; it cures fluxes, consumption, flushes, colic, smallpox, etc." Although written one hundred and eighty-one years ago this is not excelled by the pretentious claims of any modern mineral spring circular.

Dr. John Bell was perhaps the first to write anything like a treatise on the mineral springs of the United States. In his Baths and Mineral Waters, published in 1831, part II is devoted to "a history of the chemical composition and medicinal properties of the chief mineral springs of the United States and Europe." He enumerated 21 localities for the United States, which list was increased to 181 in The Mineral and Thermal Springs of the United States and Canada, which he published in 1855. Dr. J. J. Moonman, in his Mineral Springs of North America and How to Reach Them, published in 1873, refers to or describes 171 springs. This was preceded by his Mineral Springs of the United States and Canada, published in 1867, and by several books relating to the Virginia springs published in 1837, 1846, 1855, 1857, and 1859. Dr. George E. Walton's Mineral Springs of the United States and Canada, etc. (third edition), published in 1883, mentions for the United States 279 localities. Drs. William Pepper, H. I. Bowditch, A. N. Bell, S. E. Chaillé, and Charles Dennison, as a committee of the American Medical Association, in 1880 made a very complete compilation, which included about 500 localities. Dr. A. N. Bell's Climatology and Mineral Waters of the United States, published during the latter part of 1885, enumerated 173 localities. Bulletin No. 32, published by the U. S. Geological Survey in 1886 (compiled by the writer), included 2,822 mineral spring localities (and 8,843 individual springs), 634 of which were utilized as resorts and 223 as sources of commercial mineral water. One of the most recent enumerations is by Dr. Judson Daland in the list appended to Gould's New Medical Dictionary. An examination of the many works relating to the springs of the separate States or individual spring resorts is not in place here.

What is now needed most in relation to our own springs is, first, a careful chemical examination of all our mineral waters. This examination should be made upon one plan for all the waters, if not by the same chemist in all cases. We have analyses to the number of a thousand or more made upon almost as many plans as there are chemists who made them. Many of the analyses also were made long before the spectroscope was known, and the waters should be examined in the light of recent advances in chemical knowledge. Until this is done we have no way of accurately comparing them with each other or with the well known waters of other countries.

We need, secondly, a careful therapeutic and clinical study of our mineral waters. Until more study is devoted to this subject our physicians will continue to send patients abroad, because they know that at the foreign resorts the patient is at once put under the care of one who has made a study of the effects of the waters and has mastered all the details of its use in the treatment of disease. There has been a great improvement, however, in this respect, in the sanitaria of the United States in the past ten years, and before long it is hoped that none will be obliged to go abroad for treatment at a mineral spring resort. Until that day we shall have to rely upon the comparison of our waters with those of foreign countries where the study of their effect has been carried on for years. This comparison, of course, is facilitated by our knowledge of the chemical composition of the waters. It is an interesting fact that mineral waters were used by the ancients for the same diseases to which they are applied to-day.

DEFINITION.

The definition of a mineral water will depend upon the point of view, whether it be that of the chemist, or that of the physician or dealer. In the strictest sense water, being an inorganic body, that is, a compound of definite chemical composition, is itself a mineral. Common usage has restricted the term to those waters that contain appreciable quantities of foreign matter.

As water may be considered the universal solvent, all waters in a certain sense must be mineral waters from a chemical standpoint. Even glass is to a small extent soluble in water. Absolutely pure water is a product of the laboratory alone, and rain water, which is the purest natural water, acquires in its passage through the atmosphere small quantities of solid organic and inorganic matters, as well as ammonia, carbonic acid gas, and other gases.

As Daubeny says,[1] "the term mineral water in its most extended sense comprises every modification existing in nature of that universally diffused fluid, whether considered with reference to its sensible properties or to its action upon life."

From the standpoint of the physician a mineral water is any water that has an effect upon the human system, no matter how feebly mineralized it may be; that is, it is any water that possesses medicinal virtues, whether they be due to the presence of organic, inorganic, or gaseous contents, or to the principle of heat. This is the definition found in most works on mineral springs. Under this definition, therefore, would be included many waters that, from a chemical standpoint, might be considered very pure or chemically indifferent. Many of them are less highly mineralized than the ordinary potable waters of a great many localities; yet the fact that they have some specific effect from a medical point of view entitles them to consideration as mineral waters.

From the standpoint of the dealer in bottled mineral waters the definition has of course a very wide range. From his point of view all waters put upon the market for sale in bottles or barrels or in any other way, come under the head of mineral waters, and in collecting the statistics of the commercial aspect of the subject it has been found impossible to draw any definite line, either according to the mineralization of the water or the uses to which it is put. A number of the waters included, and of importance commercially, would be considered indifferent when viewed in the light of their chemical composition, but it must be remembered that some very pure waters have an undoubted therapeutical effect, and that chemical analysis, which is absolutely reliable only in its estimation of basic salts and acids, will not always explain the medicinal effect of a water, and that small quantities of some constituents are often more effective as remedial agents than others that are present in larger quantities. It is an undoubted fact that many springs which, upon chemical analysis of their waters, are found to be not so highly mineralized as the majority of potable waters, have acquired, and rightly, too, great reputations for their medicinal value. That their medicinal value is thus recognized and that they are sources of profit to their owners and also indirectly an addition to the wealth of their localities, seem sufficient reasons why they should be included under the head of mineral springs, from this commercial point of view.

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[1] Sixth Report, British Association for the Advancement of Science 1836, p. 1.

ORIGIN OF MINERAL SPRINGS.

One of the first questions that presents itself is: whence comes the great quantity of water that is poured forth by mineral springs and seems to be unfailing in its supply, changing but little in most cases from day to day and from year to year. It is an undisputed fact that the water of all springs, mineral or otherwise, is meteoric in its origin; but for a long time, in fact for ages, the origin of springs was a puzzling question and a fruitful subject of debate by ancient philosophers. Aristotle taught that there were large cavities in the interior of the earth filled with air and that this air condensed to water on the cold ceilings and made its way to the surface through fissures. Vitruvius believed that springs were due to an accumulation of rain and melted snow in subterranean reservoirs. Descartes imagined that the sea was the source of the water which flowed into subterranean caverns, was vaporized, and afterwards condensed, finally escaping to the surface through crevices in the rocks.

The water of mineral springs, as of all other springs, is now, however, recognized as no new creation, but it is well known that the spring is only one of the phases of an aqueous circulation which begins and ends in the clouds that envelope our globe. Falling through our atmosphere as rain, after it reaches the earth the water ever seeks lower levels, and while a large part passes directly to the ocean through the lakes and streams, a very considerable portion sinks into the earth through the crevices in its rocks, and issuing later as a spring in some lower and more favorable level, eventually reaches the ocean, whence by evaporation it once more becomes a part of our cloudy envelope. In the latter part of the seventeenth century, Mariott, a French physicist, and Halley, the eminent English astronomer, independently of each other, the one by physical methods and the other from an astronomical point of view, demonstrated that the evaporation from the ocean is sufficient to account for the supply of water to all the springs and lakes and rivers that supply water to the sea. Buffon later demonstrated the same theory by selecting a lake without an outlet and proving that the evaporation from its surface was equal to all the water that was poured into it. It was anciently believed that all the rain water that fell upon the earth either ran off or was absorbed by the surface strata a short distance below the soil; but the constant dripping of water from the roofs of mines and tunnels proved this view to be incorrect. In Misnia, in Saxony, water forms in drops on the roofs of mines 1,600 feet below the surface, and when the railroad tunnel through Mount Cenis was cut into rock hard enough to turn the best steel, that rock was found to be so filled with water that a canal had to be built through the center of the tunnel to carry it away. Prof. T. Sterry Hunt estimates that a square mile of sandstone 100 feet in thickness will contain water sufficient to sustain a flow of a cubic foot a minute for more than thirteen years. The water reaches the surface through springs in several ways. Sinking below the surface it penetrates the strata to a greater or less depth and is frequently subjected to an enormous hydrostatic pressure as it reaches lower levels; and when a favorable opportunity occurs through a crevice in the rocks, this pressure forces it to the surface, or boring for an artesian well gives it the necessary outlet. Many springs, however, find their way out naturally, as they flow from high altitudes to lower ones, and some waters, especially in the case of hot springs, are forced to the surface by an accumulation of steam, or exist as geysers from the very fact of their higher temperature. The accumulation of gas is also effective in the case of many cold springs, or in some springs that alternately throw out gas and water. The great majority of springs, however, reach the surface quietly either along the base of mountain ranges, or in valleys, or at the coast line. Their supply area is the higher mountain region that receives the water as rain. This, then, ordinarily sinks until an impervious stratum is reached, along which it flows until it emerges at the first favorable opportunity at the lower level, either as an ordinary spring, as a mineral spring if the rocks through which it passes are favorable, or as a hot or warm spring if it penetrates to a great depth or comes into contact with heated rocks before issuing at the surface of the earth.

FLOW OF MINERAL SPRINGS.

To those who have only casually considered the subject, the outflow from springs is somewhat surprising in amount. Le Coq says that of 500 springs in central France, 231 have been gauged and yield 2,628,000 gallons each every twenty-four hours. This, however, is small compared with the "Orange Spring," in Florida, which is said to pour out over 5,000,000 gallons per hour. During the eruptions of the Excelsior geyser, in the Yellowstone National Park, enough water is thrown out to double the volume of the Fire Hole river, upon whose bank it is situated. The river at this point is from 2 to 3 feet in depth and nearly 100 yards in width.

Very few observations have been made as to the permanence of flow of our springs, but mineral springs coming from considerable depths are not liable to the fluctuations seen in surface waters. The following is a list of our mineral springs that have a flow of 1,000 gallons or more per hour:

Name of spring and location.	Flow per hour.
	Gallons.
Addison Mineral Spring, Maine	1,800
Lake Auburn Mineral Spring, Maine	2,000
Summit Mineral Spring, Maine	2,280
Bradford Mineral Springs, New Hampshire	2,000
Brunswick White Sulphur Springs, Vermont	1,000
Allandale Springs, Massachusetts	1,250

Name of spring and location.	Flow per hour.
	Gallons.
Everett Crystal Spring, Massachusetts	3,000
Avon Sulphur Springs, New York	7,660
Iron Spring, Ballston, New York	4,000
Crystal Springs, New York	1,250
Chlorine Spring, Syracuse, New York	2,000
Excelsior Spring, Syracuse, New York	1,000
Dansville Springs. Syracuse, New York	1,000
Lebanon Thermal Spring, New York	30,000
Champion Spring, Saratoga, New York	2,500
High Rock Spring, Saratoga, New York	1,000
Pavilion Spring, Saratoga, New York	12,000
White Sulphur Spring, New York	2,400
Sharon Springs, New York	7,680
Slaterville Magnetic Spring, New York	2,700
Warm Spring, Perry county, Pennsylvania	5,400
Massanetta Mineral Springs, Virginia	30,000
Roanoke Red Sulphur Springs, Virginia	1,278
Warm Sulphur Springs, Bath, Virginia	360,000
Berkeley Springs, West Virginia	3,000
Blue Sulphur Springs, West Virginia	2,000
Greenbrier White Sulphur Springs, West Virginia	1,860
Sweet Springs, West Virginia	48,000
All Healing Springs, North Carolina	3,800
Alum Springs, Onslow county, North Carolina	90,000
Panacea Springs, North Carolina	3,700
Artesian Well, Citadel Green, Charleston, South Carolina	1,500
Chalybeate Springs, Merriwether county, Georgia	1,500
Magnolia Springs, Georgia	3,000
New Holland Springs, Georgia	1,200
Warm Springs, Merriwether county, Georgia	84,000
White Sulphur Springs, Merriwether county, Georgia	1,200
Blue Spring, Florida	73,920
Green Cove Spring, Florida	3,000
Orange Spring, Florida	5,055,000
Salt Springs, Marion county, Florida	148,000
White Sulphur Springs, Florida	1,200,000
Bladen Springs, Alabama	1,250
Healing Springs, Alabama	3,100
Belmont Springs, Mississippi	3,600
Castalian Springs, Mississippi	7,200
Castalian Springs, Tennessee	12,000
Jordan's Springs, Tennessee	6,000
Blue Lick Springs, Kentucky	12,200
Grayson Springs, Kentucky	2,800
Kuttawa Springs, Kentucky	1,200
Blanchard Springs, Arkansas	1,700
Blood Springs, Arkansas	2,000
Dove Park Springs, Arkansas	2,160
Eureka Springs, Arkansas	1,675
Floods' Chalybeate Spring, Arkansas	9,000
Hot Springs, Arkansas	20,100
Siloam Springs, Arkansas	12,800
Carrizo Springs, Texas	7,000
Dalby Springs, Texas	1,600
Pecan Springs, Texas	21,600
Sour Springs, of Caldwell, Texas	1,200
Electro-Magnetic Springs. Ohio	1,100
Green Mineral Spring, Ohio	375,000
Yellow Springs, Ohio	6,600
Cameron Springs, Indiana	1,100
French Lick Springs, Indiana	1,100
Kannal Spring, Indiana	1,800
Trinity Springs, Indiana	18,000
West Baden Spring, Indiana	1,500
Ganymede Spring, Illinois	3,000
Spring Valley Springs, Illinois	2,000
Prairie du Chien Artesian Well, Wisconsin	3,620
Bethesda Spring, Waukesha, Wisconsin	4,200
Glenn Spring, Waukesha, Wisconsin	45,000
Horeb Spring, Waukesha, Wisconsin	1,500
Mineral Rock Spring, Waukesha, Wisconsin	2,200
Siloam Spring. Waukesha, Wisconsin	1,000
Vesta Spring, Waukesha, Wisconsin	1,200
Iodo Magnesian Spring, Beloit, Wisconsin	10,000
Jacob's Artesian Well, Milwaukee, Wisconsin	18,000
Sheboygan Mineral Spring, Wisconsin	8,400
Sheridan Springs, Wisconsin	1,000
Chamberlin Mineral Springs, Iowa	2,000
Big Mineral Springs, Iowa	6,400
Linwood Springs, Iowa	30,000
Blankenship Medical Springs, Missouri	2,000
Sweet Springs, Missouri	1,100
Akesion Springs, Missouri	4,000

Name of spring and location.	Flow per hour
	Gallons.
Blue Lick Springs, Missouri	3,000
Great Salt Springs, Missouri	10,200
Boiling Spring, Benton county, Missouri	5,000
Monegaw Springs, Missouri	18,000
Union Springs, Kansas City, Missouri	1,000
Clinton Artesian Wells, Missouri	3,400
Guyer's Hot Springs, Idaho	2,000
Hot Springs, near Boise City, Idaho	15,400
Mound Springs, Boxelder county, Utah	1,000
Salt Lake City Warm Springs, Utah	32,903
Utah or Bear River Hot Springs, Utah	6,500
Artesian Magnetic Mineral Spring, Pueblo, Colorado	5,000
Hot Sulphur Springs, of Middle Park, Colorado	16,980
Idaho Hot Springs, Colorado	2,000
Poncho Hot Springs, Colorado	1,000,000
Salt Spring, Pueblo, Colorado	7,000
Seltzer Mineral Springs, Colorado	1,000
Ojo Caliente, New Mexico	6,000
Hot Springs near Wellington, Nevada	91,000
Hot Springs near Toyabe, Nevada	35,000
Goodrich Spring, Nevada	28,000
Shaw's Hot Springs, Carson, Nevada	4,000
Smoky Valley Geysers, Nevada	4,200
Whelan's White Sulphur Springs, Nevada	5,000
El Paso de Robles Springs, California	11,000
Geyser Springs, California	1,000
Hot Borate Spring, Lakeport, California	18,000
Harbin Mineral Springs, California	1,500
Matilija Hot Springs, California	8,000
Warner's Ranch Springs, California	1,400
Coronado Mineral Springs, California	50,000
Mark West Springs, California	5,700
Napa Soda Springs, California	4,000
Paraiso Hot Springs, California	2,000
Santa Ysabel Springs, California	20,000
Seigler's Springs, California	3,000
Ukiah Vichy Springs, California	20,000
Belknap Hot Springs, Oregon	1,260
Denny Springs, Washington	1,640

SOURCE OF MINERALIZATION.

What is the source from which are drawn the various gaseous and solid constituents of mineral waters? This is a question easily answered when the solvent power of water is remembered in connection with its penetration of the rocks that enter into the composition of the earth's surface. The disintegrating effect of fairly pure water upon rocks is well known, but when it is remembered how vastly it is enhanced by the presence of carbonic acid gas, acquired in the passage of water through the atmosphere and the soil, we need not look very far for the source of the constituents of mineral waters. They are derived from the decomposition of the rocks through which the waters pass in their downward course. Carbonic acid may accumulate in considerable quantities, and, besides favoring the solution of calcium, magnesium and iron, it may be held in solution in excess in the water. Sulphates may be reduced to sulphides and yield hydrogen sulphide. Organic matters also play an important part. In addition to chemical action, high temperature may assist in the breaking down of the rocks, and water under great pressure, without the aid of heat or with chemical action alone, may dissolve out not only the more soluble constituents of rocks, but others not usually considered so, as silica, which is very sparingly soluble.

In passing through the sedimentary rocks many of the previously deposited salts are redissolved, and in these and in the constituents of the metamorphic and igneous rocks may be found all the solid constituents that we find in mineral waters. They may be rearranged in the mineral waters after solution by chemical action, but there is no difficulty in accounting for the presence of any of the elements that are found upon chemical analysis.

GEOLOGICAL POSITION.

Inasmuch as mineral waters derive their solid constituents from the rocks through which they pass on their way down and up before their emergence as springs, there must be an intimate connection between them and the geological structure of the country. A comparison of the geological map of the United State with a map of its mineral springs is very instructive in this respect. In regions where the older or metamorphic rocks constitute the surface formation, or are near to it, the waters as a rule contain a much smaller percentage of solid contents than in those regions where the water, to reach the surface, must come through sedimentary rocks which are not only more readily affected by the solvent powers of the water on account of their structure, but naturally contain a larger proportion of readily soluble salts. Again, it will be seen that thermal springs in the eastern United States are limited mainly to those regions where there has been more rugged mountain corrugation. The hot and warm springs of Virginia and the warm springs of North Carolina and Georgia are found within the limits of the Appalachians, and in Arkansas the hot springs are found in connection with the Ozark mountain uplift. When the eastern section of the country is compared with the western half, which includes the Rocky mountain region, the great preponderance of hot springs in the latter is at once apparent, and the contrast between the two sections in this respect is striking. It is true that in Florida most of the springs are slightly thermal, and that in the Mississippi valley there are a number of artesian wells whose water is also thermal, but in both cases this increased temperature is probably due to the greater depth from which the water comes. In the Rocky mountain region and other parts of the far west, in addition to the mountainous character of the country, which is also of recent origin compared with the Appalachians, we have a region of more recent volcanic disturbance and one in which rocks of igneous or eruptive origin cover extensive areas. It has long been a well known fact that the lines of junction between the sedimentary rocks and the older formations, especially along the bases of mountain ranges, are localities favorable for the occurrence of warm and hot springs. Daubeny pointed out the connection of hot springs with fissures and lines of elevation, and Prof. James D. Forbes,[1] in 1835, confirmed Daubeny's views and pointed out the fact that the springs of the Pyrenees in almost every case were situated "just at the boundary of the granite with the stratified rocks."

These lines of junction are naturally weak points, and feel the stress of an uplift first, and they are therefore the points at which the greatest number of fractures and fissures occur and give the best egress to the water. When two or three axes of elevation cross each other the disturbance is greater, and as at Aix in France, and Leuk in Switzerland, and at Mont Blanc, it is not a matter of surprise to find thermal springs.

Prof. W. B. Rogers has pointed out the connection of the warm springs of Virginia with the faults and anticlinal axes of the Appalachian mountains. In almost every country the connection between thermal springs and mountain ranges is readily recognized, and just as apparent is the connection between hot and warm springs and the occurrence of volcanic rocks the world over. Mr. G. K. Gilbert some years ago called attention to the fact that the hydrothermal contrast between the eastern and western portions of the country is in accord with the geological conditions, and he referred the greater heat in the latter to local uprisings of the geiso-thermal planes, together with progressive corrugation, the intensity of the phenomena being heightened by the intrusion or extrusion of lava.

The western States may be divided into four great divisions, viz, the Rocky mountain region, the Plateau region, the Great Basin, and the Pacific coast. In the Rocky mountain region mountain corrugation is probably the primary cause of the hot springs, although in many places it is associated with the occurrence of igneous rocks, as, for instance, in the Yellowstone National Park, where the latter are undoubtedly the cause of the geyseric phenomena.

On the Pacific coast we find a similar association of the two causes, the uplifts of the Sierras and Coast ranges having been accompanied with volcanic outbursts, which in Alaska become a striking feature, the activity there being a thing of the present. All of the Alaskan mineral springs so far as known are either warm or hot.

In the Great Basin mountain corrugation is subordinate to the dislocation of strata due to profound faulting. Prof. I. C. Russell describes the region as follows: "The whole immense region lying between the Sierra Nevada and Rocky mountain systems has been broken by a multitude of fractures having an apparently north and south trend, that divide the region into long, narrow orographic blocks." With the faults thus described by Russell are associated hot springs, and a map of the hot springs of the Great Basin would be to a great extent a map of

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[1] On the temperature and geological relations of certain hot springs, particularly those of the Pyrenees. Philosophical Transactions, 1836.

its displacements, just as a map of the hot springs of the world would be a very good map of the lines of volcanic disturbance of the globe. With the faults of the Great Basin volcanic rocks are also frequently associated.

In the plateau region a similar association of faulted strata and the former outpouring of lavas is noted.

Thermal springs are not the only mineral waters found in connection with faulted strata. The disturbance accompanying the formation of faults is the most efficient cause of cracks and fissures through which waters can find their way to the surface. The springs of Saratoga are a notable instance of the association of cold mineral springs with profound faulting. In this case, however, there is no connection with igneous rocks and the water which has its source primarily in the mountains to the eastward of Saratoga is probably tapped at a comparatively short distance from the surface, and hence has not acquired the temperature that other deeper springs get from the normal downward increase of temperature of the earth. This increase of temperature, as given by different authorities, ranges from 1° F. in every 23 feet descent to 1° F. in 68 feet. Recently Dr. Wm. Hallock of Columbia College, New York, as the result of observations on the deep well at Wheeling, W. Va., states that down to 3,200 feet the gradient is 1° F. for every 81·5 feet, whereas the last few hundred feet show an increase of 1° F. for about every 60 feet.

CLASSIFICATION.

That a classification of the various mineral waters is desirable is a proposition from which no one dissents, and many writers have presented schemes.

Systematic arrangement is necessary for a comprehensive view of the subject, no matter what the standpoint, and is naturally made in some shape or other by everyone. The universal use of water for drinking purposes led men at first to divide waters into potable and nonpotable (or drinkable and nondrinkable), but mineral waters were very early differentiated, and divided into classes according to their predominant characters or the qualities which appealed most strongly to the senses of taste and smell. In the time of Aristotle they were classified according to the vapors or gases they contained, and Pliny in the first century divided them into acidulous, sulphurous, saline, nitrous, aluminous, and bituminous. Many of our classifications of to-day have advanced but little beyond this early scheme. If they are in any sense chemical, they are generally based upon properties that are not analogous, terms denoting gaseous contents being made equivalent to those referring to the solid constituents. Usually, however, there is a mixture of chemical and therapeutic classifications with other characteristics referable to physical sensations, which are all considered in these schemes as coordinate. Thus the terms alkaline, purgative, thermal, and sulphur waters, are found in most classifications as divisions of the scheme, each one of equal value so far as the classification goes.

Any classification must, from the nature of the case, be somewhat arbitrary, inasmuch as nature herself is an evolution, and we find that waters so shade into each other that it is difficult to draw hard and fast lines; but it is certainly not necessary to adopt a scheme based on such diverse properties as the contained gases, the therapeutic effect, the solid contents, and the sensation of heat, all jumbled together. The thermal waters may be alkaline, sulphureted, or purgative, and so purgative waters may be sulphureted and alkaline waters may be carbonated or sulphureted. A German classification divides the waters into I, alkaline; II, Glauber salt; III, iron; IV, common salt; V, Epsom salt; VI, sulphur; VII, earthy and calcareous; VIII, indifferent. Class IV is divided into 1, simple; 2, concentrated; 3, with bromine and iodine. This subdivision corresponds to the proportion of sodium chloride contained in the water, and with Class VII can be just as well expressed by arranging the waters according to the amount of salt contained, beginning with the weakest or with the strongest.

A classification, as already indicated, may be either geographic, geologic, therapeutic, or chemical. The first two, however, in view of the uses to which mineral waters are put, are of little practical value. A therapeutic classification would be most desirable, but the conditions at present, in this country especially, are such as to render it impossible. A chemical classification naturally precedes one based upon the application of the waters to the treatment of disease, even if we were not reduced by the necessities of the case to a scheme based mainly upon the predominance of one or more of the ingredients of the water. Minor constituents must be ignored to a certain extent, but the chemical composition can be relied upon with a reasonable degree of certainty for the therapeutic indications, as certain well defined effects, resulting from the probable combinations of the elements found, may be looked for. It is the more reliable from the fact that we have the results of the experience of those who have made a study of the well known European mineral waters and can compare our analyses with theirs, confidently expecting the same results from similar waters.

The scheme of classification briefly outlined below[1] is applicable not only to our own mineral waters, but to all, no matter from what part of the world they may come. Any truly scientific scheme ought to be broad enough to include any mineral water that may hereafter be analyzed.

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[1] This scheme is described by the writer in detail in the Transactions of the American Climatological Association, May, 1887, pp. 156-166.

The following is the

SCHEME OF CLASSIFICATION.

GROUP A. NONTHERMAL.

GROUP B. THERMAL.

- Class I, Alkaline.
- Class II, Alkaline-saline
  - 1. Sulphated.
  - 2. Muriated.
- Class III, Saline
  - 1. Sulphated.
  - 2. Muriated.
- Class IV, Acid
  - 1. Sulphated.
  - 2. Muriated.
  - 3. Siliceous
    - Sulphated.
    - Muriated.

Any spring belonging to one of the above classes in any of its subdivisions may be characterized by the absence of all gases (that is, may be nongaseous) or, by the presence of carbonic acid gas, sulphureted hydrogen, etc., when it is designated by one of the following terms, viz:

1. Nongaseous (free from gases).
2. Carbonated (containing carbonic acid gas).
3. Sulphureted (containing hydrogen sulphide).
4. Azotized (having nitrogen gas).
5. Carbureted (having carbureted hydrogen).

There may be a combination of gases, which is indicated by the combination of the terms, as sulphocarbonated, etc.

The classes may be further subdivided according to the predominant solid constituent as follows:

1. Sodic. 2. Lithic. 3. Potassic. 4. Calcic.
5. Magnesic. 6. Chălybeate. 7. Aluminous.

Here also there may be a combination which can be indicated by a combination of the terms, as calcic-magnesic, etc.

A few words of explanation may be necessary as to the classes outlined above.

The alkaline waters (Class I) include all those which are characterized by the presence of the alkaline carbonates, as the carbonates of the alkalis, the alkaline earths, alkaline metals, and even of iron alone, although the latter is usually associated with other carbonates. Generally these waters are characterized by the presence of free carbonic acid—the acidulous springs of some classifications—and would therefore be additionally designated as carbonated. There are carbonated acid sulphated springs (i. e., springs with free carbonic acid, free sulphuric acid, and sulphates) and to call them acidulous acid springs would be awkward to say the least. Nearly one half of the alkaline springs of the United States are calcic-alkaline—that is, with calcium carbonate or bicarbonate as the predominant ingredient.

The saline waters (Class III) include those in which sulphates or chlorides predominate. They are probably one-third more numerous in the United States than are alkaline waters. Almost all of the springs usually classified as purgative or aperient saline would fall under the head of sulphated salines. Thus a sodic-sulphated water and a magnesic sulphated water could hardly be mistaken for anything else than purgative waters. Under the head of muriated salines all the brines would fall, as they are characterized by the presence of sodium chloride. Any of the salines may be sodic-sulphated, or sodic-muriated, or calcic-sulphated, calcic-muriated, etc. The sodic-muriated springs constitute 88 per cent of the muriated saline waters of the United States.

The alkaline-saline waters (Class II) include all in which there is a combination of alkaline carbonates with the sulphates or chlorides, and they are divided just as the saline waters are, and may be still further subdivided in the same way into calcic, chalybeate, magnesic, etc., and are characterized still further, as are the other classes, by the absence or presence of gases. They are about one-third as numerous in the United States as the saline waters.

The acid class (IV) takes in all the waters that contain free acid, whether it be silicic acid, sulphuric acid, or hydrochloric acid. The sulphated acid springs contain free sulphuric acid and also sulphates of various salts. The muriated acid springs have free hydrochloric acid as their predominant constituent, with various chlorides; and the siliceous acid springs are characterized by the presence of silicic acid in great quantity, and are still further divided into sulphated and muriated, according to the presence of the snlphates or of the chlorides in addition to the silicic acid.

To illustrate the applicability of the scheme three cases will suffice.

The High Rock spring and most of the other springs at Saratoga would be described as carbonated sodic-muriated alkaline-saline springs, i. e., the water contains free carbonic acid gas, its predominant solid constituent is sodium chloride, but it also contains alkaline carbonates. It belongs to Group A, as no temperature is given, it being a cold spring.

The water of the Gilroy hot springs of California would be described as a hot sulpho-carbonated sodic-muriated saline water, i. e., it contains both free carbonic acid gas and sulphureted hydrogen, and its principal solid constituent is sodium chloride. It belongs to Group B, as it is a hot water.

A third example is the Hot Springs of Virginia. The water of the Boiler springs, one of its many springs, may be described as a hot carbonated calcic-alkaline water, i. e., it contains free carbonic acid gas, the principal solid ingredient is calcium carbonate, and it belongs to Group B (thermal waters).

The designation of a mineral water according to this scheme enables any one, be he physician or layman, at once to get a definite idea of its general chemical composition and to obtain a clew to its probable therapeutic effect, and qualifies him to pick it out as a water probably suitable for certain cases, after which a more careful study of its analyses will enable him to determine whether or not it meets all the requirements for the individual and particular case.

THERMAL SPRINGS.

A few words may be added upon the subject of thermal springs, as we have divided mineral springs into two groups according to their temperature. Strictly considered, all springs whose mean annual temperature (no matter in how small a degree) is above that of the mean annual temperature of their localities is a thermal spring. There is a variation, therefore, according to their geographical position. Thus, springs in Alaska or Siberia, where the ground is constantly frozen to the depth of several hundred feet, which have a temperature between 32° and 42° F. and never freeze, are warm springs, while the same springs in the East or West Indies or under the equator would be cold springs. For practical purposes we must draw an arbitrary line, and it has been found most convenient to consider all springs with temperatures above 70° F. as thermal springs; those whose waters have temperatures between 70° and 98° F. are called tepid or warm; and all over the latter temperature are designated as hot. All the thermal waters (Group B of the classification) are subdivided, as are all the nonthermal waters (Group A). They may be carbonated, sulphureted, etc., or alkaline, saline, alkaline-saline, etc. It has generally been supposed that they are less highly mineralized than nonthermal waters. A priori, hot water is a better solvent than cold water, and if sometimes a thermal water is less highly mineralized, it is probably because it comes from a greater depth, where the rocks are of such a character as to be less readily acted upon. Other things being equal, there is no reason why a thermal water should not contain the same ingredients that a nonthermal water has. The fact that a spring is thermal is dependent largely upon its geological position, as already indicated. The rocks in which they originate are usually not so readily disintegrated, as are the more soluble sedimentaries. Where the two groups of springs occur in the same geological position we find little, if any, difference in regard to the quantity of solid contents that is to be seen. At the Hot Springs of Virginia one of the springs, with a temperature of 78° F., has 18·09 grains per gallon of solid contents, while another, with a temperature of 110° F., has 33·36 grains per gallon. At the Bath Alum springs, in the same region, with a temperature of 60° F., the total solid contents are found to be 45·44 grains per gallon (Spring No. 1), which does not differ materially from the results noted at the Hot Springs. At the California geysers the coldest spring, with a temperature of 70° F., has 7·12 grains per gallon, while the hottest, at 212° F., contains 296·4 grains per gallon.

As stated under the head of "geological position" (pages 62–64), the cause of the heat of thermal springs is to be found in their proximity to, or their source in rocks of volcanic or igneous origin; in their occurrence in areas of mountain corrugation or of profound dislocations; or, if they come from great depths, in the normal downward increase of the temperature of the globe. Chemical action as a source of heat plays little, if any, part as a cause. The downward increase of heat is not the same at all places, and one can not tell, with any certainty, the depth of the spring from its temperature. The question of the permanency of the heat is an interesting one. Usually it is very persistent, especially where it is due to the temperature of the earth itself. In regions where there are active volcanic manifestations and earthquakes, fluctuations of temperature in springs have been very common. Prof. Forbes, in his study of the hot springs of the Pyrenees in 1835, compared his observations with those taken nearly one hundred years previously, and in many cases found a remarkable uniformity in the temperatures taken at different times throughout the period. In the case of our own springs, the data are insufficient for the making of careful comparisons in respect to changes of temperature. In one case, however, viz, the hot springs of Salt Lake City, a considerable variation in temperature has been noted. Ordinarily these springs have a temperature of 122° F., but in 1889, for one month, June to July, and at irregular intervals in preceding years, the springs became as cold as 50° F.

A comparison of the temperatures of the hot springs of Virginia, North Carolina, and Arkansas, taken recently, with those taken years ago, shows little change, most of the differences noted being due probably to variation in the thermometers, so that the comparative observations have little value.

CHEMICAL COMPOSITION AND ANALYSES.

The fact that we are narrowed down to the chemical composition of mineral waters as a basis for their classification makes it very important that the analyses, if not made by the same chemist in all cases, should be made upon some one definite method and be stated with some degree of uniformity. As a matter of fact, the analyses of mineral waters have been made upon almost as many plans as there have been chemists making the analyses. An inspection of about a thousand analyses of mineral waters of the United States shows that at least forty-two methods of stating the results have been employed. They range from parts per hundred to parts per million; from grains per cubic inch to grains per pint; and from grains per pint of various kinds through grains per quart to grains per gallon. Two or three scales were frequently found in the same table. Some gave only the elements actually found, and others only the probable combinations. Under such circumstances, a comparison of the different analyses is obviously impossible.

Bergman, the Swedish chemist, was the first to outline a systematic scheme of water analyses in a paper published about 1788. He began with the examination of the physical qualities, and distinguished the matters held in solution from those mechanically suspended. He also succeeded in manufacturing artificial mineral waters by combining elements similar to those found in well known mineral springs. Dr. John Murray, in 1816, still further systematized the plan for water analyses, and published a general formula for the analysis of mineral waters. He took the ground that the salts existing in the water need not be exactly the same as those obtained upon its evaporation, recognizing the fact that salts deemed incompatible may coexist in a state of weak solution, and though he combined the acids and bases determined, according to their solubility, into what he supposed was their most probable combination in the water, he held that the analysis consisted in the determination of the several acids and bases. Berzelius contended that, everything beyond the mere statement of the acids and bases being matters of hypothesis, nothing should be set down but their respective weights. This alone, however, is not sufficient, for while it might satisfy the chemist or the geologist, it would not be enough for those who are mainly concerned in the use of the water, viz, medical men. They wish the analyses to be so stated that the probable effect upon the human system may be determined, and therefore it is necessary for a clear comprehension of these points that the probable composition be also given. If at the same time the elements actually found are also given there can be no cause for complaint from anyone. It is, of course, impossible to ascertain the exact arrangement of the elements found upon analysis. In a solution of sodium chloride and potassium sulphate, both sodium sulphate and potassium chloride will be found in addition to the two original salts; and when in addition other substances by their presence render the conditions more complex, the impossibility of determining the exact arrangements of the elements in the water is very apparent. Other things being equal, however, it is probable that the strongest acid will always unite with the strongest base, and to obtain an idea of the medicinal value of the water, even if only approximate, it is desirable to state the probable combination. From these statements it can readily be seen how vastly more valuable the results of our mineral water analyses would be if this combining of the elements into their probable combinations were in all cases made upon a uniform plan.

Although nearly all of the modern works upon chemistry and chemical analysis present schemes of water analysis and give usually very complete instructions, very little is said as to the method of stating the results. Henry Noad, in his Manual of Chemical Analysis, advises that the electro-negative and electro-positive ingredients be arranged as established by direct experiment into binary combinations in the ratio of their mutual affinities, the strongest acid being combined with the strongest base, attention being paid to the fact that the force of affinity is considerably modified by the degree of solubility of the salts. He also says that the direct results should be given, and the total amount of the final constituents must agree with the joint amounts of the several ingredients. Such examples as he gives are expressed in grains to the imperial gallon. Nearly all of the forms in which analyses are expressed can be reduced to one or another of the following methods of expression:

(1) In grains per English or imperial gallon (277 cubic inches or 10 pounds, 70,000 grains of pure water).

(2) In grains to the United States or wine gallon (231 cubic inches, 58,372 grains of pure water).

(3) On a decimal basis as parts per 100, 1,000, 1,000,000, etc. This is usually the form adopted in Germany and France, also in the reports of the Rivers Pollution Committee of Great Britain, and in the United States by the National Board of Health, and by many State boards of health.

(4) As so many milligrams to the liter, which would be the same as parts per 1,000,000 if the liter always weighed exactly 1,000 grams.

The variation of the specific gravity in the case of ordinary potable waters would be of little account, but in the case of most mineral waters, especially of those that are highly mineralized, the difference between parts per million and milligram per liter is too great to be disregarded, and precludes in the same analysis the use or combination of measure by weight and measure by volume if the analyses are to be exact and mutually comparable. The following recommendations were made by a committee of the Chemical Society of Washington in February, 1886.

(1) That water analyses be uniformly reported in parts per million or milligrams per kilogram, with the temperature stated, and that Clark's scale and all other systems be abandoned.

(2) That all analyses should be stated in terms of the radicals found, whether elementary or compound.

(3) The constituent radicals should be arranged in electro-chemical series, the positive radicals first.

(4) The combinations deemed most probable by the chemist making the analyses should be stated both by symbol and by name.

By "terms of the radical found" is to be understood the immediate results of the actual analysis, so that any one examining the analytical results will have the same facts as the chemist making the analysis. Thus, if ammonia is found it should be stated as ammonia (NH_4), if nitrogen (N) alone it should be so stated. The use of symbols was

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[1] Bulletin No. 2 of the Chemical Society of Washington, 1887, p. 44. Report of committee (A. C Peale, W. H. Seaman, C. H. White) on method of stating water analyses.

recommended to do away with any obscurity as to the compounds, as, for instance, in the case of the salts of iron.

It is generally supposed that the statement "grains per gallon" presents to nonprofessional people a more definite idea than parts per million. Yet investigation will show that outside of chemists and pharmacists the idea as to what a grain of any particular substance means is very vague. A gallon of water also varies according to temperature, and besides, grains per gallon are incommensurable quantities, whereas parts per million, per hundred, or per thousand can be readily understood by anyone.

It is frequently desirable to convert an analysis from one form to another, and a few words on this subject may not be out of place here.

As the weight of the same volume of water differs according to its density and its temperature, the value of a gallon, even if it is a wine gallon, is somewhat indefinite unless these factors are stated. The following table compiled from Oldberg will show how this varies:

Apparent weight of water at different temperatures.[1]

	Temperature of air = 62° F.; temperature of water = 39·2° F.; 1 cubic inch = 252·761 grains.		Temperature of air = 62° F.; temperature of water = 59° F.; 1 cubic inch = 252·554 grains.		Temperature of air = 62° F.; temperature of water = 62° F.; 1 cubic inch = 252·48843 grains.		Temperature of air=71·6° F.; temperature of water = 71·6° F.	
	Grams.	*Grains.*	*Grams.*	*Grains.*	*Grams.*	*Grains.*	*Grams.*	*Grains.*
One liter..........	999·512	15, 424·831	998·695	15, 412·215	998·435	15, 408·204	997·5	15, 393
One United States or wine gallon....	3, 783·466	58, 387·855	3, 780·371	58, 340·011	3, 779·387	58, 324·827	3, 776	58, 270
One imperial or English gallon....	4, 540·820	70, 075·500	4, 537·199	70, 018·111	4, 535·926	70, 000	4, 532	69, 934

[1] From Oldberg's Manual of Weights, Measures, and Specific Gravity, etc., Chicago, 1885, pp. 167–171.

Oldberg recommends the temperature of 71·6° F. as the best for all practical purposes in pharmacy, as it is probably the most common room temperature.

According to the Century Dictionary the United States gallon contains 231 cubic inches, and is equal to a cylinder 7 inches in diameter and 6 inches high, and is taken at the value of 8·3389 pounds avoirdupois of water at its greatest density weighed in air at a pressure of the barometer of 30 inches, and a temperature of 62° F. It is equal to 3·7853 liters. Prof. Paul Schweitzer of the Missouri state geological survey, using this statement in connection with the values published by the Office of Standard Weights and Measures (T. C. Mendenhall, superintendent, Washington, D. C., 1890), makes the following statement: "In view of the differences in the weight of the same volume of water, each one of which seems to rest upon an equally secure basis, and in further view of the fact that the liter flask, as made and sold by dealers in chemical apparatus, is intended to discharge 1 kilogram of water at 15·5° C., the value commonly employed in such calculations, viz, 3·785 liters to the gallon and 15·432 grains to the gram, are employed; they make 1 gram per liter equal to 58·410120 grains per gallon, the value adopted."

He gives the following table for the reduction of grains in the liter to grains United States gallon:

Grains per liter.	Grains per United States gallon.
1	58·41
2	116·82
3	175 23
4	233·64
5	292·05
6	350·46
7	408·87
8	467·28
9	525·69

The following conversion table is given by Leffmann & Beam in their book on the examination of water for sanitary and technical purposes, Philadelphia, 1889:

Parts per 100,000 ×0·7=grains per imperial gallon.
Parts per 1,000,000 ×0·07=grains per imperial gallon.
Parts per 10,000 ×0·583=grains per United States gallon.
Parts per 1,000,000 ×0·058=grains per United States gallon.
Parts per 1,000,000 ×0·00833=number of pounds per 1,000 United States gallons.
Grain per imperial gallon, 0·7=parts per 100,000.
Grain per imperial gallon, 0·07=parts per 1,000,000.
Grains per United States gallon, 0·583=parts per 100,000.
Grains per United States gallon, 0·058=parts per 1,000,000.

GEOGRAPHICAL DISTRIBUTION.

The geographical distribution of the mineral springs of the United States (see Pls. III and IV) is of course connected with the consideration of their geological position, and as already indicated, a map of the thermal or hot springs shows that they are most numerous in the western part of the country. A map upon which all the mineral springs were indicated would show that no state or territory in the Union is without some spring that is utilized either for commercial purposes or as a place of summer resort or a sanitarium. A map (see Pl. IV) upon which only the springs whose waters are used commercially are platted at once shows that the majority of such springs are found in the eastern United States and in the Mississippi valley. West of the one hundred and first meridian they are largely confined to the Pacific coast. In Idaho, Colorado, New Mexico, and Montana we find altogether barely a dozen springs so used. This is not because the total number of springs in the east is so much greater than in the west, but is mainly because the former is the seat of the greatest population and consequently it is more thoroughly developed as to the utilization of its resources in the matter of mineral waters. A map of the mineral spring resorts (see Pl. III) presents a much larger total number of springs and a more equitable distribution over the country, for many of our most improved and best known resorts are now found in the middle west, and in the Rocky mountain region. They in no respect suffer in comparison with those in the east or with those on the Pacific coast.

There are in some sections of the country waters commonly used for drinking purposes which if located elsewhere might be considered mineral waters. This is because all of the waters of those sections are mineralized, as in certain alkali regions of the west, and the people gradually become habituated to their use.

So far as the general geological features of the North Atlantic States are concerned they might be divided into the sections so long recognized in our older school geographies, viz, the New England and the Middle States. In the former the older rocks form a large part of the surface, which accounts for the fact that, as a rule, the mineral springs of that section are somewhat less highly mineralized than are those of the Middle States. No thermal springs occur in the section. The springs of Maine are slightly alkaline-saline and chalybeate. A few are carbonated and some are sulphureted. They range in temperature from 40° to 46° F. The solid contents range usually from 3 to 31 grains per gallon, the Lubec Saline spring being the only exception, the solid contents of its water reaching the total of 322 grains. In New Hampshire, chalybeate waters are the most common, and in respect to their total amount of solids they range from 2 to 15 grains per gallon. In Vermont also the conditions are much the same, except that sulphureted springs are more numerous. Massachusetts is not remarkable for its mineral springs. Chalybeate waters are common throughout the State, occurring in nearly every town. A mineral spring near Williamstown, in the northwest portion of the State, is said to be very slightly thermal, but it is hardly a warm spring. Very much the same statements may be made for Connecticut and Rhode Island as for Massachusetts. Many of the mineral springs of the New England States are utilized both for commercial purposes and for places of resort. In the Middle States we find a much larger number of mineral waters that are utilized, and the total number of springs is also greater. New York stands at the head of the section in regard to the total number of springs, and has more commercially used waters than any other State in the Union. There is also a very large production of salt from the salt springs of New York, in what are known as the Onondaga and Warsaw districts. New York has also one of the most celebrated acid springs in the country in the Oak Orchard spring, which contains free sulphuric acid. The Lebanon Thermal spring, with a temperature of 75° F., is the one spring of the group in this State, and Pennsylvania possesses, in the Perry County Warm spring, a very slightly thermal spring which has a temperature of 66° to 70° F. Bedford Springs is one of the oldest resorts in the latter State. Chalybeate springs outnumber all others in Pennsylvania, New York, and New Jersey. In the latter, the Schooley mountain spring is the best known resort.

In their general geologic features the South Atlantic States are not unlike the Middle States, and naturally the springs are of the same general character. Thermal springs are, however, more numerous. Delaware has never had but one spring resort—the Brandywine Chalybeate spring—and this is now practically abandoned. Maryland has a fair number of resorts and several well known commercial waters; but Virginia is par excellence a mineral spring State, occupying among South Atlantic States the same position that New York does in the North Atlantic section, being second only to that State in the number of springs that are utilized commercially, and exceeding it in the number of resorts. The Hot Springs of Virginia are among the most celebrated in the country. The literature relating to the mineral springs of Virginia is very extensive. West Virginia is equally noted for its springs, having two of the oldest resorts in the United States in Berkeley springs, at Bath, and the Greenbrier White Sulphur springs. The general character of the springs in Virginia and West Virginia is the same, saline sulphureted waters being most numerous, although alkaline, chalybeate, and acid springs are found, both hot and cold. North Carolina also enjoys the distinction of possessing hot springs. In most respects the springs are not unlike those of the Virginias. Georgia, in the Warm Springs of Meriwether county, has an important thermal spring, and the State ranks with North Carolina and Virginia as a mineral spring State. Florida is remarkable, as already noted, for the great size of its springs, the flow from some of them being sufficient to float steamboats of considerable size. These springs are generally deep seated in their origin and are all slightly thermal and mostly sulphureted.

In the Southern Central States the saline springs outnumber all others, and the thermal springs are relatively few. A large part of the area is occupied by comparatively recent formations. Yet in the northern and western portions of the section, Carboniferous rocks with the underlying formations are well developed, and they are usually prolific of mineral spings. Tennessee, Kentucky, Arkansas, and Texas are the important mineral spring States of the section. The Hot Springs of Arkansas occupy a first place among the thermal waters, not only of that State but of the entire country. The springs of Kentucky and Tennessee have had considerable attention paid to them by geologists and chemists, and they have many well known resorts. Texas is noted for its springs, among which are a number of acid springs containing free sulphuric acid. In the western part of the State there are also many hot springs. In Alabama, Mississippi, Louisiana, and Indian territory there are a great many mineral springs, but they apparently have had little attention paid to them and we find that fewer of them have been improved than in the other States of the section.

The broad areas of Carboniferous rocks with underlying Devonian and Silurian strata that enter so largely into the surface formation of the Northern Central States, especially in the more southern portions, would lead us to expect in this section a development of mineral springs similar in general character to those of the Southern Central States, and this we find to be the case. Calcic springs are naturally numerous, while thermal springs are inconspicuous, most waters of this group being derived from artesian borings. In Ohio, calcic waters are especially abundant. In the belt of black Devonian shale that traverses the State from the Ohio valley to Lake Erie, nearly all the springs issuing from the base of the formation carry iron and are sulphureted. Out of the hundreds of springs that actually exist, only a few are utilized for medicinal purposes. In other parts of the State the waters come from the drift and underlying beds of bog iron ore, and they are therefore strongly chalybeate. The brine springs of Ohio have not been included in the list of mineral waters, as they are the source of one of the most important industries of the State, and have been considered from an economic standpoint elsewhere very fully. The Pomeroy or Ohio valley district is the most important in this respect, its salt wells being the most prominent in the State. The brines carry a small amount of sulphates and considerable iron, and, like all the Ohio brines, are rich in bromides.

The conditions in Indiana are similar to those of Ohio, and consequently the springs are much the same. Sulphureted and chalybeate springs predominate. The brines of Indiana are not so numerous as those of Ohio, and the production of salt is of comparatively little account. A fair number of the springs are utilized commercially, and in the total number of springs and the number of resorts the State ranks next to Missouri, which is first on the list for this section.

Illinois differs little from neighboring States, the same classes of springs being found within its borders that are seen in Indiana and Missouri.

Missouri is a State rich in mineral springs, and they are of great value in its economic resources. Nearly every county possesses mineral springs of wide local reputation, and many are well known beyond the State limits. The production of salt from salt wells was at one time a considerable industry. The Sweet Springs, of Saline county, are perhaps the best known, but there are many other well known health resorts, and the State holds average rank as a producer of commercial mineral waters. The springs are mainly saline and chalybeate, and many are slightly sulphureted.

Kansas derives a considerable portion of its mineral waters from ordinary wells and artesian borings. The waters are mostly saline, and are generally sulphureted. Chalybeate waters are abundant in certain sections of the State. *In the eastern part sulphates of lime and* magnesia are found in the hard waters of shallow wells, and as deeper strata are penetrated, the sulphates decrease in amount and the chlorides increase. Nebraska is slightly developed so far as its mineral springs are concerned. Its known mineral waters, however, do not differ materially from those of Kansas.

Returning to the eastern part of the section, we find that Michigan derives its mineral waters largely from artesian wells, which are locally called mineral springs. These borings are mainly in the Corniferous limestone and the Huron group of the Devonian. The waters are well mineralized, and are popularly supposed to be magnetic. Sulphureted saline waters predominate. The brines of the State are very important, the salt industry dependent upon the salt wells being of large proportions.

In the northern part of the northern central section, where there are very considerable areas of metamorphic rocks, the springs are somewhat like those of the New England States in general character, especially in not being so highly mineralized as those of the States lying to the south of them.

The mineral springs of Wisconsin are particularly valuable, and the springs of Waukesha have a wide reputation. In the production of mineral waters for commercial purposes the State outranks all the others, as it does also in the value of the production. In the number of springs so used it is third upon the list. The springs are mainly calcic, alkaline, and chalybeate.

Minnesota and Iowa contain numerous springs whose waters are much like those of Wisconsin in respect to the comparatively small quantity of contained solids, and in their general character. The occurrence in Iowa of acid springs is interesting. So far as known, Minnesota has few mineral spring resorts. Iowa has several resorts and a number of its waters are bottled for sale.

In the Dakotas the recent development of these new States has resulted in little attention being paid to their mineral spring resources. In South Dakota many wells are known to be highly mineralized, and near the Black Hills we have in the Dakota hot springs the one thermal spring locality of the section.

In a general survey of the Western States the first thing to attract attention is the inequality in the development of the mineral spring resources. Another noticeable point is the far greater prevalence of thermal springs. Very naturally we find that California has made the greatest advance in mineral spring development. This is due to the fact that it has been longer settled, and has more time to devote to the mineral springs of which it has so large a number. Other States are beginning to appreciate the importance of a careful study of their mineral springs, and we find more and more attention being paid to them from year to year. The Western States (i. e., those west of the one hundred and first meridian) include a little more than 39 per cent of the total area of the country, and yet we find that they contain more than 80 per cent of its known thermal springs. This great preponderance is likely to be increased in the future. It cause has been stated and described under the head of thermal springs. When we consider the number of individual springs contained within the limits of the Western States, the contrast with the Eastern sections is even more striking; not only is the number greatly in excess in the former, but the thermal phenomena are overwhelmingly greater in intensity. The Yellowstone National Park is the seat of thermal manifestations not equaled in any other part of the country, and in fact not excelled in any part of the world.

The proportion of improved springs in the Western States is, however, necessarily less than in other sections on account of the comparatively recent settlement of most of the country in and beyond the Rocky mountains.

California, as we have said, stands at the head of this section so far as the improvement of the springs is concerned, both in respect to the number of resorts and of its commercially used waters. Its mineral waters are of all classes and they are not confined to any one section of the state, but are found from one end to the other. With the exception of Wyoming, which includes the Yellowstone National Park, California contains a greater number of mineral springs than does any other State.

Of the Pacific coast States Oregon comes next to California in the number of its mineral spring resorts. The waters of several of these are bottled and sold.

The State of Washington, in its Medical lake, presents one of the best known mineral waters of the West. This water is condensed and bottled, and the evaporated salts, put up in packages, are extensively sold. Nevada is probably better off in respect to springs than in regard to streams of running water. Hot and cold mineral springs are found in every county, the former outnumbering the latter. Steamboat spring is probably the best known locality. Salt springs, soda springs and lakes, and borax lakes abound, and the ordinary potable waters in many parts of the State are strongly alkaline. In Arizona and New Mexico alkaline and saline waters, many of them carbonated and sulphureted, are so numerous that they attract but little attention. Frequently they are more common than pure waters. Many of the springs are thermal, and many were utilized by the Franciscan and Dominican friars when they first traversed the country, and also by the Indians long prior to the advent of Europeans. Saline springs are most abundant in Arizona, while both alkaline and saline springs are numerous in New Mexico. Several springs in New Mexico are utilized for commercial purposes, and Las Vegas Springs is one of the finest mineral spring resorts in the country.

Colorado, sometimes called the Switzerland of America, has had considerable attention devoted to its springs, and there are now within the limits of the State many well known resorts, of which perhaps Manitou, near Colorado Springs, is most widely known. A number of waters are also used commercially. Hot and cold springs are both found; many are alkaline, others chalybeate, and saline springs are numerous. They are sulphureted and carbonated in many cases.

In Utah the presence of mineral springs, both hot and cold, was noted by all the early explorers and travelers who were obliged to cross the territory on their way to the Pacific. The hot springs near Ogden and those at Salt Lake City are the best known and most used. They are thermal, as are most of the mineral springs of the territory. Salt lake itself is one of the most highly mineralized bodies of water in the world.

The mineral springs of Idaho have secured very little attention, but it is well known that warm and hot springs are of frequent occurrence, especially in the granitic and igneous rocks of the mountainous portions of the State. "Hailey's hot springs" and the "Soda springs" of Bear river are the best known localities. The latter were first described by Fremont, who called them the Beer springs, and from one of the cold springs of this now well known resort is drawn the Idanha mineral water, which is extensively sold throughout the west.

Wyoming, with the immense number of springs in the Yellowstone National Park, easily stands at the head of the list for the entire country when we consider the total number of springs, as there are more than two thousand individual springs within the limits of the Park alone. The Yellowstone Park is, of course, the greatest spring resort in the country, and it is deservedly so, not only from the presence of its geysers but also on account of the great variety in its springs, which will one day undoubtedly be more highly prized for their medicinal virtues than they are now.

The proximity of Montana to the National Park is the principal reason why its numerous and important mineral springs have not received the attention and development that they undoubtedly deserve. Many of them have been known since the days of Lewis and Clarke's famous expedition across the mountains of Montana from the head of the Missouri river to the Pacific. Most of the springs in the State are thermal, and a number of them have been improved and are used to a considerable extent as resorts. The White Sulphur springs, Hunter's hot springs and Ferris's hot springs are well known locally, while the Broadwater hot springs near Helena are scarcely excelled anywhere, especially in respect to their improvements. The plunge bath there connected with one of the hotels, is one of the largest in the world. The springs of Montana present a great variety in their composition, and the water of one of the cold springs in the valley of the Yellowstone is almost identical with the celebrated Apollinaris water from Prussia.

Last of all, in Alaska we have a hot spring territory that has few equals. Little is known as to the mineral contents of the springs, but their number is very large and they are often found in contact with glaciers. So far as a cursory examination goes the springs are mainly saline and most of them are sulphureted. There are many cold springs that never freeze and that are therefore in a strict sense thermal. The geysers or warm springs near Sitka, having a temperature of 153½° F., were used as the site of a hospital by the Russian authorities before our purchase of the country. Many of the hot springs have been used by the Aleuts from time immemorial for cooking purposes, while others are used as bathing places. Our knowledge of the Alaskan springs is due to scattered notes of travelers and explorers who usually have not the means of making careful scientific examinations, and we have no analysis of any of the waters.

The following table gives the rank of the States according to commercial statistics of 1892.

Rank of States according to commercial statistics.

	Rank according to springs used commercially.	Rank according to number of gallons produced.	Rank according to value of production.		Rank according to springs used commercially.	Rank according to number of gallons produced.	Rank according to value of production.
Alabama	12	36	23	Montana	15	35	28
Arkansas	11	32	31	Nebraska	15	38	39
California	4	15	10	New Hampshire	13	7	3
Colorado	8	11	9	New Jersey	15	37	38
Connecticut	11	34	24	New Mexico	12	29	34
Georgia	13	23	18	New York	1	2	2
Idaho	15	19	14	North Carolina	6	17	15
Illinois	8	18	20	Ohio	7	6	6
Indiana	7	22	33	Pennsylvania	6	5	4
Iowa	11	25	26	Rhode Island	14	16	32
Kansas	9	3	8	South Carolina	13	30	35
Kentucky	11	31	36	South Dakota	15	26	30
Louisiana	15	39	37	Tennessee	10	21	22
Maine	10	9	13	Texas	5	14	21
Maryland	11	27	25	Vermont	12	24	19
Massachusetts	8	8	12	Virginia	2	10	7
Michigan	8	4	5	Washington	13	20	11
Minnesota	15	12	27	West Virginia	10	33	29
Mississippi	12	13	17	Wisconsin	3	1	1
Missouri	7	28	16				

THE UTILIZATION OF MINERAL WATERS.

The principal use to which mineral waters are put is of course their application in the treatment of disease, and in this respect the mineral waters of the United States are no exception. The mineral spring circulars issued for the purposes of advertisement abundantly prove the statement. In many States salt springs are used as the source of common salt and thus add largely to the economic resources of their localities. Mineral waters are also utilized for the manufacture of borax, bromine, and carbonate of magnesia, and the waters of certain Western lakes are the sources of large quantities of soda. The mere mention of these facts is sufficient in this place. Returning to their primary use, that is, as remedial agents, the waters are utilized, first, at the springs both for drinking and bathing purposes and, secondly, they are bottled or otherwise put up for sale and thus rendered available in the market at a distance from their source.

The discussion of the therapeutic application of mineral waters does not come within the scope of the present article. It is a medical question and lies without the province of the geologist or economist. The mineral-spring resorts of the country have never been very thoroughly studied from a statistical point of view, although there is scarcely a state in the Union that has not its mineral spring resorts, even if only locally important, or its sanitaria erected usually in connection with mineral springs. Many springs are utilized both as resorts and as sources of water for commercial purposes.

LIST OF AMERICAN MINERAL SPRING RESORTS.

ALABAMA.

Bailey springs.
Bladen springs.
Blount mineral springs.
Butler springs.
Chandler's springs.
Cullom's springs.
Healing springs.

ARIZONA.

Castle Creek springs.
Hooker's hot springs.

ARKANSAS.

Hot springs.
Cluster springs.
Eureka springs.
Dove Park springs.
Fairchild's potash sulphur springs.
Mountain Valley springs.

CALIFORNIA.

Adams springs.
Ætna springs.
Aguade Vida springs.
Alum rock springs, near San Jose.
Anderson mineral springs.
Byron hot springs.
California seltzer springs.
Campbell's hot springs.
Coronado mineral springs.
El Paso de Robles springs
Felts mineral spring.
Fulton wells.
California geysers.
Geyser spa spring.
Litton seltzer spring.
Gilmore Glen spring.
Gilroy hot springs.
Glen alpine springs.
Gordon's mineral springs.
Harbin springs.
Highland springs.
Howard springs.
Klamath hot springs.
Lane's mineral spring.
Carnelian hot springs.
Madrone mineral springs.
Mark West springs.
Matilija hot springs.
Monticeto hot springs
Napa soda springs.
Newsome's Arroyo Grande springs.
Paraisa spring.
Pacific congress springs.
Piedmont white sulphur springs.
Rubicon soda springs.
San Bernardino hot springs.
Santa Barbara hot springs
Santa Rosa springs.
Santa Ysabel springs.
Seigler's springs.
Skaggs' hot springs.
Summit soda springs.
Tuscan springs.
Tolenas springs.
Upper soda springs.
Ukiah vichy springs.
Upper soda springs, Siskiyou County.
Saint Helena white sulphur springs.
Witters' springs.
Wilbur springs.

COLORADO.

Douglas springs.
Canyon City springs.
Siloam springs.
Idaho springs.
Poncho springs.
Ouray mineral springs.
Manitou springs.
Liberty hot springs.
Rock Creek springs.
Trimble springs.
Steamboat springs.
Glenwood springs.
Pagosa springs.
Seltzer mineral springs.
Hot springs of Middle Park.
Cottonwood springs.
Heywood springs.
Mineral springs of Pueblo.

CONNECTICUT.

Stafford mineral springs.
Oxford chalybeate spring.

FLORIDA.

Magnolia springs.
Turner springs.
Orange springs.
Tarpon springs.
Benson's salt springs.
Wakulla spring.
Green Cove springs.
Blue springs.
Newport sulphur springs.
Wesson's iron springs.
Suwannee sulphur springs.
White sulphur springs.

GEORGIA.

Beall's springs.
Daniels' mineral spring.
Franklin springs.
Bowden lithia springs.
Chalybeate springs.
New Holland springs.
White sulphur springs.
Watson's springs.
Porter's springs.
Catoosa springs.
Hughes mineral springs.
Indian springs.
Magnolia springs.
Warm springs.
Powder springs.

IDAHO.

Ahlfor's springs.
Elliott's springs.
Easbly springs.
Hailey hot springs.
Guyer hot springs.
Soda springs.

ILLINOIS.

Alcyone springs.
Glen Flora springs.
Silver spring.
Diamond mineral spring.
Green Lawn springs.
Peoria magnetic artesian well.
Kirkwood springs.
Perry springs.
Hygienic western Saratoga springs.
Illinois lithia springs.
Moonlawn springs.
Okawville mineral spring.

INDIANA.

Ash iron springs.
Cameron springs.
French Lick springs.
Hosea saline sulphur springs.
Trinity springs.
Lithium springs.
Avoca springs.
West Baden springs.
Central springs.
Greencastle springs.
Saint Ronan's well.
Spring Beach springs.
Kickapoo magnetic mineral springs.
Cartersburg magnetic springs.

IOWA.

Ottumwa mineral springs.
Cherokee magnetic mineral springs.
Black Hawk mineral springs.
Lake View medical springs.
Linwood springs.
Siloam springs.
White sulphur springs.

KANSAS.

Iola mineral well.
Blaging's artesian mineral springs.
Arlington mineral springs.
Great Spirit springs.
Jewell County lithia springs.
Geuda springs.
Mound Valley springs.
Providence mineral well.
Topeka mineral wells.
Wichita mineral springs.
Louisville springs.

KENTUCKY.

Anita springs.
Allen springs.
Bedford springs.
Blue Lick springs.
Crab Orchard Springs.
Cerulean springs.
Forrest springs.
Drennon springs.
Buena Vista springs.
Hardin springs.
Kentucky alum springs.
Rock Castle springs.
Saint Patrick's well.
White sulphur springs.

LOUISIANA.

De Soto mineral springs.
White sulphur springs.
Abita springs.
Chinchula spring.
Castor sulphur springs.
Ocean springs.
Claiburn spring.

MAINE.

Addison mineral springs.
American chalybeate springs.
Auburn mineral springs.
Barker mill spring.
Cold Bowling spring.
Hartford cold spring
Lake Auburn mineral spring.
Lubec saline spring.
Keystone spring.
Old Point Indian spring.
Poland spring.
Rosicrucian springs.
Seal Rock springs.
Scarborough mineral spring.
Underwood springs.
Wilson springs.

MARYLAND.

Bentleys springs.
Carroll springs.
Chattolanee mineral springs.
Flintstone mineral springs.
River springs.
Spa spring.
Strontia mineral spring.
Takoma park spring.
Windsor sulphur springs.

MASSACHUSETTS.

Allandale springs.
Beckster soda springs
Bethlehem spring.
Belmont Hill springs.
Belmont natural springs.
Commonwealth mineral springs
Echo grove spring.
Everett crystal spring
Sheep rock springs.
Simpson spring.
Undine spring.
Vishnu springs.

MICHIGAN.

Alpena mineral well.
Americanus well.
Cascade spring.
Eastman springs.
Butterworth magnetic spring.
Eaton Rapids magnetic springs.
Bethlehem magnetic mineral springs.
Erie sulphur springs.
Flints magnetic springs.
Grand Haven mineral spring.
Hubbardston magnetic well.
Leslie magnetic well.
Midland magnetic well.
Mount Clemens original mineral spring.
Moorman well, Ypsilanti.
Otsego mineral springs.
Riverside mineral spring.
Salutaris springs.
Sprudel well.
Spring Lake mineral springs.
Shawnee mineral springs.
Saint Clair mineral springs.
Saint Louis magnetic spring.
Zauber Wasser springs.
Ypsilanti mineral springs.

MINNESOTA.

Geissinger springs.
Inglewood spring.

MISSISSIPPI.

Artesian springs.
Belmont spring.
Brown's wells.
Castalian springs.
Godbolds mineral well.
Juka mineral springs.
Lafayette springs.
Stafford mineral springs.
White's springs.
Winston springs.

MISSOURI.

Arkoe springs.
Blankenship medical springs.
Blue Lick springs.
Belcher's artesian well.
Boon's Lick springs.
B. B. springs.
Barnard mineral well.
Clinton artesian white sulphur well.
Denver mineral spring.
Eldorado springs.
Elk Lick springs.
Electric springs.
Excelsior springs.
Fair Haven springs.
Fair View springs.
Forest springs.
Greenwood springs.
Greene springs.
Haupt's mineral well.
Glasgow mineral springs.
Harris springs.
Jordan artesian well.
Indian springs.
Jamesport mineral springs.
Jerico springs.
Lanandreths springs.
Lebanon springs.
Landreth's mineral well.
Monegaw springs.
Montesano springs.
Moundsville mineral springs.
McAllester springs.
Paris springs.
Randolph springs.
Reiger springs.
Reed springs.
Rogers springs.
Spaulding springs.
Siloam springs.
Sweet springs.
Windsor medical spring.
Young's medical well.
Vichy springs.
Panacea springs.

MONTANA.

Alhambra springs.
Allan's mineral springs.
Boulder hot springs.
Ferris' hot springs.
Helena hot springs.
Hunter's hot springs.
Lou Lou hot springs.
Mill Creek Apollinaris spring.
Puller's springs.
Pipestone springs.
Warm springs, Deer Lodge valley.
White sulphur springs.
Ryan's hot springs.

NEBRASKA.

Victoria mineral spring.

NEW HAMPSHIRE.

Amherst soda springs.
Birchdale springs
Bradford mineral spring
Londonderry lithia spring.
Ponemah springs.
Unity springs.
White Mountain spring.
Yacum springs.

NEW JERSEY.

Kolium springs.
Spa spring.
Schooly's Mountain spring.
Warwick spring.

NEW MEXICO.

Hudson hot springs.
Ojo Caliente.
Baca springs.
Jemes hot springs.
Aztec springs.
Coyote soda springs.
Las Vegas springs.

NEW YORK.

Adirondack mineral springs.
Avon sulphur springs.
Ballston Spa springs.
Cairo white sulphur springs.
Cayuga springs.
Crystal springs.
Columbia springs.
Chittenango white sulphur springs.
Clifton springs.
Dansville springs.
Deep rock springs.
Darien mineral spring
Dryden springs.
Doxtater's mineral well.
Excelsior spring and Chlorine spring, Syracuse.
Florida springs.
Franklin springs.
Lebanon thermal spring.
Nunda mineral springs.
Oak Orchard acid springs
Oneita springs.
Richfield springs.
Saratoga springs.
Sharon springs.
Slaterville magnetic springs.
Miller's Geneva mineral spring.
Verona mineral springs.
Victor sulphur springs.
Massena springs.
Ried springs.
Empire Seneca spring.

NORTH CAROLINA.

All-healing springs.
Ashleys bromine and arsenic springs.
Barium springs.
Black Mountain iron and alum spring
Cherokee springs.
Cleveland spring.
Creswell's white sulphur spring.
Ellerbe springs.
Blackwell's white sulphur spring.
Haywood white sulphur springs.
Jackson springs.
Lemon springs.
Lincoln lithia springs.
Millenheimers sulphur springs.
Minnekahta springs.
Panacea springs.
Parks alkaline springs.
Piedmont spring.
Seven springs.
Shaws healing springs.
Thompsons bromine arsenic spring.
Mount Vernon mineral spring.

OHIO.

- Adams county mineral spring.
- Bellbrook magnetic spring.
- Crystal mineral spring.
- Cedar springs.
- Devonian mineral spring
- Electro-magnetic springs.
- Lenape spring.
- Howland springs.
- Knisely's springs.
- Greene mineral spring.
- Magnetic and saline spring.
- Marquis mineral spring.
- Ohio magnetic springs.
- Rex mineral water.
- Ripley bromo lithia spring.
- Stryker mineral well.
- Sulphur Lick spring.
- Sulphur spa.
- Williamsport sulphur spring.
- Yellow springs.

OREGON.

- Belknap hot springs.
- Foley springs.
- MacAlister's soda springs.
- Sodaville springs.
- Wagner soda spring.
- Wilhoit spring.

PENNSYLVANIA.

- Allegheny spring.
- Bedford springs.
- Black barren Mineral spring.
- Blossburg springs.
- Carlisle White Sulphur spring.
- Corry artesian fountain.
- Cresson springs.
- Doubling Gap springs.
- Ephrata spring.
- Eureka mineral springs.
- Frankfort springs.
- Gettysburg Katalysine spring.
- Kingsland spring.
- Minnequa springs.
- Parker's magnetic mineral spring.
- Pavilion spring.
- Perry county warm spring.
- Pulaski mineral spring.
- Roscommon springs.
- Saltillo springs.
- Sizerville magnetic spring.
- Susquehanna spring.
- Wildwood springs.
- Yellow springs.
- York sulphur spring.

RHODE ISLAND.

- Darling's mineral spring.
- Holly springs.
- Ochee mineral and medical springs.

SOUTH CAROLINA.

- Ambler's mineral spring.
- Charleston artesian well.
- Cherokee springs.
- Chick's springs.
- Garrett springs.
- Glen springs.
- New springs, near Spartanburg.
- Reedy creek springs.
- West springs.

SOUTH DAKOTA.

- Dakota hot springs.
- Wessington springs.

TENNESSEE.

- Alleghany springs.
- Austin springs.
- Beersheba springs.
- Black sulphur springs.
- Bon Aqua springs.
- Cascade springs.
- Castalian springs.
- Clarkstown springs.
- Dandridge springs.
- Draper springs.
- Estill springs.
- Galbraith springs.

Glover's springs
Graham's springs.
Hager springs.
Hinson springs.
Howard springs.
Idaho springs.
Jordan's springs.
Klippert's springs.
Melrose springs.
Mineral Hill springs.
Montvale springs.
Nashville sulphur springs.
Oliver's springs.
Park's sulphur spring.
Patterson's springs.
Pettigrews springs
Primm's springs.
Red boiling springs.
Rhea springs.
Tate's Epsom spring.
Wayland springs.
White Cliff springs.
White creek spring.
White sulphur spring.

TEXAS.

Bell mineral well.
Boston chalybeate spring.
Burdetts sour wells.
Capp's well.
Dalby springs.
Duffau's wells.
Elkhart mineral wells.
Georgetown mineral wells.
Glenmore sulphur springs.
Hancock springs.
Hughes springs.
Hynson's Iron mountain springs.
Mineola mineral wells.
Mineral wells.
Montvale springs.
Overall mineral well.
Page's well.
Richards wells.
Roxboro springs.
Sharp's springs.
Slack's well.
Sulphur springs.
Texas sour springs.
Tioga mineral well.
Wisner's springs.
Wooten wells.

VERMONT.

Albaugh sulphur and lithia spring.
Brunswick white sulphur springs.
Clarendon springs.
Guilford springs.
Highgate springs.
Middletown mineral springs.
Missisquoi mineral spring.
Montebello springs.
Plainfield spring.
Weldon spring.
Wolcot springs.

VIRGINIA.

Alleghany springs.
Bath alum spring.
Bear lithia springs.
Buckingham white sulphur springs.
Buffalo lithia springs.
Cedar Bluff springs.
Chase City chlorine spring.
Chilhowie sulphur springs.
Clifton springs.
Cold sulphur springs.
Cove lithia water.
Coyner's sulphur springs.
Elk lithia springs.
Farmville lithia springs.
Grayson sulphur springs.
Harris antidyspeptic and tonic spring.
Healing springs.
Hot springs.
Huguenot springs.
Hunter's Pulaski alum springs.
Jordan alum springs.
Jordan white sulphur spring.
Kimberling springs.
Massanetta springs.
Millboro springs.
Osceola springs.
Otterburn lithia springs
Paeonian springs.
Powhatan springs.
Rawley springs.
Roanoke red sulphur springs.
Rockbridge alum springs.
Rockbridge baths.
Rock Enon springs.
Rockingham springs.
Seven springs.

Sharon springs.
Shenandoah alum springs.
Stafford springs.
Steep Hill springs.
Stribling springs.
Sweet chalybeate springs.
Valley View springs.
Virginia arsenic bromine and lithia springs.
Wallawhatoola alum springs.
Washington springs.
Wolf Trap lithia springs.
Yellow springs.

WASHINGTON.

Cascade springs.
Medical lake.
Yakima soda springs.

WEST VIRGINIA.

Berkeley springs.
Blue sulphur springs.
Capon springs.
Columbia sulphur spring.
Floding springs.
Greenbrier white sulphur springs.
Hart mineral well.
Irondale springs.
Parkersburg mineral well.
Red sulphur springs.
Salt sulphur springs.
Shannondale springs.
Sweet springs.
Triplett springs.

WISCONSIN.

Allouez magnetic springs.
Almanaris springs.
Arcadian springs.
Arctic springs.
Ashland springs.
Bethania mineral spring.
Bethesda spring, Waukesha.
Black Earth mineral spring.
Clysmic spring, Waukesha.
Crescent spring, Waukesha.
Darlington mineral spring.
Fort Crawford spring.
Fountain spring, Waukesha.
Gihon springs.
Glen spring, Waukesha.
Heuk mineral spring.
Horeb mineral spring, Waukesha.
Hygeia spring, Waukesha.
Iodo magnesian springs.
Jacobs artesian well, Milwaukee.
Lebenswasser spring.
Lethian spring, Waukesha.
Mineral Rock spring, Waukesha.
Nee-ska-ra spring.
New Saratoga spring.
Palmyra springs.
Saint Croix mineral spring.
Salvator springs.
Shealtiel mineral springs.
Sheboygan mineral spring.
Sheridan springs.
Siloam spring, Waukesha.
Silver Sand spring.
Sparta mineral wells.
Vesta spring, Waukesha.
Vita mineral spring.
White Rock spring, Waukesha.

RESULTS OF STREAM MEASUREMENTS.

BY

F. H. NEWELL.

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ILLUSTRATIONS.

RESULTS OF STREAM MEASUREMENTS.

By F. H. Newell.

CHARACTER OF DATA.

This report, the fifth of the series[1] relating to the measurement of discharges of rivers, mainly of the western part of the country, sums up briefly the results obtained by the Geological Survey during the past year, and in connection with these data discusses a few related facts regarding river flow. The gagings made by the Geological Survey have been for the purpose of obtaining a knowledge of the water resources of those parts of the country where the streams have the greatest value. As it was obviously impossible to measure all important rivers, points were selected with reference to the general application of the data obtained. The choice of localities was largely dictated by considerations of expense and convenience. As far as possible, gaging stations were located in each of the larger drainage basins of the west, so that measurements might be made in streams controlled by different topographic and climatic conditions. A brief description of each of the gaging stations from which observations have been obtained during 1892 is given in the following pages, these being located in nine of the western states and territories.

In the preceding reports not only have the data available at the time of publication been presented, but somewhat detailed descriptions have also been given embodying the results of examinations of the drainage basins of the upper Missouri, Yellowstone, Platte, Rio Grande, Gila, and Bear rivers. In this paper, besides the results of stream measurements obtained at a later date, there are presented a few facts concerning large rivers in the East, casting light upon the subject

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[1] The preceding papers of this series are as follows·

First. "Hydrographic Work." First annual report of the Irrigation Survey, part 2 of the tenth annual report of the U. S Geological Survey, pp. 78-90.

Second "Hydrography." Second annual report of the Irrigation Survey, part 2 of the eleventh annual report of the U. S. Geological Survey, pp 1-110

Third. "Hydrography of the Arid Regions" Third annual report of the Irrigation Survey, part 2 of the twelfth annual report of the U. S Geological Survey, pp. 213-361.

Fourth "Water Supply for Irrigation" Thirteenth annual report of the U. S Geological Survey, part 3, pp 1-99 under discussion and bringing out peculiarities distinctive of rivers influenced by different topographic conditions. A special study has been made of the Potomac and the results are herein given, since this river is in many ways typical of the streams of the eastern humid regions. The data thus acquired has been of value in discussions of geological problems as well as of the water resources of the country.

Besides the stream measurements conducted by the Geological Survey there have been other investigations of similar character, the results of some of which have lately become available for discussion and comparison, so that it is now possible to obtain a fairly accurate knowledge of the habits of rivers in many parts of the United States. One of the most important of recent investigations is that carried on by the geological survey of New Jersey upon water supply and water power, the work being under the immediate direction of Mr. C. C. Vermeule.[1]

METHODS.

The methods of stream measurement were briefly described in the second irrigation report, beginning on page 5. In the three years which have elapsed since that report was written many improvements have been made in the instruments used, particularly in the form of meter employed in measuring small streams. One of the principal changes has consisted in making the Haskell meters smaller and more portable, and having but two flukes upon the revolving wheel instead of four. In its later form this meter is provided with two revolving wheels, one for use in swift waters, the other in more sluggish currents. These wheels are of the same size, the flukes of one of the wheels having somewhat greater pitch than that of the other. The internal diameters are the same, and either one can be used upon the supporting axis of the meter. The reduction in size can best be appreciated by the statement that the complete meter, with the exception of the rods, can be packed in a light carrying case 8 inches long, 4½ inches wide, and 2 inches thick. The accompanying illustration shows this meter without the supporting rods (Fig. 6).

The small Haskell electric meter, when in use, is generally screwed upon the lower end of a rod 6 feet in length, this being provided with joints, so that it can be unscrewed from the meter, and also at the middle, for convenience in carrying. Through the center of the rod runs the insulated wire, by which connection is made with the batteries and recording device. For use in rivers of moderate velocity the meter can be lowered from a bridge or boat by means of a double incandescent electric light cord, this being extremely pliable, and serving at the same time to conduct the electric current. In gagings made from the shore by means of wires or light cables, as mentioned on page 17 of the second irrigation report, this new form of meter is especially serviceable on account of the relatively trifling weight.

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[1] Annual report of the state geologist for the year 1890, pp. 137-257, also for 1891, pp 141-216.

For use in small streams and canals, where the gager standing on a low bridge or boat can readily reach all parts of the cross section with the meter mounted on short rods, the direct recording form of instrument is still preferred. The Colorado type of wheel, figured on page 7 of the second irrigation report, is used to a considerable extent, the form of meter being improved in minor details. One of the most important changes has been in making the method of locking and release of the registering wheels depend not upon a spring but upon a direct geared motion. In the new form the registering wheels are stopped or allowed to start by turning a small rod placed inside of the rod upon which the meter is held. This later form of meter is shown by the accompanying drawing (Fig. 7). This meter has no direction tail, but is used only under circumstances such that the

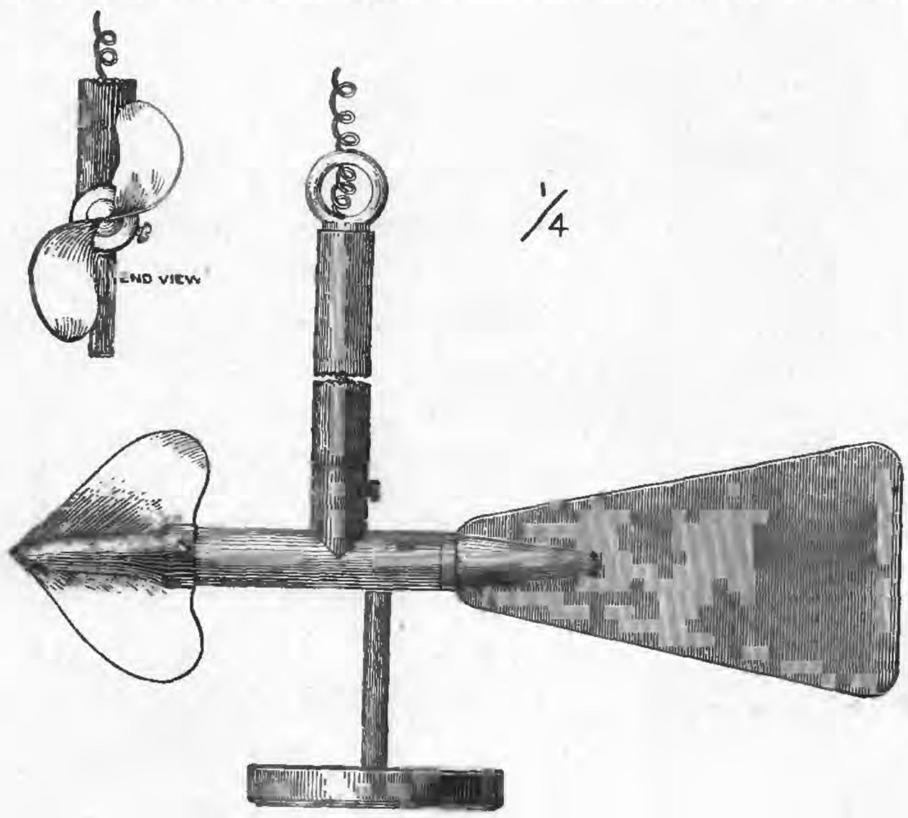

FIG. 6.—Small form of Haskell electric current meter.

gager can at all times see that it is pointed upstream. In practical use the method of employment of this meter is that sometimes known as integration; that is to say, instead of obtaining the velocity at one point at a time, as in the case of deep rivers measured by the electric meter, this instrument is lowered and raised alternately with very slow motion from top to bottom of comparatively shallow streams. This lowering and raising, if performed at a uniformly slow rate, should not affect the revolutions of the wheel, and the meter should thus indicate the average velocity of that section.

Besides the electric and direct recording meters mention should be made of a third type of instrument, the sounding meter, which, although not in use by the Geological Survey to any considerable extent, possesses certain advantages. In its ordinary form this is the simplest and most durable of measuring apparatus of its kind, since it has but one moving part, the vane or wheel. These meters, devised by Joseph P. Frizell and used by the Engineer Corps on the headwaters of the Mississippi, are described as consisting merely of a rotating wheel, so monnted that when in motion the wheel is forced forward at each revolution by a small cam or helical step from one-thirty-second to one-sixty-fourth of an inch. The two surfaces bearing the step fit exactly in one position, but as the wheel turns it is forced forward on the supporting spindle, and as the steps pass each other drops

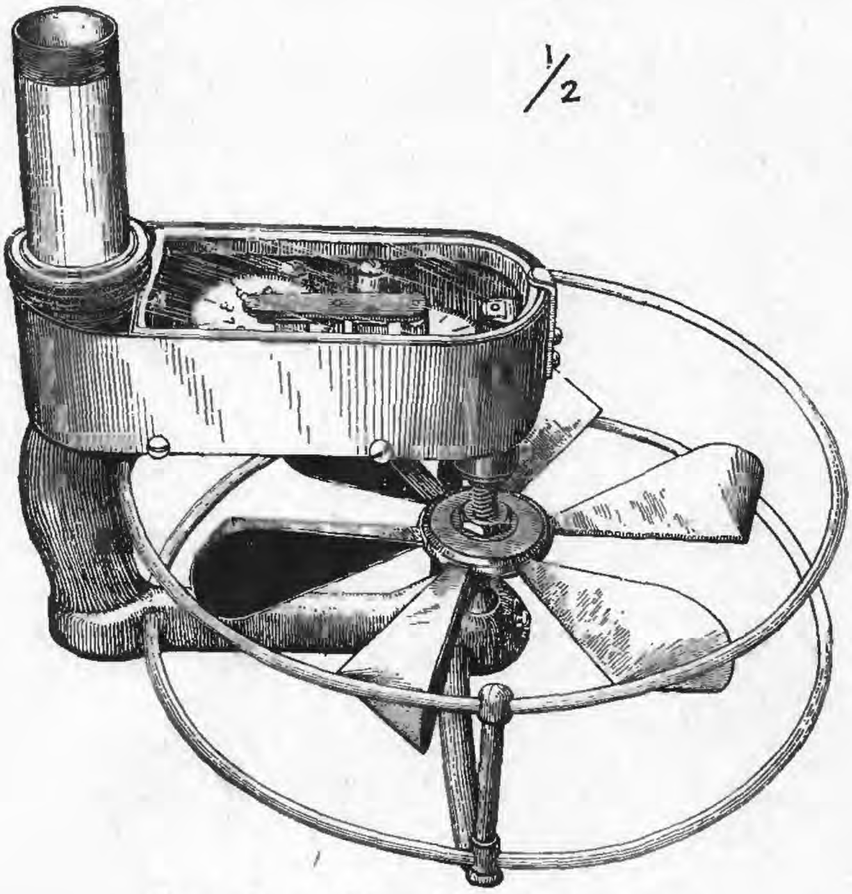

FIG. 7.—Improved form of the Colorado meter.

back, causing a distinct "click," audible along the metallic rod upon which the meter is held. The operator holding the meter at the desired place in the stream, with his ear near the rod, counts the clicks and notes the number of seconds, usually by means of a stop-watch. It is customary either to take the time of one hundred revolutions or to count the number of revolutions in fifty or one hundred seconds.

Electric recording meters have also been converted into sounding meters by making connections with an ordinary telegraphic "sounder." They have, however, the very disadvantage that the original sounding meter was devised to overcome, namely, a complication of parts requiring considerable skill in their successful employment. A careful man, though not experienced as an engineer or mechanician, can be quickly instructed in the use of the simple sounding meter and can take observations from time to time, sending in his notes for computation by the engineer in charge.

Besides the current meters used in determining the velocity of the streams, the Survey has used a number of instruments for recording automatically the fluctuations in height of various rivers. These self-recording tide gages or nilometers, as they are usually called when used upon rivers, have not proved satisfactory except at points where a person of some considerable mechanical skill could watch them and see that they were kept in order. It has been found on the whole preferable to have readings taken at short intervals of the height of water on the inclined or vertical gage rods fastened securely to the river's bank or to the pier of some bridge. The Survey has in use three forms of nilometers, viz, the horizontal cylinder, the vertical cylinder, and the vertical disk. All of these are driven by clockwork and are designed to run a week before renewing the paper. The horizontal and vertical instruments are similar, the latter being found to have a few mechanical advantages over the former, arising from the fact that the cylinders appear to move more easily when mounted vertically. The accompanying illustration (Fig. 8) shows one of these instruments.

The record of river height registered by the nilometer is, of course, on a scale less than the actual range of the water service, the recording pencil being connected by a suitable reducing device with a float which rises or falls with the river. This float is usually placed in a small well near the bank, the bottom communicating with the bed of the river by a pipe of such size that it will not become readily clogged. In the case of the instrument shown in the figure the large wheel at the right is connected with the float by means of a cord or metallic tape which winds or unwinds as the float rises or falls. This large wheel is fastened to a smaller one, around which is wound the cord giving motion to the carriage supporting the recording pencil. In the improved forms this cord is dispensed with, the pencil carriage being geared directly to the smaller wheel, so that there is no lost motion.

The disk nilometers are provided with a face or dial similar in some respects to that of a clock, with the exception that instead of being fixed the dial moves forward at a uniform rate, making one revolution a week. The recording pencil, mounted on an arm, moves across this face from one side toward the center. The instrument, in general appearance, is similar to that of the self-recording standard thermometer, of which, in fact, it is simply a modification, the thermometric strips being replaced by a suitable rack and pinion movement.

The mean daily gage heights, as shown by the self-recording nilometer or by direct readings of the gage rods, are tabulated and against each is set the computed discharge corresponding to the water heights as shown by a table constructed for that locality. The method of preparing this table, or, as it is usually termed, of rating the station, has been explained in some detail on page 19 of the Eleventh Annual Report, part 2, and illustrations of the rating curve are given on the following pages in connection with the discharge data for the Arkansas and other rivers.

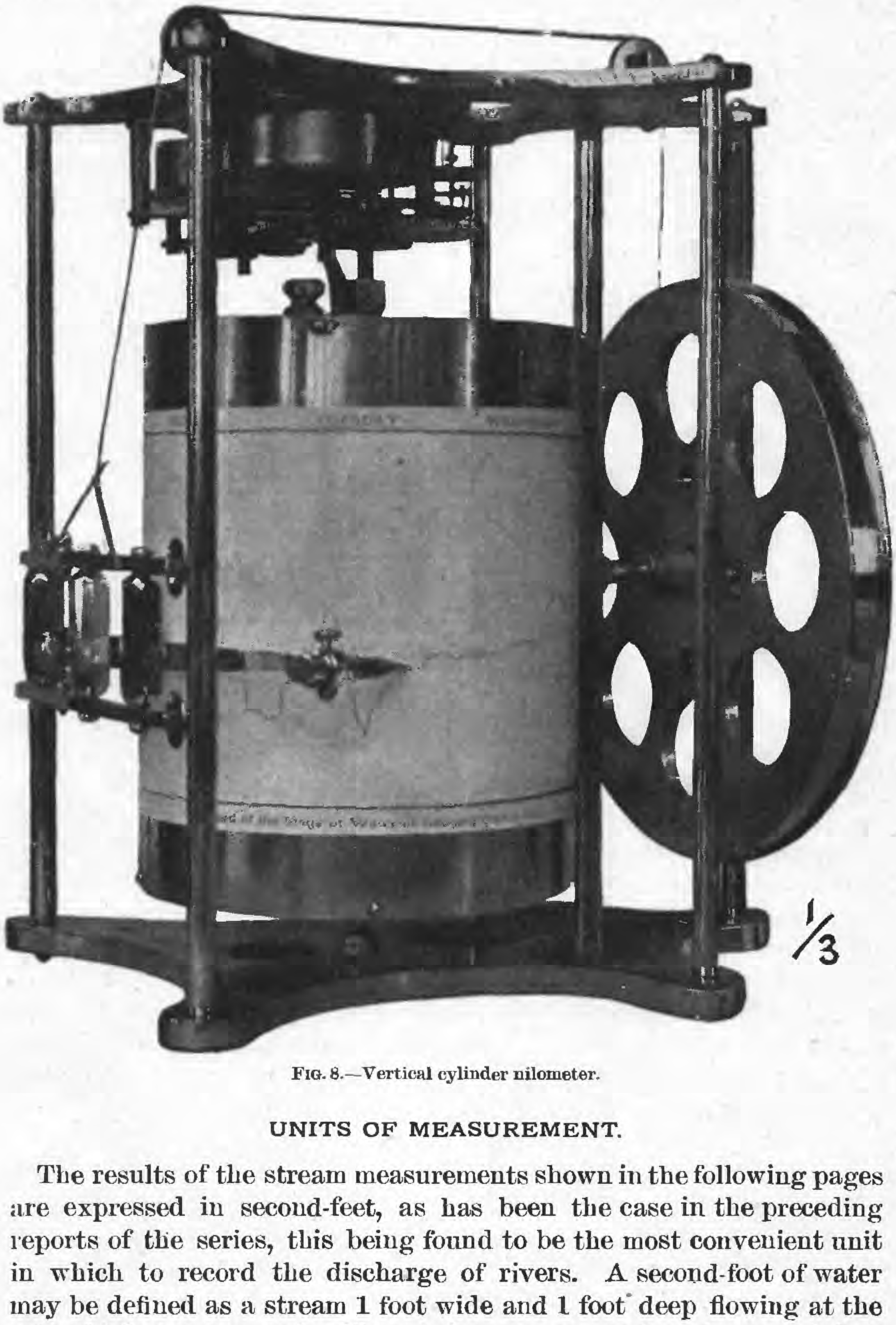

FIG. 8.—Vertical cylinder nilometer.

UNITS OF MEASUREMENT.

The results of the stream measurements shown in the following pages are expressed in second-feet, as has been the case in the preceding reports of the series, this being found to be the most convenient unit in which to record the discharge of rivers. A second-foot of water may be defined as a stream 1 foot wide and 1 foot deep flowing at the rate of 1 foot per second. There is in common use by miners and irrigators throughout the West another unit, the miner's inch, which will probably continue to be employed. This is an indefinite quantity, but it is generally coming to be recognized as the fiftieth part of a second-foot. If thus clearly defined by statute or by common consent among engineers the objection on the score of uncertainty will disappear.

The unit of quantity or capacity commonly employed in considerations of storage is the acre-foot, equivalent to 43,560 cubic feet. There is a convenient connection between these units, since one second-foot flowing for one day will deliver 86,400 cubic feet of water, or nearly 2 acre-feet (in more exact figures 1·983471 acre-feet). Many engineers are, however, still inclined to use the million gallons as a unit of water storage, as this is well fixed in computations relating to municipal water supply. For convenience it may be stated that 1 acre foot equals 325,851·45 gallons, or a little less than one-third of a million gallons.

In the following tables the maximum, minimum, and mean quantity in the streams each month are given in second-feet and the total discharge in acre-feet, as in former reports. To obtain this total for the month in acre-feet, the usual practice is to multiply the mean daily discharge for all months except February, April, June, September, and November by 61·5, for February by 55·5, and for the remaining months by 59·5. This involves a small error, as the factors are respectively 61·4876 +, 55·5372 +, and 59·5041 +, but this is far within the range of accuracy of the original observations. These factors represent, of course, the number of seconds in a month divided by the number of square feet in an acre.

The depth of run-off over the whole basin is also given for each month in inches, for convenience of comparison with rainfall, and also in second-feet per square mile drained. The former is obtained by multiplying the acre-feet per month by 12, to obtain acre-inches, and dividing this by 640, the number of acres in a square mile, and also by the area of the drainage basin given at the top of the table. The run-off in second-feet per square mile is simply the mean monthly discharge divided by the total area of the basin from all of which the water is assumed to come. The mean discharge for the year is taken to be the average of the mean monthly discharges, and the total quantity of run-off is the sum of the monthly run-offs, these also involving slight errors, as the months are not of equal length. In most cases with the new data are given figures previously published, but which are essential as showing the whole record for the locality.

WEST GALLATIN RIVER

The gaging station on this river is about 20 miles southwesterly from Bozeman, Montana, at the mouth of the canyon a few hundred feet below Spanish creek, being thus above the head of canals. The results of the gagings obtained at this point are shown graphically upon Pl. LX of the Twelfth Annual Report and upon Fig. 53 of the Thirteenth, the diagram in this latter case extending to the middle of July, 1892. The accompanying table gives all of the data up to the present time.

Discharge of West Gallatin river.

[Drainage area, 850 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1889.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre feet.*	*Inches.*	*Sec.-feet.*
August 16 to 31	437	402	426	26,200	·58	·50
September	640	402	450	26,775	·59	·53
October	437	367	402	24,723	·54	·47
November			*400	23,800	·52	·47
December			*400	24,600	·54	·47
1890.						
January			*320	19,680	·43	·38
February			*320	17,760	·39	·38
March 23 to 31	320	320	320	19,680	·43	·38
April	1,255	280	460	27,370	·60	·54
May	3,195	1,300	2,092	128,658	2·84	2·46
June	3,800	2,060	2,641	157,139	3·47	3·11
July	2,165	800	1,388	85,362	1·88	1·63
August	890	570	761	46,801	1·03	·89
September	690	570	607	36,112	·80	·72
October	650	570	591	36,346	·80	·70
November	570	430	506	30,107	·66	·60
December			*450	27,675	·61	·54
Per annum	3,800	280	871	632,690	13·94	1·03
1891.						
January			400	24,600	·54	·47
February			400	22,200	·47	·47
March			450	27,675	·61	·53
April			500	29,750	·65	·59
May 6 to 31	2.535	1,390	1,897	116,665	2·57	2·23
June	2,975	1,615	2,516	149,702	3.30	2·95
July	1,760	1,090	1,534	94,341	2 06	1·81
August	1,050	570	761	46,801	1.03	·90
September	650	570	583	34,688	·77	·69
October	610	570	587	36,100	·80	·69
November	570	370	501	29,809	·66	·59
December	500	430	434	26,691	·59	·51
Per annum	2,975	370	880	639,022	14·05	1.03
1892.						
January	430	430	430	26,445	·59	·51
February	430	400	429	24,667	·55	·50
March	400	400	400	24,600	·54	·47
April			*450	26,775	·59	·53
May	4.065	465	1,483	91,512	2·02	1·75
June	6,800	2,270	4,163	247,698	5·48	4·90
July	5,170	1,300	2,544	156,456	3·46	3·00
August	1,300	810	957	58,855	1·30	1·12
September	850	650	734	43,673	·97	·86
October	890	650	743	45,694	1·01	·87
November	650	570	589	35,045	·77	·69
December	570	500	549	33,763	·74	·64
Per annum	6,800	400	1,123	815,183	18·02	1·32
1893.						
January	500	430	469	28,844	·64	·55
February			*430	23,865	·53	·51
March 19 to 31	430	370	375	23,063	·51	·44
April	500	430	463	27,549	·61	·54
May	3.360	500	1,414	86,961	1·93	1·67
June 1 to 14	5,900	1,810	3,396			
July						
August 22 to 31	730	570	622			
September	650	570	587	34,927	·77	·69
October	730	500	576	35,424	·82	·68
November	570	430	458	27,251	·60	·54
December	430	370	400	24,600	·54	·47

*Estimated.

MADISON RIVER.

The gaging station on this river is in the lower end of the canyon below the mouth of Hot Spring creek, at Hayward bridge, 4 miles from the town of Red Bluff. The discharge at this point is shown graphically for the period from April, 1890, to May 23, 1891, on Pl. LXI of the Twelfth Annual Report, and from January 1, 1891, to July 15, 1892, on Fig. 54 of the Thirteenth Annual Report. For a description of the drainage basin reference should be had to this latter volume. The river at the gaging station flows in a rocky channel with swift current, the left banks being high and the right relatively low. The gage or nilometer, like that of most of the other stations, consists of an inclined stick of timber following the general slope of the bank. Measurements of the river have been made from a box or small car suspended by a cable five-eighths of an inch in diameter. The results of the computations of daily discharge are given by months in the following table:

Discharge of Madison river.

[Drainage area, 2,085 square miles.]

Month.	Maximum	Minimum.	Mean	Total for month	Run-off.	
					Depth.	Per square mile.
1890.	*Sec.-ft.*	*Sec.-ft*	*Sec. ft*	*Acre-feet*	*Inches.*	*Sec.-ft*
January	....	....	*1,200	73,800	·66	·58
February	....	....	*1,200	66,600	·60	58
March	....	....	*1,200	73,800	66	58
April 4 to 30	2,580	1,370	1,620	96,390	87	78
May	6,420	3,060	4,823	296,614	2·67	2·32
June	6,360	3,780	4,977	296,131	2 66	2·38
July	3,660	1,715	2,518	154,857	1 39	1·21
August	1,640	1,375	1,535	94,462	·85	·74
September	1,580	1,420	1,466	87,250	78	·70
October	1,520	1,420	1,498	92,125	·83	·72
November	1,470	1,285	1,380	82,110	74	·66
December	1,520	1,285	1,400	86,100	77	·67
Per annum	6,420	1,285	2,068	1,500,239	13 48	·99
1891						
January	1,580	1,240	1,406	86,469	·78	·67
February	1,580	1,265	1,436	79,698	·72	·69
March	1,790	1,470	1,631	100,306	90	·78
April	1,960	1,640	1,774	105,530	·95	·85
May	4,260	1,790	3,389	208,423	1 88	1 62
June	4,620	3,788	4,167	247,936	2·20	2 00
July	3,660	1,155	2,045	125,767	1·13	98
August	1,640	1,200	1,429	87,883	80	·68
September	1,375	1,240	1,309	77,885	·70	·63
October	1,470	1,240	1,351	83,086	·75	65
November	1,470	1,285	1,400	83,300	·75	·67
December	1,240	1,070	1,137	69,925	·63	55
Per annum	4,620	1.070	1,872	1,356,208	12 19	·90
1892.						
January	1,375	1,240	1,305	80,257	·72	63
February	1,640	1,330	1,504	86.480	·78	72
March	1,640	1,330	1,488	91,512	82	·71
April	1,420	1,240	1,295	77,052	·69	·62
May	2,580	1,330	1,454	89,421	·81	·70
June	5,940	2,820	4,900	291,550	2 62	2 35
July	5,340	1,790	3,225	198,337	1·78	1 55
August	1,885	1,285	1,519	93,418	·84	·73
September	1,420	1,330	1,360	80,920	·73	·65
October	1,420	1,285	1,327	81,610	·74	64
November	1,420	1,330	1,424	84,728	·76	68
December	1,420	1,240	1,324	81,426	73	·64
Per annum	5,940	1,240	1,844	1,336,711	12 02	89
1893.						
January	1,375	1 155	1,229	75,584	·68	·59
February	1,960	1,030	1,287	71,428	64	·62
March	1,200	1,030	1,082	66,543	60	·52
April	1,240	910	1,019	60.631	·55	·49
May	1,520	1,070	1,326	81,549	·74	64
June	3,180	1,580	2,421	144,050	1·20	1·16

*Estimated.

MISSOURI RIVER.

The principal gaging station on the upper Missouri has been at Craig, about 30 miles northerly from Helena, where observations were begun on April 18, 1890. The fluctuations of river discharge at this point for the greater part of 1890 and for April and May of 1891 are shown graphically upon Pl. LXII of the Twelfth Annual Report, and for the flood season of 1891 and 1892 upon Fig. 55 of the Thirteenth Annual Report.

Discharge of Missouri river.

[Drainage area, 17,615 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off	
					Depth.	Per square mile.
1890	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
January	....	....	*3,000	184,500	20	17
February	....	....	*3,000	166,500	18	17
March	....	....	*3,000	184,500	20	17
April 17 to 30	6,100	3,595	4,662	277,389	29	26
May	12,500	6,900	10,472	644,030	68	59
June	11,900	8,100	10,074	599,401	64	57
July	7,800	2,614	5,020	308,730	33	28
August	2,505	1,960	2,216	136,284	15	13
September	2,396	1,960	2,232	132,804	14	13
October	2,722	1,742	2,379	146,308	16	13
November	3,159	2,723	2,868	170,646	18	16
December	3,159	1,742	2,763	169,924	18	16
Per annum	12,500	1,742	4,307	3,121,016	3.33	24
1891						
January	3,823	1,742	2,967	182,470	19	17
February	....	....	*3,500	215,250	24	20
March	....	....	*4,000	246,000	26	23
April	9,130	4,576	5,794	344,743	37	32
May	12,050	7,150	9,015	554,422	59	51
June	16,355	11,000	13,645	811,877	85	77
July	12,960	5,890	9,115	560,572	60	52
August	5,890	2,832	4,415	271,522	29	25
September	3,704	2,614	3,078	183,141	19	17
October	3,704	3,159	3,511	215,926	23	20
November 1 to 10	4,358	3,486	3,802	226,219	25	22
December	16,355	....	*3,200	196,800	21	18
Per annum	16,355	1,742	5,503	4,008,942	4.27	31
1892						
January	....	....	*3,000	184,500	20	17
February	....	....	*3,000	172,500	18	17
March	....	....	*3,200	196,800	21	18
April	4,140	3,268	3,552	211,344	23	20
May	18,550	3,486	8,004	492,246	52	45
June 1 to 25	28,650	13,270	21,027	1,251,106	1.34	1.19

* Estimated.

YELLOWSTONE RIVER.

The measurements of this stream have been made mainly at the station at Horr, about four miles below Cinnabar, as described in the general discussion of the Yellowstone basin on page 66 of the Thirteenth Annual Report. The fluctuations of the river are shown diagrammatically from August 12, 1889, to May 30, 1890, on Pl. LXIV of the Twelfth Annual Report, and from January 1, 1891, to July 15, 1892, on Fig. 56 of the succeeding volume. The discharge for the remainder of 1892 was slightly greater than that for 1891. The following table gives the figures relating to the discharge since the beginning of the observations:

Discharge of Yellowstone river.

[Drainage area, 2,700 square miles]

Month.	Maximum.	Minimum.	Mean	Total for month.	Run-off.	
					Depth	Per square mile
1889	*Sec.-ft*	*Sec.-ft*	*Sec.-ft*	*Acre-feet.*	*Inches*	*Sec.-ft*
August 12 to 31	1,853	1,411	1,660	102,090	71	62
September	1,653	1,126	1,270	75,565	52	·47
October	1,126	841	976	60,024	42	·36
November	841	651	743	44,208	31	·27
December	....	....	*650	39,975	28	·24
1890.						
January	....	....	*550	33,825	·23	·20
February	....	....	*550	30,525	21	·20
March 23 to 31	620	560	585	35,977	·25	·22
April	4,495	510	1,417	84,311	59	·53
May	11,915	5,090	7,522	462,603	3·21	2 79
June	11,915	8,720	10,086	600,117	4 17	3·74
July	9,410	5,760	7,682	472,443	3 28	2 84
August	5,600	3,145	4,375	269,065	1 87	1 62
September	3,145	1,670	2,276	135,422	94	·84
October	1,920	1,160	1,473	90,589	63	55
November	1,160	850	970	57,715	40	·36
December	815	590	695	42,742	30	·26
Per annum	11,915	510	3,181	2,315,334	16 08	1 18
1891						
January	590	470	488	30,012	·21	·18
February 1 to 14	....	....	*500	27,750	19	·18
March	360	285	316	19,434	13	·12
April	2,720	360	1,082	64,379	45	·40
May	7,480	1,855	5 227	321,460	2 24	1 93
June	8,975	6,685	7,592	451,724	3 13	2 81
July	7,110	5,090	6,135	377,302	2 62	2·27
August	4 920	2,060	3,442	211,683	1 47	1 28
September	2,625	1,250	1,641	97,639	68	·61
October	1,610	1,080	1 264	77,736	54	·47
November	1,080	680	891	53,014	·37	33
December	745	360	475	29,212	21	·18
Per annum	8,975	285	2,421	1 761,345	12·24	90
1892						
January	....	....	*500	30,750	21	·19
February	650	470	570	32,775	·23	21
March	780	620	713	43,849	30	·26
April	780	590	664	39,508	27	·25
May	10,200	710	3 544	217,956	1·51	1 31
June	15,200	6,520	11,201	666,460	4 63	4·15
July	15,500	6,770	10,180	626,070	4 35	3 78
August	6,770	3,400	4,931	303,257	2 10	1·82
September	3,485	1,920	2,808	167,076	1 16	1 04
October	1,920	1,200	1,555	95,632	66	·58
November	1,200	745	952	56,644	39	35
December	....	....	*800	49,200	·34	·30
Per annum	15,500	470	3,202	2,329,177	16 15	1 19
1893						
January	....	....	*800	49,200	34	·30
February	....	....	*700	38,850	27	·26
March	....	....	*700	43,050	·30	·26
April 16 to 30	745	590	665	39,568	27	·25
May	8,630	650	3,282	202,274	1·42	1 22
June	13,610	5,090	9,602	571,319	3 98	3 58
July	9,590	5,430	7,399	455,039	3 16	2·74
August	5,345	2,455	3,780	232,470	1 62	1·40
September	2,540	1,855	2,098	124,831	87	·78
October	2,060	1,440	1,630	100,245	70	·60

* Estimated.

ARKANSAS RIVER.

A general description of the drainage basin of this river, accompanied by a map, has been given by Mr. H. M. Wilson in the Thirteenth Annual Report, part 3, and the measurements of the stream have been referred to on pages 45–52 of the Eleventh Annual Report, part 2. The principal gaging station was located at the mouth of the canyon, about a mile above the city of Canyon, there being a relatively small amount of water diverted at points above. The following table gives the dates of measurement, height of river, and quantity of water flowing in the stream, these later being the data upon which have been based the computations of the relation of river height to quantity of water expressed by what is commonly known as the rating table. In the accompanying diagram these results of measurements have been plotted, each being shown by a black dot, against which is placed a figure corresponding to the number of the gaging as shown in the table. For example, number 7 refers to a gaging made on May 1, 1890, at which time the water stood at a height of 2·73 feet on the gauge and the discharge was found by the use of the current meter to be 775 second-feet. In the same way 19 refers to a gaging made on July 12, 1890, at which time the river was at a height of 4·05 feet and the meter measurements gave a discharge of 1,806 second-feet. The heavy curved line drawn through or near the points thus obtained is known as the rating curve and serves to express the general relation between river height and

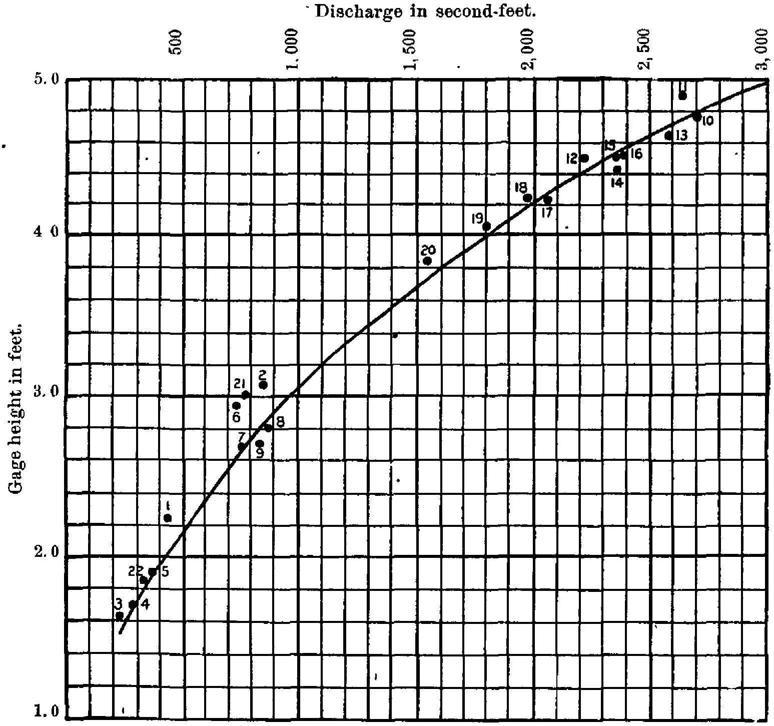

FIG. 9.—Rating curve for gaging station at Canyon, Colorado.

discharge. From the position of this curve is taken the value of discharge corresponding to each fraction of a foot rise of the stream.

Gagings of the Arkansas river at Canyon City, Colo

No.	Date	Gage height.	Discharge
		Feet	*Sec feet*
1	July 26, 1889	2·25	421
2		3·00	833
3	April 1, 1890	1·62	222
4	April 2, 1890	1·70	286
5	April 3, 1890	1·88	360
6	April 28, 1890	2·93	744
7	May 1, 1890	2·73	775
8	May 2, 1890	2·80	891
9	May 2, 1890	2·78	862
10	May 23, 1890	4·77	2,705
11	June 5, 1890	4·85	2,641
12	June 12, 1890	4·53	2,220
13	June 14, 1890	4·65	2,598
14	June 19, 1890	4·48	2,380
15	June 23, 1890	4·55	2,386
16	June 27, 1890	4·55	2,394
17	June 30, 1890	4·23	2,055
18	July 9, 1890	4·22	1,988
19	July 12, 1890	4·05	1,806
20	July 16, 1890	3·82	1,546
21	April 13, 1891	3·00	777
22	December 4, 1891	1·85	328

The following table gives the discharges by months since 1888, an estimate of the quantities for the spring and winter months being added in a number of instances. The fluctuations in mean annual discharge of this river have been discussed and shown diagrammatically on pages 19 to 21 of the Thirteenth Annual Report, bringing out the general coincidence of these fluctuations with those of other bodies of water. The daily variations in discharge for the greater part of 1888, 1889, 1890, and 1891 are shown upon Pl. LXVII of the Twelfth Annual Report, and those for 1891 and 1892 upon the accompanying diagram, Fig. 10. By reference to this figure and the following table of discharges

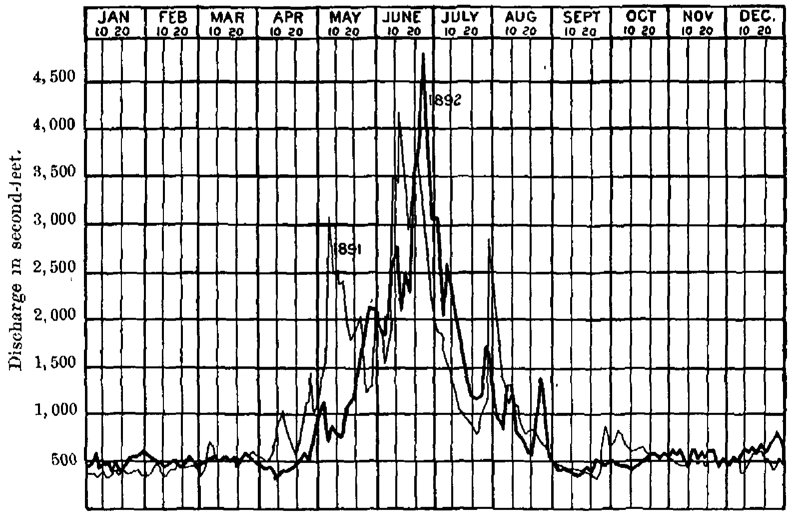

FIG 10.—Daily discharge of Arkansas river at Canyon, Colorado, for 1891 and 1892.

it will be seen that the maximum flood of June, 1892, was greater than that of the preceding year, but that the average discharge for 1892 was somewhat below that for 1891, this latter quantity, 1,012 second-feet, being greater than any of the years during which measurements had been made at Canyon City. By making use of measurements of the river at other points it has been found possible to compute the probable discharge for the six midyear months, including the summers, of 1886 and 1887, from which it appears that the discharge of 1891, although above the average, did not reach the unusually high water of preceding years.

Discharge of Arkansas river.

[Drainage area, 3,060 square miles]

Month.	Maximum	Minimum	Mean	Total for month	Run-off	
					Depth	Per square mile.
1888	*Sec -ft*	*Sec. ft*	*Sec.-ft*	*Acre-feet*	*Inches*	*Sec -ft.*
January			*400	24, 600	15	13
February			*500	27, 750	17	·16
March			*600	36, 900	22	·20
April			*1, 000	59, 500	·36	·33
May	1, 570	1, 280	1, 440	88, 560	·54	47
June	2, 760	1, 120	2, 090	124, 355	76	·68
July	1, 870	850	1, 350	83, 025	51	44
August	1 100	800	932	57, 318	35	·30
September	850	430	605	35, 997	22	20
October			*500	30, 750	19	16
November			*500	29, 750	18	16
December			*400	24, 600	15	·13
Per annum	2, 760	430	860	623 105	3 ·80	·28
1889.						
January			*300	18, 450	11	10
February			*300	16, 620	10	10
March			*300	18 450	11	10
April 17 to 30	438	214	300	17, 850	·11	10
May	1, 960	324	600	36, 900	23	·20
June	2, 010	1, 002	1, 374	81, 753	50	45
July	1, 150	290	602	37, 023	·23	20
August	2, 620	243	340	20, 910	13	·11
September	258	190	220	13, 090	08	07
October	284	190	223	13, 715	08	·07
November	335	243	299	17, 790	11	10
December	438	274	335	20, 602	·13	11
Per annum	2, 620	190	433	313, 153	1 ·92	14
1890						
January	494	180	310	19, 065	12	·10
February	446	250	363	20, 146	12	·12
March	391	180	320	19, 683	12	·10
April	980	200	477	28, 381	17	16
May	3, 270	841	2, 090	128, 535	79	·68
June	3, 260	2, 068	2, 611	155, 354	95	·85
July	2, 132	920	1. 571	96, 616	·59	51
August	1, 425	580	670	41, 205	25	·22
September	625	455	519	30, 880	10	·17
October	605	505	531	32, 656	20	17
November	555	480	522	31, 059	19	·17
December	580	455	502	30, 873	19	16
Per annum	3, 270	180	874	634, 453	3 88	28

* Estimated.

Discharge of Arkansas river—Continued.

Month.	Maximum	Minimum.	Mean.	Total for month	Run-off	
					Depth	Per square mile
1891	*Sec -ft*	*Sec -ft.*	*Sec. ft*	*Acre-feet*	*Inches*	*Sec -ft*
January	505	325	431	26, 506	16	·14
February	580	365	474	26, 307	16	·15
March	685	530	586	36, 039	22	·19
April	1, 600	580	857	50, 992	31	·28
May	3, 700	1, 340	2 012	123 738	76	·66
June	4, 230	1, 600	3, 291	195, 814	1 20	1 07
July	2, 810	770	1, 468	90, 282	55	·48
August	1, 925	530	951	58, 486	36	31
September	715	345	473	28, 143	17	·15
October	825	530	624	38 376	24	·20
November	530	430	498	29, 631	18	·16
December	605	345	476	29, 274	18	·16
Per annum	4, 230	325	1, 012	733, 588	4 49	35
1892						
January	630	345	496	30, 504	19	16
February	555	430	493	28, 347	17	·16
March	605	430	524	32, 226	20	·17
April	715	410	522	31, 059	19	·17
May	2, 250	685	1, 241	76, 322	47	·41
June	4, 750	1, 780	2, 787	165, 826	1 01	·91
July	3, 050	1, 060	1, 798	110, 577	68	·59
August	1, 425	455	769	47, 293	29	·25
September	530	365	435	25, 882	16	·14
October	605	410	511	31, 426	·19	·17
November	605	455	527	31, 356	19	·17
December	630	480	561	34, 502	21	·18
Per annum	4, 750	345	889	645, 320	3·95	29
1893						
January	580	430	505	31, 058	19	·16
February	630	455	533	29, 582	·18	·17
March	885	480	555	34, 133	21	·18
April	800	480	568	33, 796	21	·19
May	3, 210	480	1, 480	91, 020	·56	·48
June	4, 750	1 875	3, 115	185, 343	1 14	1·02

The waters of this river are diverted by many ditches and canals heading at short intervals in succession and covering lands on both sides of the stream. Some of these canals rank among the largest in the United States, and the aggregate capacity of all these systems of irrigation, when they are completed and in operation, will probably far exceed the mean annual discharge of the river. During the latter part of the summer season all of the waters are diverted and the river bed is almost completely dry, at least at points above the Kansas line. There are, however, many pools of water and occasionally little sluggish streams meandering across the broad sandy channel, showing that the underlying material is fully saturated and that there is considerable percolation from higher beds. At various points in western Kansas attempts have been made to utilize this seepage water by draining it out by gravity into the irrigation canals which are left dry during the summer. A large amount of money has been expended in trenching or digging the so-called "underflow" canals in the pervious sands and gravels of the flood plains of the river and in some instances an apparently constant stream of a few cubic feet per second has been obtained, there being, however, no definite measurements available as to the quantity or fluctuations of the water thus drained from the low lands.

After passing through western Kansas the river changes its character and becomes a perennial stream, subject, however, to irregular fluctuations of short duration. The floods of May and June, so characteristic of the upper river, are obscured by earlier and later rises, so that they do not become noticeable upon the diagram of gage height. The river takes on the character of streams of the humid region, with less difference between the average amount of water flowing in the earlier and later months of the year.

RIO GRANDE.

This river, as mentioned in preceding reports, has been gaged at three places: Del Norte, Colorado; Embudo, New Mexico, and El Paso, Texas. The drainage basin of this river has been described in some detail on pages 240 to 282 of the Twelfth Annual Report, and the discharges have been shown diagrammatically for the years 1889, 1890, and 1891 upon the plates accompanying. The gaging station in Colorado is at a point about 3 miles above the town of Del Norte, being thus above the heads of the principal irrigating canals. The results of measurements at this point are shown in the following table and the accompanying diagram, Fig. 11, which gives the daily fluctuations for 1891 and 1892. The rating curve for this station is given on Pl. LXX of the Eleventh Annual Report, the results of nineteen measurements being plotted upon it. Since the time of publication fifteen other

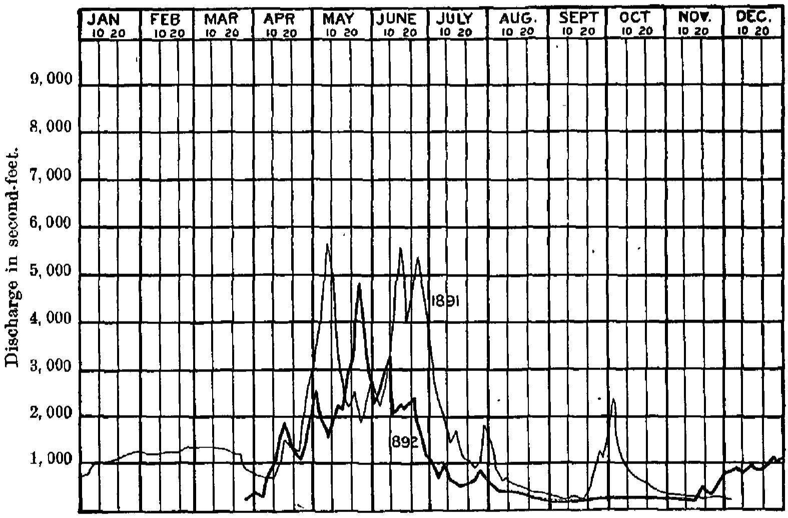

FIG. 11.—Daily discharge of Rio Grande at Del Norte, Colorado, for 1891 and 1892.

measurements have been made, all of which fall along the plotted curve with as close agreement as could be anticipated, showing that there has been little change in the channel of the stream.

Discharge of Rio Grande at Del Norte, Colorado.

[Drainage area, 1.400 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off	
					Depth	Per square mile.
1889	*Sec.-ft*	*Sec -ft*	*Sec.-ft.*	*Acre-ft*	*Inches.*	*Sec -ft.*
October 11 to 31	345	214	278	17,097	·23	·20
November	364	290	319	18,980	·25	·23
December	364	200	281	17,281	·23	·20
1890.						
January	1,000	326	552	33,948	45	·39
February	896	745	796	44,178	59	·57
March	842	404	487	29,950	·40	·35
April	1,380	404	913	54,323	73	·65
May	5,930	1,990	4,331	266,356	3·57	3·09
June	5,555	2,550	3,807	226,516	3 03	2·72
July	2,260	862	1,515	93,172	1 25	1·08
August	930	450	612	37,638	·50	·44
September	450	326	383	22,788	·31	·27
October	862	307	470	28,905	39	·34
November	610	345	478	28,441	38	·34
December	670	475	565	34,747	·46	·40
Per annum	5,930	307	1,242	900,962	12 06	·89
1891						
January	1,320	670	990	60,885	81	·71
February	1,410	1,196	1,294	71,817	·96	·92
March	1,460	930	1,280	78,720	1·05	·91
April	3,160	796	1,410	83,895	1·12	1·01
May	5,650	1,860	3,245	202,027	2 70	2·34
June	5,555	2,190	4,146	246,687	3·31	2·96
July	3,565	862	1,693	104,119	1·39	1 21
August	1,460	404	663	40,774	·54	·47
September	1,234	290	527	31.356	·42	·38
October	2,475	450	844	51,906	·69	·60
November	450	308	374	22,253	·30	·27
December	....	... ..	*325	19,987	27	·23
Per annum	5,650	290	1,403	1,014,426	13 56	1·00
1892						
January	....	....	*300	18,450	·25	·21
February	....	....	*300	17,250	·23	·21
March 22 to 31	345	290	316	19,484	·26	·23
April	2,400	345	1,047	62,296	·83	·75
May	4,710	1,510	2,605	160,207	2·15	1·86
June	3,160	1,152	2,187	130,126	1·74	1 56
July	1,074	554	740	45,510	61	·53
August	610	308	444	27,306	·38	·32
September	308	243	262	15,589	·21	·19
October	290	243	259	15,928	·21	·18
November	829	243	360	21,420	29	·26
December	1,074	862	922	56,703	·76	·66
Per annum	4,710	243	812	590,219	7 92	·58
1893						
January	1,113	862	966	59,409	·80	·69
February	....	....	*700	38,850	·52	·50
March	....	....	*500	30,750	41	·36
April	1,037	326	533	31,714	42	·38
May	3,320	732	1,944	119,556	1 60	1 39
June	2,850	670	1,749	104,066	1 39	1·25
July	640	290	395	24,292	·33	·28
August	450	258	324	19,926	27	·23
September	345	228	270	16,065	·22	·19
October	308	243	263	16,175	22	·19
November	450	214	278	16,600	·22	·19
December	862	228	642	39,483	·53	·46
Per annum	3,320	214	714	516,886	6 93	51

*Estimated.

The gaging station at Embudo was the earliest established by this Survey, observations having been carried on since the fall of 1888. The daily fluctuations at this station for 1889 and 1890 are shown upon

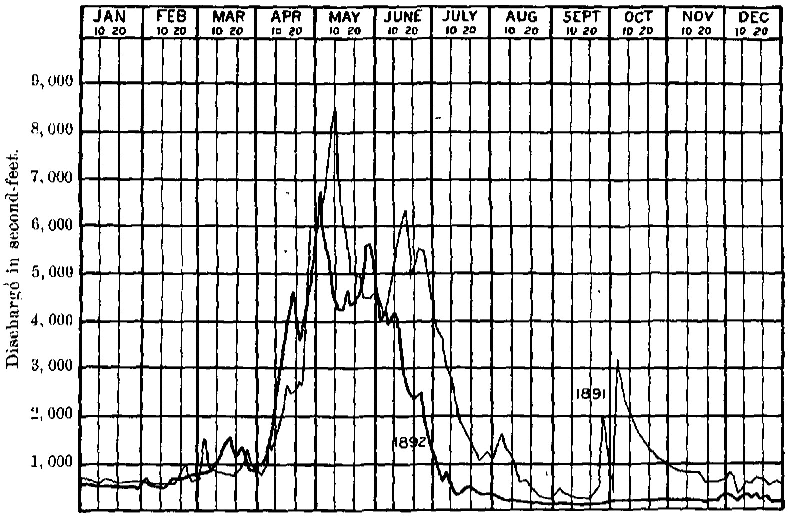

FIG. 12.—Daily discharge of Rio Grande at Embudo, New Mexico, for 1891 and 1892.

Pl. LXXIII of the Eleventh Annual Report and those for 1891 and 1892 upon the accompanying diagram, Fig. 12, the details by months being given in the following table:

Discharge of Rio Grande at Embudo, New Mexico.

[Drainage area, 7,000 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month	Run-off.	
					Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft*
January	495	379	431	26, 506	·07	·06
February	576	420	473	26, 251	·07	·07
March	1, 042	537	784	48, 216	·13	·11
April	4, 420	970	2, 261	134, 530	·36	·32
May	5, 075	2, 443	3, 430	210, 945	·56	·49
June	5, 660	1, 390	2, 922	173, 859	·47	·42
July	1, 105	236	471	28, 966	07	·07
August	253	181	206	12, 669	·03	·03
September	264	184	212	12, 614	03	·03
October	324	243	283	17, 404	·05	·04
November	507	253	366	21, 777	·06	·05
December	610	364	542	33, 333	·09	·08
Per annum	5, 660	181	1, 032	747, 070	1 99	·15
1890						
January	617	260	437	26, 875	·07	·07
February	670	344	553	30, 691	·08	·08
March	1, 044	330	682	41, 943	·11	·10
April	3, 220	842	2, 083	123, 938	·33	·30
May	6, 071	2, 660	4, 960	305, 040	·82	·71
June	5, 740	2, 768	4, 107	244, 366	·65	·59
July	2, 640	920	1, 593	97, 969	·26	·23
August	1, 134	636	814	50, 061	·13	·12
September	1, 044	496	545	32, 427	·09	·08
October	606	523	562	34, 563	·09	·08
November	699	550	616	36, 652	·10	·09
December	660	636	648	39, 852	·11	·09
Per annum	6, 071	260	1, 467	1, 064, 377	2·84	·21

Discharge of the Rio Grande at Embudo, New Mexico—Continued.

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1891.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
January	666	550	586	36,039	·10	·08
February	1,000	550	616	34,182	·09	·09
March	1,450	735	917	56,395	·15	·13
April	5,690	735	2,370	141,015	·38	·34
May	8,550	4,520	5,965	366,847	·98	·85
June	6,340	4,325	5,040	299,880	·80	·72
July	4,130	1,250	2,356	144,894	·39	·34
August	1,805	320	933	57,379	·15	·13
September	2,025	320	469	27,905	·08	·07
October	3,350	225	1,681	103,381	·28	·24
November	970	515	778	46,291	·12	·11
December	880	340	553	34,009	·09	·08
Per annum	8,550	225	1,855	1,348,217	3·61	·26
1892.						
January	615	440	497	30,565	·08	·07
February	700	490	596	34,270	·09	·08
March	1,550	700	1,051	64,636	·17	·15
April	4,910	860	2,979	177,250	·47	·42
May	6,665	4,130	4,890	300,735	·81	·70
June	4,715	1,550	3,146	187,187	·50	·45
July	1,400	280	538	33,087	·09	·08
August	300	152	191	11,746	·04	·03
September	165	140	152	9,044	·02	·02
October	260	165	202	12,423	·03	·03
November	400	243	317	18,861	·05	·05
December	490	165	324	19,926	·05	·05
Per annum	6,665	140	1,240	899,730	2·40	·18
1893.						
January	360	280	332	20,418	·06	·05
February	465	340	415	23,033	·06	·06
March	670	360	501	30,812	·08	·07
April	2,465	700	1,436	85,442	·23	·21
May	5,105	1,500	3,119	191,819	·51	·45
June	3,740	540	2,533	150,714	·41	·36
July	1,150	130	226	13,899	·04	·03
August	565	140	230	14,145	·04	·03
September	440	225	287	17,077	·05	·04
October	420	340	363	22,325	·06	·05

The gaging station at El Paso is located at Fort Bliss, about a mile above the center of the town, and above the dam built for diverting the water into the Mexican canals. The fluctuations at this locality for 1889, 1890, and the early months of 1891, are shown upon Pl. LXXIII of the Twelfth Annual Report, and those for 1891 and 1892 upon the accompanying diagram, Fig. 13. The most noticeable feature is the unusual flood of May, 1891, reaching a computed discharge of 16,620 second-feet. The average discharge for 1891 was, as shown by the table, about twice as great as that for the years 1890 and 1892. The rating curve for this station has been reproduced on page 555 of vol. 20 of the Transactions of the American Institute of Mining Engineers, illustrating the peculiar form due, probably, to partial obstruction of the river by the dam below the gauging station.

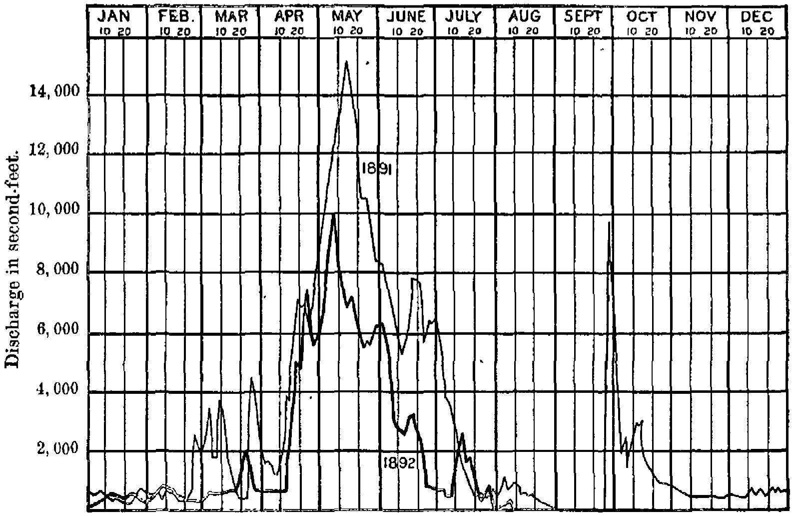

FIG. 13.—Daily discharge of Rio Grande at El Paso, Texas.

Discharge of Rio Grande at El Paso, Texas.

[Drainage area, 30,000 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1889.	*Sec. ft*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
May 10 to 31	4,705	2,060	3,116	191,634	·120	·104
June	4,460	660	2. 638	156,961	·098	·090
July	930	0	237	14,575	·009	·007
August	0	0	0	0	0	0
September	0	0	0	0	0	0
October	0	0	0	0	0	0
November	0	0	0	0	0	0
December	252	0	71	4,366	·003	·002

Discharge of Rio Grande at El Paso, Texas—Continued.

Moth.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1890.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
January	280	126	196	12, 054	·008	·007
February	458	108	290	16, 095	·010	·010
March	1 140	45	424	26, 076	·016	·014
April	4. 108	470	2, 190	130, 305	·081	073
May	7, 200	3, 495	5, 771	354, 916	·221	·190
June	7, 200	2, 925	4, 404	262, 038	·164	·147
July	2, 355	235	854	52, 521	·033	·028
August	2, 497	170	734	45, 141	·028	024
September	660	40	176	10, 472	·006	·006
October	116	40	65	3, 997	·003	·002
November	610	40	284	16, 898	·011	·009
December	610	430	535	32, 902	·020	·018
Per annum	7, 200	40	1, 327	963, 415	·601	·044
1891.						
January	715	140	451	27, 736	·017	·015
February	2, 640	470	809	44, 899	·028	·027
March	4, 635	470	1, 866	114, 759	·072	·062
April	8, 625	1, 040	4, 265	253, 767	·159	·142
May	16, 620	8, 340	11, 852	726, 528	·454	·396
June	8, 340	5, 045	6, 714	399, 483	·249	·224
July	6, 845	610	2, 271	139, 666	·088	·076
August	1, 785	17	662	40, 713	·025	·022
September	9, 480	0	768	45, 695	·030	·027
October	3, 535	560	1, 488	91, 512	·057	·050
November	515	235	341	20, 289	·012	·011
December	560	190	344	21, 156	·013	·011
Per annum	16, 620	0	2, 653	1, 926, 203	1·204	·088
1892.						
January	470	155	326	20, 049	·013	·011
February	830	290	476	27, 370	·017	·016
March	2, 070	390	752	46, 248	·029	·025
April	7, 485	470	3, 147	187, 246	·117	·105
May	10, 050	5, 205	7, 093	436, 219	·272	·236
June	6, 485	560	2, 948	175, 108	·109	·098
July	2, 500	0	668	41, 082	·026	·022
August	140	0	13	800	·000	·000
September	0	0	0	0	0	0
October	0	0	0	0	0	0
November	0	0	0	0	0	0
December	0	0	0	0	0	0
Per annum	10, 050	0	1, 285	934, 122	0·583	·043
1893.						
January	190	0	134	8, 241	·005	·004
February	355	62	144	7, 992	·005	·005
March	128	0	35	2, 152	·001	·001
April	3, 495	0	808	48, 076	·030	·027
May	6, 630	660	3, 764	231, 486	·145	·125
June	660	20	225	13, 388	·008	·007

CARSON RIVER.

Gagings on the two principal branches of this river were carried on through 1891, those upon the West Carson being discontinued at the end of that year. The accompanying diagram (Fig. 14) shows the daily fluctuations of the East Carson for 1891 and 1892, the principal feature being the extraordinary discharge in December, reaching an estimated amount of 5,540 second-feet, this continuing, however, but a short time.

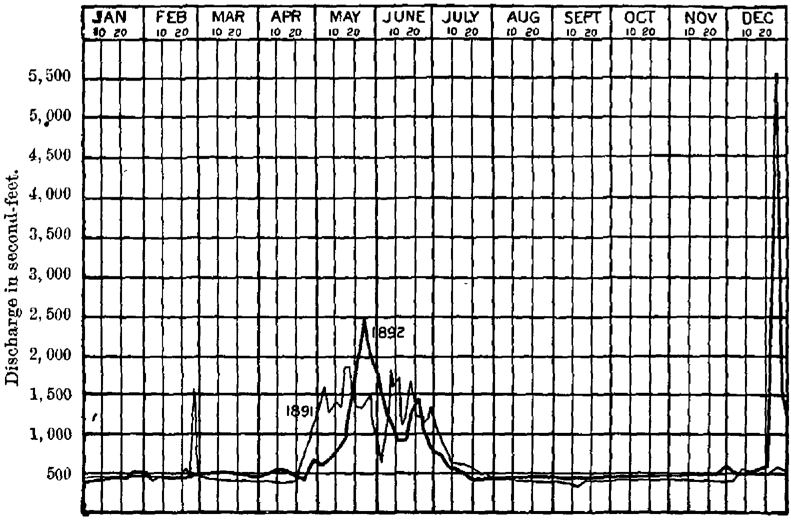

FIG 14.—Daily discharge of East Carson river at Rodenbahs for 1891 and 1892.

Discharge of East Carson river at Rodenbahs, Nevada.

[Drainage area, 414 square miles]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1890	*Sec.-ft*	*Sec.-ft*	*Sec.-ft.*	*Acre-feet*	*Inches*	*Sec.-ft.*
January	....	....	*390	23,985	1·08	94
February	....	....	*400	22,200	1·01	·97
March	....	....	*780	47,970	2·18	1·89
April 7 to 30	1,565	752	1,026	61,047	2·76	2·48
May 4 to 31	4,260	1,315	2,654	163,221	7·38	6·41
June	3,900	1,745	2,430	144,585	6·55	5·87
July	2,780	750	1,789	110,024	4·98	4·32
August	875	437	597	36,715	1·66	1·44
September	437	400	415	24,692	1·12	1·00
October	390	385	386	23,740	1·07	·93
November	385	380	384	22,848	1·04	·93
December	400	375	379	23,308	1·06	92
Per annum	4,260	375	970	704,335	31·89	2·34

* Estimated.

Discharge of East Carson river at Rodenbahs, Nevada—Continued.

Month	Maximum.	Minimum.	Mean	Total for month.	Run off.	
					Depth.	Per square mile
1891.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches*	*Sec.-ft.*
January	395	385	388	23,862	1·08	·94
February	715	377	402	22,311	1·01	·97
March	1,650	390	783	48,154	2·18	1·89
April	590	410	452	26,894	1·22	1·09
May	1,884	1,010	1,445	88,867	4·02	3·49
June	1,884	565	1,328	79,016	3·58	3·12
July	1,190	445	618	38,007	1·72	1·50
August	447	390	408	25,092	1·14	·99
September	400	385	388	23,086	1·04	·93
October	385	385	385	23,677	1·08	·93
November	385	385	385	22,907	1·05	·93
December	480	385	438	26,937	1·19	1·06
Per annum	1,884	377	619	448,810	20·31	1·50
1892.						
January	405	375	390	23,985	1·08	·94
February	400	290	388	22,310	1·00	·94
March	415	400	422	25,953	1·17	1·02
April	535	400	478	28,441	1·29	1·15
May	2,590	480	1,226	75,400	3·41	2·96
June	1,790	715	1,158	68,782	3·11	2·81
July	715	420	506	31,119	1·40	1·22
August	420	410	413	25,399	1·15	1·00
September	420	410	414	24,633	1·12	1·00
October	420	410	416	25,584	1·16	1·01
November	535	400	414	24,633	1·12	1·00
December	5,540	400	1,097	67,465	3·06	2·65
Per annum	5,540	290	610	443,704	20·07	1·47
1893.						
January	3,230	390	554	34,071	1·54	1·34
February	715	390	425	23,588	1·07	1·03
March	1,980	390	728	44,772	2·03	1·76
April	2,320	535	1,139	67,770	3·06	2·75
May	2,920	1,055	1,629	100,184	4·56	3·94
June	3,070	1,460	2,021	120,250	5·46	4·88
July	2,125	1,100	1,462	89,913	4·07	3·53
August	1,010	410	507	31,181	1·42	1·22
September	438	400	416	24,752	1·12	1·01
October	420	890	408	24,684	1·11	·99
November	493	390	425	25,288	1·14	1·03
December	460	382	404	24,846	1·13	·98
Per annum	3,230	382	843	611,299	27·71	2·04

Discharge of West Carson river at Woodford, California.

[Drainage area, 70 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month	Run-off.	
					Depth.	Per square mile.
1890.	*Sec.-ft.*	*Sec.-ft*	*Sec.-ft.*	*Acre-feet*	*Inches*	*Sec.-ft*
January	....	....	*50	3,075	·82	·71
February	....	....	*50	2,775	·75	·71
March	....	....	*60	3,690	·99	·86
April 9 to 30	448	145	284	16,898	4·56	4·06
May	924	318	657	40,405	10·83	9·40
June	1,284	448	614	36,533	9·79	8·77
July	606	252	380	23,370	6·27	5·43
August	240	90	135	8,302	2·23	1·93
September	86	70	75	4,462	1·09	1·07
October	78	54	67	4,120	1·10	·96
November	58	46	49	2,915	·78	·70
December	58	42	53	3,259	·87	·76
Per annum	1,284	42	206	149,804	40·08	2·95
1891.						
January	62	46	52	3,198	·86	·74
February	58	42	48	2,664	·71	·69
March	68	50	61	3,758	1·01	·87
April	384	62	127	7,556	2·02	1·82
May	740	300	534	32,820	8·79	7·62
June	456	260	338	20,111	5·38	4·83
July	280	82	130	7,995	2·14	1·86
August	78	50	65	3,997	1·07	·93
September	50	34	41	2,439	·65	·60
October	54	42	48	2,952	·80	·69
November	50	38	43	2,558	·69	·61
December	54	42	47	2,890	·77	·67
Per annum	740	34	128	92,938	24·89	1·83

*Estimated

BEAR RIVER

Measurements of this river have been made at two points, the first being at Battle Creek, Idaho, a few miles north of the Utah line and in the upper part of the Cache valley, the second at Collinston, Utah,

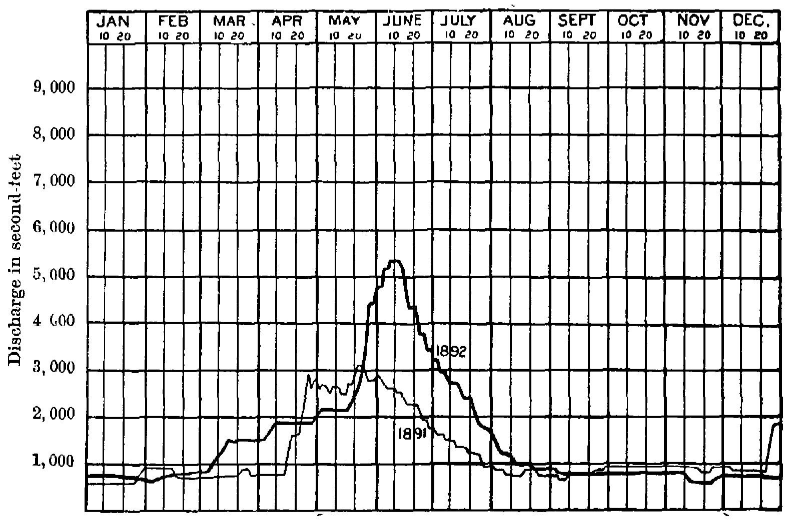

FIG 15.—Daily discharge of Bear river at Battle Creek, Idaho, for 1891 and 1892.

at the lower end of the canyon through which the river escapes from this valley into that of Salt lake. The drainage basin of this river has been briefly described upon pages 327 to 334 of the Twelfth Annual Report, and diagrams of the discharge of the river at both stations are shown on the accompanying plates. The data obtained at later times are given in the following table and illustrated by Figs. 15 and 17.

Discharge of Bear river at Battle Creek, Idaho.

[Drainage area, 4,500 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft*	*Acre-feet*	*Inches.*	*Sec.-ft.*
October 11 to 31	430	300	355	21,832	·09	07
November	830	430	487	28,976	·12	·11
December	735	350	565	34,747	·11	·13
1890						
January	1,255	270	875	53,812	22	·19
February	2,040	600	809	44,900	·18	·18
March	2,040	780	1,271	78,166	·32	·28
April	3,960	2,170	2,978	177,191	·74	·66
May	5,980	3,960	5,199	319,738	1 33	1·60
June	5,980	2,300	4,074	242,403	1 01	·91
July	2,170	1,200	1,582	97,293	·40	·35
August	1,200	880	1,000	61,500	·26	·22
September	880	780	843	50,158	·21	·19
October	880	780	854	52,521	·22	·19
November	880	780	783	46,588	·19	·17
December	780	690	748	46,002	·19	·17
Per annum	5,980	270	1,751	1,270,272	5 27	·42
1891.						
January	690	690	690	42,435	·18	·15
February	....	....	780	43,290	·18	·17
March	880	780	790	48,585	·20	·17
April	2,950	780	1,623	96,509	·40	·36
May	3,030	2,440	2,652	163,098	·68	·59
June	2,870	1,660	2,245	133,578	·56	·50
July	1,660	980	1,288	79,213	·33	·29
August	980	780	835	51,352	·21	19
September	980	690	798	47,481	·20	·18
October	980	980	980	60,270	·25	·22
November	980	880	957	56,941	·24	·21
December	1,910	880	1,053	64,759	27	23
Per annum	3,030	690	1,224	887,511	3·70	·27
1892.						
January	800	800	800	49,200	21	18
February	880	780	855	49,162	·20	·19
March	1,540	880	1,304	80,196	·33	29
April	2,040	1,540	1,824	108,528	·45	·41
May	4,370	2,040	2,710	166,665	·69	60
June	5,260	3,200	4,446	264,537	1·10	99
July	3,200	1,540	2,345	144,217	60	·52
August	1,420	880	1,025	63,037	·26	23
September	880	780	793	47,183	20	·18
October	780	780	780	47,970	·20	17
November	780	600	687	40,876	·17	·15
December	880	880	880	54,120	·23	·20
Per annum	5,260	600	1,537	1,115,691	4 64	34
1893.						
January	980	880	909	55,904	23	·20
February	980	780	873	48,452	20	·19
March	1,310	780	861	52,952	·22	·19
April	2,720	1,420	2,131	126,795	·53	·47
May	3,960	2,720	3,401	209,162	87	·76
June	3,960	2,870	3,577	212,832	89	·79
July	2,720	880	1,567	96,371	·40	·35
August	880	690	772	47,478	·20	·17
September	690	690	690	41,055	·17	·15
October	880	690	737	45,326	·19	·16
November	980	880	890	52,955	·22	·20
December	1,090	980	1,019	62,669	26	·23
Per annum	3,960	690	1,452	1,051,951	4 38	·32

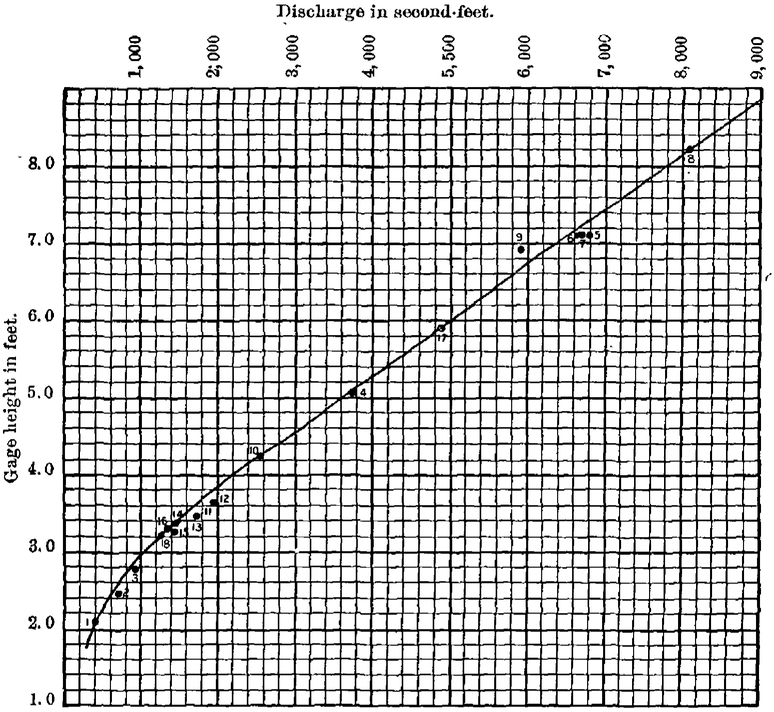

FIG. 16.—Rating curve of gaging station at Collinston, Utah, for 1891 and 1892.

Discharge of Bear river at Collinston, Utah.

[Drainage area, 6,000 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
June			*800	47,600	·15	·13
July	385	340	362	22,263	·07	·06
August	450	385	417	25,645	·08	·07
September	610	450	509	30,285	·09	·08
October	825	610	728	44,772	·14	·12
November	1,000	780	848	50,456	·16	·14
December	1,925	955	1,395	85,792	·27	·23
1890.						
January			*1,500	92,250	·29	·25
February			*1,000	55,500	·17	·17
March 2 to 31	4,860	1,100	3,188	196,062	·61	·53
April	6,680	3,600	4,953	294,703	·92	·83
May	8,220	6,890	7,924	487,326	1·52	1·32
June	7,940	4,440	6,234	370,923	1·16	1·04
July	4,230	2,060	3,250	199,875	·62	·54
August	2,060	1,545	1,754	107,871	·34	·29
September	1,425	1,310	1,344	79,968	·25	·22
October	1,665	1,365	1,544	94,956	·30	·26
November	1,425	1,365	1,403	83,478	·26	·23
December	1,545	1,000	1,243	76,444	·24	·20
Per annum	8,220	1,000	2,945	2,139,356	6·68	·49

* Estimated.

Discharge of Bear river, at Collinston, Utah—Continued.

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1891.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
January	....	....	1,000	61,500	·19	·17
February	2,200	825	1,308	72,594	·23	·22
March	2,340	1,425	1,766	108,710	·34	·29
April 1 to 11	5,000	1,665	2,729	162,375	·51	·45
May	5,000	4,020	4,569	280,993	·88	·76
June	4,720	2,480	3,595	213,902	·67	·60
July	2,270	1,100	1,565	96,063	·30	·26
August	1,100	825	938	57,687	·18	·16
September	1,200	825	986	58,667	·18	·16
October	1,310	1,200	1,235	75,952	·24	·21
November	1,310	1,200	1,262	75,089	·24	·21
December	1,545	1,100	1,216	74,784	·23	·20
Per annum	5,000	825	1,847	1,338,316	4·19	·31
1892.						
January	1,545	1,000	1,202	73,923	·23	·20
February	1,310	1,000	1,209	69,517	·22	·20
March	2,480	1,310	2,037	125,275	·39	·34
April	2,760	1,925	2,397	142,621	·45	·40
May	6,260	2,480	3,869	237,943	·74	·64
June	6,260	4,790	5,660	336,770	1·05	·94
July	4,650	1,545	3,037	186,775	·58	·51
August	1,545	1,000	1,195	73,492	·23	·20
September	1,000	1,000	1,000	59,500	·19	·17
October	1,200	1,000	1,131	69,556	·22	·19
November 1 to 26	1,310	1,100	1,195	71,102	·22	·20
December	1,425	1,100	1,235	75,952	·24	·21
Per annum	6,260	1,000	2,097	1,522,406	4·76	·35
1893.						
January	1,100	1,000	1,052	64,698	·20	·17
February	1,255	825	969	53,779	·17	·16
March	2,720	750	1,340	82,410	·26	·22
April	4,020	2,770	3,579	212,950	·67	·60
May	6,470	3,740	4,920	302,580	95	·81
June	5,140	3,740	4,645	276,378	·87	·77
July	3,670	1,000	2,000	123,000	·38	·33
August	1,000	675	765	47,048	·15	·13
September	910	675	760	45,220	·14	·13
October	1,100	910	990	60,885	·19	·17
November	1,310	1,100	1,090	64,855	·20	·17
December	1,425	825	1,144	70,356	·22	·19
Per annum	6,470	675	1,938	1,404,159	4·40	.32

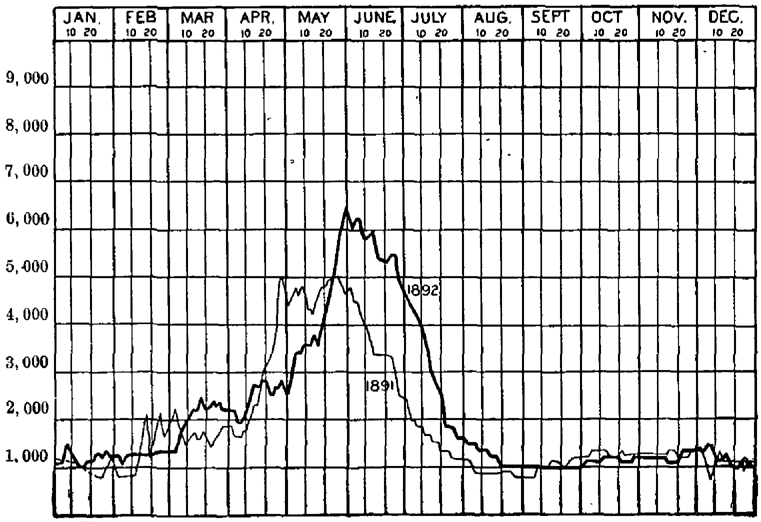

FIG. 17.—Discharge of Bear river at Collinston, Utah, for 1891 and 1892.

WEBER RIVER.

The gaging station on this river is located in the lower end of the canyon about 1,000 feet east of the bridge, at the point known as Devil Gate, about 2 miles above the town of Uinta. Brief mention is made of the drainage basin of this river upon page 334 of the Twelfth Annual Report and comparisons are drawn between the fluctuations of this and of Bear river. The following table and the diagram (Fig. 18) give information obtained since the publication of that report:

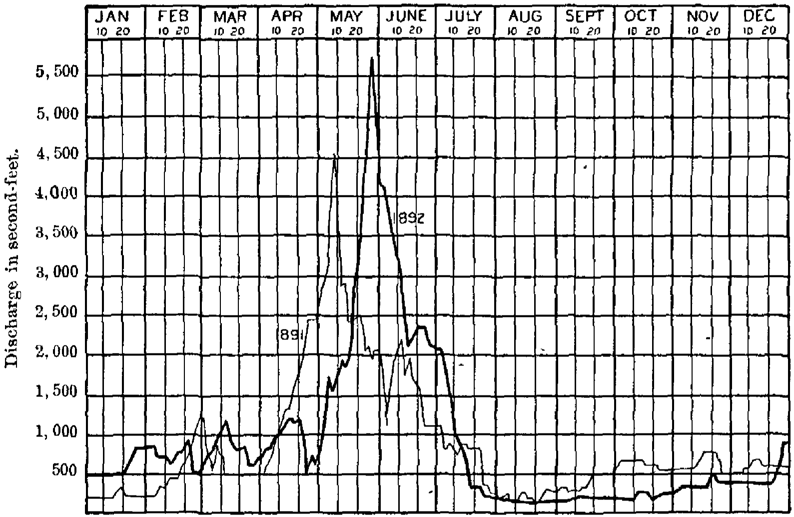

FIG. 18.—Daily discharge of Weber river above Uinta, Utah, for 1891 and 1892.

Discharge of Weber river.

[Drainage area, 1,600 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
October 13 to 31	290	130	181	11,131	·13	·11
November	290	160	208	12,376	·14	·12
December	815	200	430	26,445	·31	·27
1890.						
January	815	290	457	28,105	·33	·29
February	1,400	200	547	30,358	·36	·34
March	2,130	200	1,091	67,096	·79	·68
April	4,280	970	2,184	129,948	1·52	1·36
May	5,465	3,470	4,528	278,472	3·26	2·83
June	3,635	1,220	2,017	120,011	1·41	1·27
July	1,220	290	549	33,763	·40	·34
August	450	200	280	17,220	·20	·18
September	290	240	265	15,767	·18	·17
October	450	200	331	20,356	·22	·21
November	340	290	298	17,731	·21	·19
December	340	240	290	17,835	·21	·18
Per annum	5,465	200	1,070	776,662	9·09	·67

Discharge of Weber river—Continued.

Month	Maximum	Minimum	Mean.	Total for month	Run-off.	
					Depth	Per square mile.
1891.	*Sec.-ft*	*Sec.-ft.*	*Sec.-ft*	*Acre-feet.*	*Inches.*	*Sec.-ft*
January	450	290	303	18, 634	23	19
February	1, 220	290	461	25, 586	·30	·29
March	1, 220	450	625	38, 437	45	·39
April	2, 420	520	1, 502	89, 369	1 05	·94
May	4, 655	1, 940	2, 752	169, 250	1 98	1 72
June	2, 225	1, 135	1, 621	96, 449	1 13	1 01
July	1, 265	395	844	51, 906	·61	·53
August	520	240	338	20, 787	24	·21
September	520	290	402	23, 919	·28	·25
October	665	520	599	36, 838	43	·38
November	665	520	573	34, 093	40	·36
December	665	520	534	32, 841	39	·33
Per annum	4, 655	240	880	638, 109	7 19	·55
1892						
January	890	520	599	36, 838	·43	·37
February	890	520	605	39, 962	47	·43
March	1, 220	590	800	49 200	·58	·50
April	1, 220	450	900	53, 550	·63	·56
May	5, 750	590	2, 705	166, 357	1 95	1 ·69
June	4, 530	2, 035	2, 867	170, 586	2 00	1 79
July	2, 035	160	819	50, 368	59	·51
August	160	100	239	14, 698	·17	·15
September	200	160	187	11, 126	·13	·12
October	290	200	240	14, 760	·17	·15
November	450	290	357	21, 241	·25	·22
December	890	395	476	29, 274	·34	·30
Per annum	5, 755	100	907	657, 960	7 71	·57
1893.						
January	740	200	264	16, 236	·19	·16
February	200	200	200	11, 100	13	·12
March	2, 225	200	912	56, 088	·66	·57
April	2, 930	240	1, 605	95, 498	1 12	1 00
May	7, 280	2, 225	3, 772	231, 978	2 ·72	2 36
June	4, 530	1, 135	2, 991	177, 965	2 08	1 87

PROVO RIVER.

The gagings of this stream have been continued at the point in Provo canyon about 6 miles from the city. For a description of this river reference should be made to page 72 of the Eleventh Annual Report, part 2, and for the fluctuations of discharge to Pl. XCIV of the Twelfth Annual Report. The data obtained since the publication of these volumes are given in the following table and are shown upon the accompanying diagram forming the upper half of Fig. 19:

Discharge of Provo river.

[Drainage area, 640 square miles]

Month.	Maximum.	Minimum.	Mean.	Total for month	Run-off.	
					Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches*	*Sec.-ft.*
July 27-31	150	149	150	9, 225	·27	23
August	149	144	145	8, 917	26	23
September	174	144	150	8, 925	·26	·23
October	200	174	180	11, 070	·32	·28
November	280	200	224	13, 328	·30	·35
December	630	240	384	23, 616	·69	·60

Discharge of Provo river—Continued.

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth	Per square mile.
1890.	*Sec.-ft*	*Sec.-ft*	*Sec. ft.*	*Acre feet.*	*Inches.*	*Sec.-ft*
January	700	200	305	18, 751	55	·48
February	564	280	377	20, 923	61	·59
March	700	240	519	31, 918	93	·81
April	1, 240	500	840	49, 980	1 46	1 32
May	2, 180	1, 316	1, 926	118, 450	3 47	3 01
June	2, 260	440	1, 184	70, 448	2 06	1 85
July	440	280	314	19, 311	56	·19
August	280	240	252	15, 498	·45	·39
September	280	240	244	14, 518	43	·38
October	330	280	304	18, 696	·55	48
November	330	280	303	18, 028	·53	·47
December	330	240	293	18, 020	·53	·46
Per annum	2, 260	200	572	414, 541	12·13	89
1891						
January	280	240	255	15, 684	·46	·40
February	500	280	311	17, 240	50	·48
March	1, 316	280	492	30, 258	89	·77
April	930	280	478	28, 430	·83	·75
May	1, 704	851	1, 226	75 399	2 21	1 92
June	1, 470	851	1, 190	70, 805	2 ·07	1 86
July	1, 240	200	423	26, 014	76	·67
August	280	200	260	15, 990	·47	41
September	440	280	314	18, 683	·55	·49
October	380	330	364	23, 386	·68	·57
November	380	380	380	22, 610	67	·60
December	380	330	343	21, 094	·62	54
Per annum	1, 704	200	503	365, 591	10 71	79
1892.						
January	330	330	330	20, 295	59	·52
February	380	330	351	20, 182	59	·55
March	440	330	361	22, 201	·65	.57
April	440	330	377	22, 431	66	·59
May	1, 780	774	1, 079	66, 358	1 95	1·68
June	1, 626	1, 316	1, 511	89, 905	2 64	2·37
July	1, 240	200	441	27, 121	·80	·69
August	280	174	201	12, 361	36	·31
September	240	200	201	11, 959	35	·31
October	280	200	241	14, 821	43	·38
November	280	240	279	16, 600	49	·44
December	330	240	257	15, 805	·45	·40
Per annum	1, 780	174	469	340, 039	9 96	·73
1893.						
January	280	240	252	15, 498	·45	·39
February	280	240	271	15, 041	·44	·42
March	774	280	326	20, 049	59	·51
April	928	380	638	37, 961	1 11	1·00
May	2, 340	564	1, 237	76, 076	2 23	1·93
June	2, 260	774	1, 579	93, 951	2 75	2·47
July	1, 006	280	400	24, 600	72	·63
August	280	240	250	15, 375	·45	·39
September	280	240	260	15, 470	45	·41
October	380	280	348	21, 402	·63	·54
November	440	380	388	23 086	68	·61
December	440	380	413	25, 400	·75	·65
Per annum	2, 340	240	530	383, 909	11 25	83

SEVIER RIVER.

The gaging station on this stream is in the lower part of its course, being at Leamington, at the foot of a narrow gorge through which the river winds on its way to Sevier lake. Along the upper part of the river, south of and above this point, are many irrigating canals, diverting at times the entire amount of water in the stream. A small amount returns, however, by seepage or from the drainage area below Sevier valley to maintain a constant flow at Leamington. Below this point are canals irrigating lands in the vicinity of Deseret, Oasis, and other settlements in the vicinity. There are, northeasterly from Sevier lake, enormous areas of land upon which water is needed, the extent being so great that even if all the water is held by storage a small part only of the land can be supplied. The measurements at this point, therefore, have an especial value in determining the possibility of future development in this broad valley. The matter has been discussed briefly on pages 74 to 77 of the Eleventh, and on pages 339 to 344 of the Twelfth Annual Reports, since which time the amount of information at hand has been greatly increased, that concerning the water supply being shown by the following table and the diagram forming the lower half of Fig. 19:

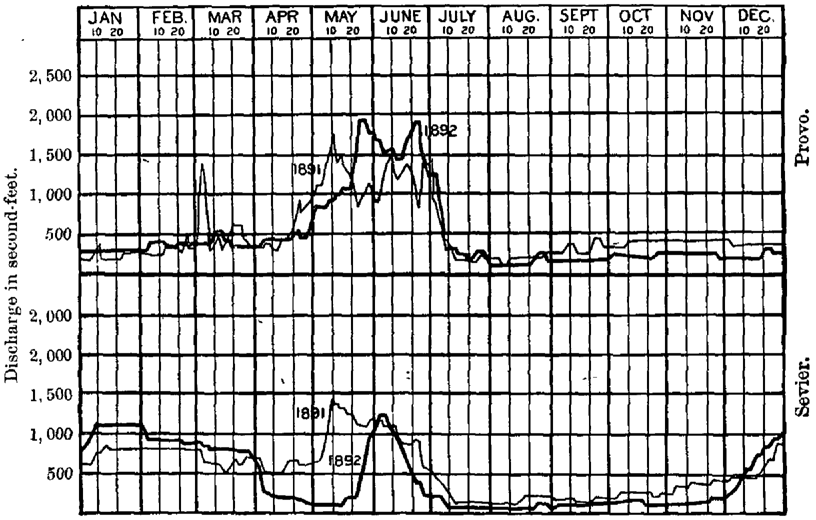

FIG. 19.—Daily discharge of Provo and Sevier rivers, Utah, for 1891 and 1892.

Discharge of Sevier river.

[Drainage area, 5,595 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
1889.						
August 23 to 31	60	40	48	2,952	·01	·01
September	80	48	53	3,153	·01	·01
October	160	48	111	6,826	·02	·02
November	444	210	274	16,303	·05	·05
December	526	280	395	24,292	·08	·07
1890.						
January	1,058	280	625	38,437	·13	·11
February	1,140	567	713	39,571	·13	·13
March	690	567	630	38,745	·13	·11
April	976	608	726	43,197	·14	·13
May	2,329	976	1,705	104,857	·35	·31
June	2,206	649	1,250	74,375	·25	·22
July	649	185	346	21,279	·07	·06
August	185	150	153	9,409	·03	·03
September	185	150	157	9,342	·03	·03
October	362	185	310	19,065	·06	·06
November	403	321	373	22,194	·07	·07
December	649	403	509	31,304	·10	·09
Per annum	2,329	150	625	451,775	1·49	·11
1891.						
January	772	649	735	45,202	·15	·13
February	772	772	772	42,846	·14	·14
March	772	526	618	38,007	·13	·11
April	608	526	503	29,928	·10	·09
May	1,386	608	1,114	68,511	·23	·20
June	1,140	567	952	56,644	·19	·17
July	526	140	297	18,265	·06	·05
August	245	140	195	11,992	·04	·03
September	185	160	175	10,412	·03	·03
October	210	185	202	12,423	·04	·04
November	403	210	312	18,564	·06	·06
December	813	403	551	33,886	·11	·10
Per annum	1,386	140	535	386,680	1·20	·10
1892.						
January	1,058	813	1,016	63,485	·21	·18
February	1,017	895	931	53,532	·18	·17
March	854	608	738	45,387	·15	·13
April	567	100	232	13,804	·05	·04
May	1,017	80	250	15,375	·05	·04
June	1,222	210	718	42,721	·14	·13
July	210	48	88	5,412	·02	·02
August	80	48	53	3,259	·01	·01
September	60	48	49	2,915	·01	·01
October	80	48	53	3,259	·01	·01
November	120	100	117	6,961	·02	·02
December	976	140	570	35,055	·12	·10
Per annum	1,222	48	401	291,165	·97	·07
1893.						
January	1,304	526	798	49,077	·16	·14
February	1,304	567	630	34,965	·12	·11
March	1,058	245	274	16,851	·06	·05
April	895	280	642	38,199	·13	·11
May	1,058	245	775	47,662	·16	·13
June	976	120	479	28,500	·10	·09
July	1,304	40	157	9,655	·03	·03
August	567	35	280	17,220	·06	·05
September	403	40	273	16,243	·05	·05
October	100	35	55	3,383	·01	·01
November	100	60	83	4,939	·02	·01
December	140	80	104	6,396	·02	·02
Per annum	1,304	35	379	273,090	92	·07

SNAKE RIVER AND TRIBUTARIES.

The gaging stations on the upper tributaries of the Snake river, in Idaho, mentioned on pages 78 to 83 of the Eleventh Annual Report, have in the main been abandoned on account of the expense and the difficulty of securing observers of river height. At two localities, however, later readings have been made, these being on the Teton river near the mouth of its canyon, about 3 miles from the town of Wilford, Idaho, and that on the Snake river itself, 2 miles below Eagle Rock, or, according to the change of name, Idaho Falls. The results of these later observations are shown in the following tables and by the accompanying diagrams, Figs. 20 and 21. In the case of Snake river no observations were made during 1891, the diagram therefore showing the fluctuations for 1890 and 1892. The gage rod or nilometer at this point has an inclination of about 30 degrees, and is located on the right or western bank of the river.

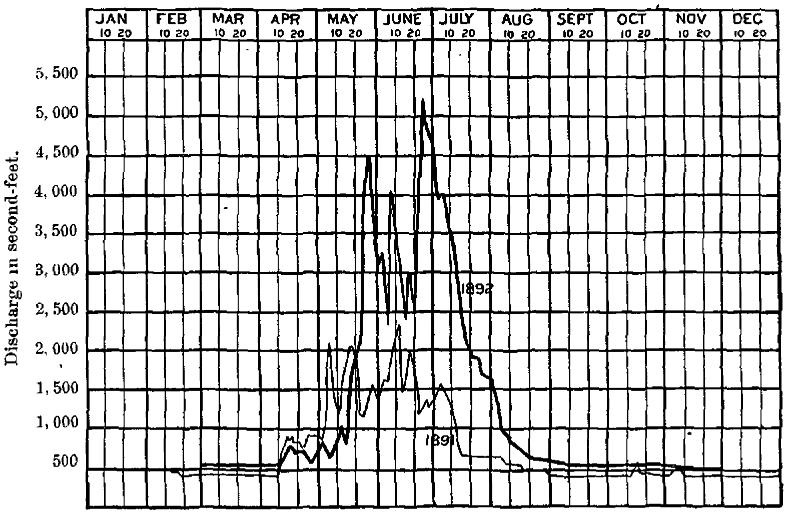

FIG. 20.—Daily discharge of Teton river, Idaho, for 1891 and 1892.

Discharge of Teton river.

[Drainage area, 967 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth	Per square mile.
1890.	*Sec.-ft.*	*Sec.-ft*	*Sec.-ft*	*Acre feet*	*Inches*	*Sec.-ft.*
January	....	....	*400	24,600	48	·41
February	....	....	*465	25,807	50	·47
March	....	....	*450	27,675	·54	·47
April 5 to 30	1,295	545	740	44,030	85	·77
May	4,445	1,545	2,730	167,895	3 26	2 82
June	4,065	1,925	2,812	167,314	3 26	2 91
July	2,950	935	2,130	130,995	2·54	2 20
August	935	510	678	41,697	·81	·70
September	510	450	462	27,489	·53	·48
October	510	450	475	29,212	57	·49
November	450	450	450	26,775	52	·46
December	510	450	459	28,228	·55	·47
Per annum	4,445	450	1,0.1	741,717	14·41	1·05

* Estimated.

Discharge of Teton river—Continued.

[Drainage area, 967 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1891.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
January	....	....	*400	24, 600	·48	·41
February 17 to 28	475	450	465	25, 807	·50	·48
March	450	450	450	27, 675	·54	·47
April	935	450	630	37, 485	·72	·65
May	2, 360	720	1, 402	86, 223	1·66	1·45
June	2, 360	1, 295	1, 661	98, 829	1·91	1·72
July	1, 635	670	1, 050	64, 575	1·25	1·09
August	670	450	547	33, 640	·65	·57
September	450	450	450	26, 775	·52	·47
October	450	425	444	27, 306	·53	·46
November	....	....	*425	25, 287	·49	·44
December	2, 360	425	*425	26, 137	·51	·44
Per annum	2, 360	425	696	504, 339	9·76	·72
1892.						
January	....	....	*400	24, 600	·48	·41
February	....	....	*425	24, 437	·47	·44
March	450	450	450	27, 675	·54	·47
April	820	450	575	34, 212	·66	·60
May	4, 990	585	1, 911	117, 526	2·28	1·92
June	5, 270	2, 245	3, 845	228, 777	4·43	4·00
July	4, 575	1, 545	2, 780	170, 970	3·32	2·88
August	1, 455	545	758	46, 617	·90	·79
September	510	475	488	29, 036	·56	·51
October	475	450	471	28, 965	·56	·49
November	450	450	450	26, 775	·52	·47
December	....	....	*450	27, 675	·54	·47
Per annum	5, 270	450	1, 084	777, 265	15·26	1.12
1893.						
January	....	....	*425	26, 138	·51	·44
February	....	....	*425	23, 588	·46	·44
March 19 to 31	425	425	425	26, 138	·51	·44
April	820	425	628	37, 366	·73	·65
May	2, 590	670	1, 400	86, 100	1·67	1·45
June	5, 830	1, 725	3, 868	230, 146	4·47	4·00
July	2, 950	1, 215	1, 770	108, 855	2·12	1·83
August	1, 140	585	794	48, 831	·95	·82
September	625	475	530	31, 535	·61	·54

* Estimated.

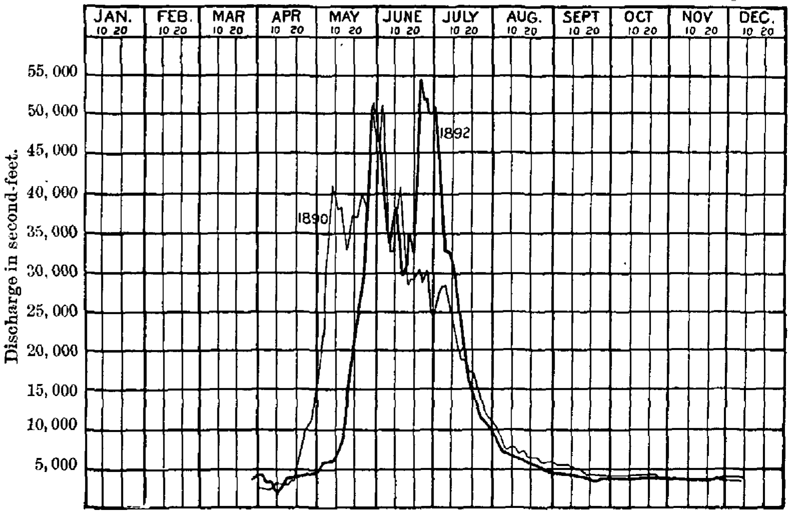

FIG. 21.—Daily discharge of Snake river at Idaho Falls, Idaho, for 1891 and 1892.

Discharge of Snake river at Idaho Falls, Idaho.

[Drainage area, 10,100 square miles.]

Month.	Maximum.	Minimum.	Mean.	Total for month.	Run-off.	
					Depth.	Per square mile.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Acre-feet.*	*Inches.*	*Sec.-ft.*
July	8, 646	3, 174	5, 184	318, 816	·59	·51
August	3, 130	2, 286	2, 596	159, 654	·30	·26
September	2, 508	2, 286	2, 300	136, 850	·25	·23
October	2, 730	2, 286	2, 425	149, 137	·28	·24
November	2, 952	2, 508	2, 737	162, 851	·30	·27
December	2, 730	2, 508	2, 601	159, 961	·30	·26
1890.						
January			*2, 000	123, 000	·23	·20
February			*2, 000	111, 000	·21	·20
March			*2, 000	123, 000	·23	·20
April	15, 000	2, 900	5, 702	339, 269	·63	·57
May	49, 350	16, 900	35, 606	2, 189, 769	4·06	3·52
June	50, 450	24, 930	34, 870	2, 074, 765	3·85	3·45
July	28, 800	10. 700	19, 970	1, 228, 155	2·28	1·98
August	10. 350	6, 250	7, 875	484, 312	·90	·79
September	5, 950	4, 350	4, 934	293, 573	·54	·48
October	4, 600	4, 350	4, 552	279, 948	·52	·45
November	4. 350	3, 900	4, 207	250, 316	·47	·42
December			*3, 900	239, 850	·45	·39
Per annum	50, 450	2, 900	10, 635	7, 736, 957	14·37	1·05
1892.						
January			3, 000	184, 500	·34	·30
February			3, 000	172, 500	·32	·30
March 24 to 31	4, 100	3, 500	3, 900	239, 850	·44	·39
April	4, 600	2, 250	3, 760	223, 720	·41	·38
May	51, 000	4, 725	18, 187	1, 118, 500	2·08	1·80
June	54, 300	29, 675	41, 357	2, 460, 741	4·56	4·10
July	51, 000	10, 000	24, 069	1, 480, 243	2·75	2·40
August	9, 650	4, 850	6, 463	397, 474	·74	·64
September	4, 850	3, 900	4, 312	256, 546	·48	·43
October	4, 350	4, 100	4, 156	255, 594	·47	·41
November	4, 100	4, 100	4, 100	243, 950	·45	·41
December			*4, 000	246, 000	·46	·40
Per annum	54, 300	2, 250	10. 025	7, 279, 618	13·50	1·00
1893.						
January			*4, 000	246, 000	·46	·40
February			*3, 500	194, 250	·36	·35
March			*3, 500	215, 250	·40	·35
April 23 to 31	4, 100	3, 900	4, 025	239, 488	·44	·40
May	30, 113	4, 100	13, 341	820, 471	1·52	1·32
June	44, 400	16, 400	31, 214	1, 857, 233	3·42	3·09
July	25, 650	7, 450	14, 486	890, 889	1·65	1·43
August	7, 150	3, 500	4, 744	291, 756	·54	·47
September			3, 500	208, 250	·39	·35
October			3, 500	215, 250	·40	·35
November			3, 500	208, 250	·39	·35

* Estimated.

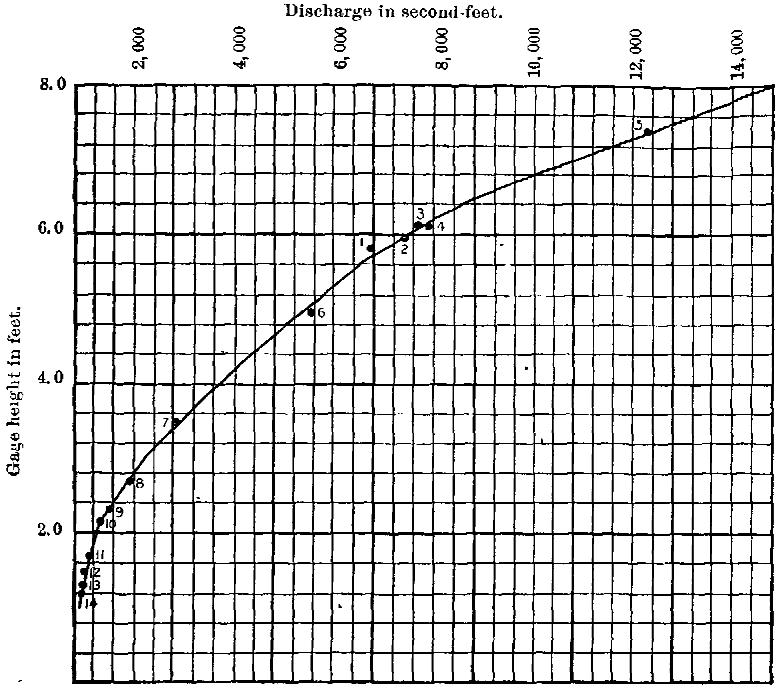

FIG 22.—Rating curve of the Owyhee river at Rigsby, Oregon.

OWYHEE RIVER.

The drainage basin of Owyhee, a tributary of Snake river, has been described in a general way on pages 85 and 86 of the Eleventh Annual Report, and a diagram showing the fluctuations has been published as

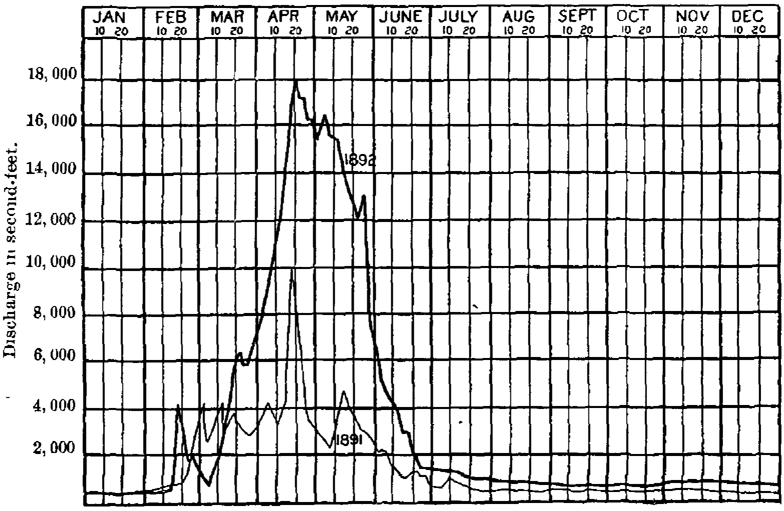

FIG 23.—Daily discharge of the Owyhee river at Rigsby, Oregon, for 1891 and 1892.

Pl. CIV of the Twelfth Annual Report. The gaging station has been at Rigsby, this being about 4 miles above the point where this river empties into the Snake and about 20 miles from the railroad station of Ontario, Oregon. The measurements of discharge upon which the rating curve is based are contained in the following table, accompanying which is Fig. 22, showing the relation of the points thus obtained to the adopted curve. The flow of the river as thus computed is shown by months in the second table, the fluctuations being exhibited by Fig. 23. The most notable feature of this is the great increase in discharge of 1892 over 1891.

Discharge of Owyhee river.

[Drainage area, 9,875 square miles]

	Maximum.	Minimum.	Mean	Total for month	Run-off	
					Depth	Per square mile
1890.	*Sec.-ft*	*Sec.-ft.*	*Sec.-ft*	*Acre-feet*	*Inches*	*Sec.-ft.*
March 26 to 31	7,350	5,190	6,140	377,610	72	62
April	8,225	5,395	6,558	390,201	74	·66
May	11,230	3,010	5,913	363,649	69	·60
June	2,850	620	1,403	83,478	·16	·14
July	560	200	343	21,094	04	·03
August	200	170	179	11,108	02	·02
September	170	170	170	10,115	02	·02
October	170	170	170	10,455	02	·02
November	280	200	221	13,150	02	·02
December	360	280	309	19,004	·04	·03
1891						
January	400	320	360	22,140	·04	·04
February	3,265	450	932	51,726	·10	·09
March	4,335	2,600	3,313	203,649	·39	·34
April	10,000	2,900	4,984	296,548	56	·51
May	4,600	2,075	3,114	191,511	·36	·31
June	2,150	500	1,267	75,386	·14	·13
July	800	240	448	27,552	05	·04
August	320	200	232	14,268	·03	·02
September	360	280	317	18,861	·04	·03
October	360	280	325	19,987	04	·03
November	400	320	376	22,372	04	04
December	320	320	320	19,680	04	·03
Per annum	10,000	200	1,332	963,680	1 83	14
1892.						
January	320	320	320	19 680	04	03
February	4,165	320	1,250	71,875	14	·13
March	7,500	630	3,900	239,850	45	·39
April	18,000	7,500	13,466	801,227	1 52	1 35
May	16,400	6,700	13,082	804,543	1 53	1·31
June	6,230	1,200	2,980	177,310	·34	30
July	1,100	700	948	58,302	·11	·10
August	700	560	594	36,531	07	06
September	560	500	506	30,107	·06	05
October	700	500	570	35,055	·07	·06
November	800	700	783	46,588	09	08
December	800	800	800	49,200	·09	08
Per annum	18,000	320	3,268	2 370,268	4 51	33
1893						
January	900	800	810	49,815	09	·08
February	1,200	900	1,032	57,276	11	·10
March	6 230	1,200	2,944	181,056	34	·30
April	10,400	2,600	6,740	401,030	76	68
May	14,800	2,150	6,857	421,705	80	70
June	2,150	1,320	1,540	91,630	17	·16
July	1,320	1,100	1,197	73,616	14	·12
August	1,100	800	916	53,334	10	·09
September	1,000	800	963	57,299	10	·09
October	1,000	1,000	1,000	61,500	·12	·10
November	1,700	1,000	1,382	82,229	16	·14

Gagings of the Owyhee river at Rigsby, Oregon.

No.	Date.	Gage height.	Discharge.
	1890.		
1	Mar 28	5 80	5 952
2	Apr. 14	5 95	6,681
3	Apr 25	6 10	6,937
4	May 3	6 10	7 105
5	May 12	7 40	11,563
6	May 20	5 0	4;788
7	June 7	3 5	2,109
8	June 17	2 7	1,101
9	June 25	2 35	756
10	July 4	2 10	589
11	July 14	1 70	363
12	July 23	1 50	273
13	July 30	1 35	209
14	Aug 13	1·20	145

YAKIMA RIVER.

This stream is one of the principal tributaries of Columbia river, in Washington. Its drainage basin is a trifle south of the center of the state, and inclines southeasterly, the waters discharging into the Columbia about 10 miles above the mouth of Snake river. The extreme length of the basin is approximately 135 miles, the greatest width 65 miles, the average width less than 40 miles, and the total area 5,200 square miles, or 7·78 per cent of the total land area of the state. The upper edge of the basin lies along the eastern crest of the Cascade mountains, which rise to heights of from 10,000 to 14,000 feet, the most prominent peak, Mount Tacoma, or Rainier, having an altitude of 14,450. The passes over the range are at altitudes of 4,000 feet and upward. This side of the basin is 75 miles long, thus including nearly one third of the eastern slopes of this mountain range, or at least of that portion of it in Washington.

Among the mountains, which are densely covered with timber, the precipitation in the form of rain and snow is heavy, and the streams, relative to the area drained, carry a large amount of water. Many of the higher valleys contain lakes, some of them of notable size, as, for example, Keechelus, Kahchass, and Tleealum, near the northern end of the basin. These lakes serve as natural reservoirs, regulating, to a certain extent, the discharge of the streams, reducing the height of the floods, and increasing the summer flow. Their usefulness in this regard could be greatly increased at moderate expense by erecting suitable dams and gates at their outlets. From the lakes and tributary torrents a number of creeks flow in a general easterly direction, finally uniting in Yakima river, which flows near the eastern side of its drainage basin. Few if any perennial streams come in from this side below the head waters, the hills which traverse the plain or plateau of the Columbia not having sufficient altitude to receive much rain.

The topography of this region has been quite fully described by Prof. I. C. Russell in Bulletin No. 108, U. S. Geological Survey, entitled

"A Geological Reconnaissance in Central Washington," wherein is shown the peculiar structure of valleys and plains along the Yakima. This river passes with rapid fall in succession through a number of transverse ranges of hills, flowing with more gentle current through the intervening valleys. The total length of the river is about 170 miles, not taking into account the smaller bends. In the upper part of its course it falls at the rate of from 18 to 20 feet per mile, or more; lower down, between Ellensburg and Yakima, it averages 14 feet per mile, decreasing toward Prosser to about 12 feet per mile, and then to 6 feet per mile or even less. Throughout its course, however, it is a remarkably swift stream and one which, flowing through a dry country, is unusually well adapted for employment in irrigation.

A few measurements of water have been made in this basin, and several gages established for the purpose of obtaining the height of water and from this the probable daily discharge at these points. The uppermost of these gage rods is near the outlet of Lake Kahchass and about 2 miles northerly from the railroad station of Easton. The altitude of this latter place is, according to railroad levels, 2,180 feet, and it is probable that the waters of the lake are at an elevation of over 2,200 feet. The lake, or at least the main body of water, is about 9 miles long and from 1½ to 2 miles wide. On August 16, 1893, the outflow of the lake, as measured at a point less than one-fourth of a mile below the outlet, was 211 second-feet. About 2 miles below, and a half mile above Easton, this water joins that from Lake Keechelus, the two streams being approximately of the same size. The area drained by each of these head-water streams above their junction, and including the lake surfaces, is about 100 square miles. The Yakima river, after receiving the waters of this lake region, flows in a general southeasterly and southerly course through the broad Kittitas valley, and then cutting across a series of ridges enters Selah valley, from which it escapes through a gap to Moxee valley. Throughout this upper course its flow is greatly increased by the creeks entering from the north and west. On leaving the gap in Selah ridge, and at a point 75 miles below Lake Kahchass and a mile above North Yakima, the Naches river, one of the largest tributaries, comes in from the west. This stream was measured on August 14, 1893, at a point an eighth of a mile above its mouth. At that time the height of water on the gage rod at the railroad bridge over the Naches was 1·00 feet, and the discharge was 1,193 second feet. The area drained, as measured from the Land Office map of Washington, is 1,000 square miles, of which 300 square miles is within the catchment area of Tiaton river, the principal fork of the Naches river. The gage rod at this point is fastened to the crib on the south side of the river, 60 feet west of the railroad bridge, the 12-foot mark of the gage being 9·97 feet below the top of the rails.

After passing along the west side of Moxee valley, Yakima river cuts through Yakima ridge, forming Union gap, this point being 7 miles below Naches river and 6 miles from North Yakima. Here the stream has been measured and gage rods established to obtain the fluctuation of water. The principal rod is under the west end of the county bridge which crosses at this point. The zero of this gage is 19·02 feet below the top of the rails on the railroad, which lie about 40 feet away. The high-water marks, presumably those of the spring flood of 1893, were on a level with the readings 9·90 of this gage. On August 14, 1893, when the water stood at 0·90, the discharge was 2,963; and on September 26, 1893, as measured by J. B. Rogers and Samuel Storrow, the water standing —0·25, the discharge was 1,186 second-feet. By assuming intermediate values for discharges between the heights given, it has been computed that the average discharge for October, 1893, was 2,662 second-feet, or, for the whole month, a total of 163,713 acre-feet. The total drainage area above this point, as measured from the Land Office map, is 3,300 square miles. Comparing this with the discharge for October, the average depth of run-off over the whole was 0·93 inches, or 0·81 second-feet per square mile drained.

There are a number of irrigating ditches taking water from Yakima river and its tributaries above this gaging station, most of these being in the Kittitas valley or in the vicinity of North Yakima. The principal irrigating works of the country are, however, below this point, taking water out upon the large valley in the vicinity and to the east of Topenish, or further down the river near Prosser and Kiona. The largest canal in operation is that of the Northern Pacific, Yakima and Kittitas Company, known as the Sunnyside canal. This is 60 feet wide at top and about 40 miles long, covering, it is estimated, about 240,000 acres situated both above and below the new town of Zillah. Other canals under construction, heading near Prosser or at points below, cover valleys along the river, or when completed will irrigate lands in the Columbia valley.

POTOMAC RIVER.

The discharge of this river has been measured at what is known as the Chain bridge, 3 miles above Washington, District of Columbia. The work and the discussion of results obtained were done by Mr. Cyrus C. Babb, from whose report the following statements have been compiled. Readings of the height of river were made three times a day, eliminating to a large degree the influence of the tides, whose daily range at this locality is about 3 feet. This river, rising in the Allegheny mountains, flows in a general southeasterly course directly across the trend of the mountains, receiving most of its branches from the narrow longitudinal valleys which it cuts. The drainage area of the north branch, mainly in the western part of the state of Maryland, is 1,365 miles, and of the south branch, coming from West Virginia, 1,407 square miles, while the total area drained at Harpers Ferry, above the junction of the Shenandoah, is 6,354 square miles. The Shenandoah itself drains 3,009 square miles.

The greater part of the catchment basin of the Potomac is composed of sharp ridges and narrow valleys, from which a large proportion of the rainfall flows in short, violent floods. The slope of the river is relatively great, the average fall from Cumberland to Washington being at the rate of 3·3 feet per mile. At the locality where gaged the river flows over a rocky bed, in high water spreading out upon the flood plains on the northern or Maryland side. Measurements were made by means of the Haskell electric current meter, either suspended from a cable across the river or from Chain bridge. The total length of span of the main and stay cable was about 300 feet, this being one of the widest rivers upon which this method of gaging has been successfully put into operation.

A long series of observations have been kept of the height of the Potomac river at the dam of the Washington aqueduct, about 5 miles farther upstream. From the comparison of readings of water height at Chain bridge and at the aqueduct dam a table was constructed by means of which and of the gagings at Chain bridge the mean daily discharges of the river were computed since 1886, as given in the following table:

Discharge of Potomac river at Great Falls, Maryland.

[Drainage area, 11,043 square miles.]

Month	Maximum	Minimum	Mean	Run-off	
				Depth	Per square mile.
1886.	*Sec.-ft*	*Sec ft.*	*Sec -ft*	*Inches*	*Sec -ft*
January	154,560	2,620	13,711	1 43	1 24
February	161,600	2,460	22,523	2 20	2·04
March	65,100	2,800	5,537	·58	·50
April	224,600	2,800	44,313	4 46	4 01
May	167,840	2,620	24,206	2 52	2 19
June	3,240	2,800	2,993	30	·27
July	24.800	2,800	5,280	55	·48
August	20,400	3,240	6,010	63	·54
September	3,580	3,240	3,387	·34	31
October	4,290	3,240	3,318	35	30
November	39,500	3,240	7,948	80	72
December	29,700	3,240	10,903	1·14	99
Per annum	224,600	2,460	12,511	15·30	1 13
1887					
January	104,320	4,290	12,208	1 27	1 11
February	54,200	5,460	24,256	2 28	2 30
March	84,000	5,460	27,311	2 84	2 48
April	71,000	4,290	14,113	1 42	1 28
May	104,320	5,460	25,181	2 62	2·28
June	29,700	4,290	14,159	1 43	1 28
July	29,700	3,240	6,118	64	·55
August	5.460	3,000	3,541	37	·32
September	4,290	3,240	3,581	37	·32
October	3,580	3,240	3,349	·35	·30
November	3,240	3,240	3,240	33	·29
December	10,500	3,240	5,613	·58	·51
Per annum	104,320	3,000	11,880	14·50	1 07

Discharge of Potomac river at Great Falls, Maryland—Continued.

Month	Maximum.	Minimum	Mean	Run-off.	
				Depth.	Per square mile
1888	*Sec.-ft.*	*Sec.-ft*	*Sec.-ft*	*Inches*	*Sec.-ft*
January	44,400	3,240	12,754	1·33	1 15
February	65,400	4,290	27,768	2 70	2·51
March	59,800	7,900	28,897	3·01	2 62
April	44,400	4,290	17,990	1 82	1 63
May	29,700	3 580	10,634	1·11	·96
June	34,600	3,000	8,707	·88	79
July	213,000	3,240	18,640	1·94	1 69
August	24,800	3,000	4,942	·51	·45
September	84,000	3,240	16,833	1 70	1 52
October	39,500	3,580	7,077	·74	64
November	54,200	5,460	16,435	1·66	1 49
December	84,000	3,580	13,703	1 43	1 24
Per annum	213,000	3,000	15,365	18 83	1 39
1889.					
January	120,080	5,460	31,292	3 26	2 83
February	65,400	5,460	19,049	1 77	1 72
March	188,200	10,500	37,932	3 95	3 43
April	167,840	7,900	35,791	3 61	3 24
May	44,400	7,900	19,020	1 98	1 72
June	471,700	3,580	47,761	4 65	4 32
July	65,400	3,240	9,610	1 00	·87
August	65,400	5,460	16,393	1 71	1 48
September	71,000	5,466	25,497	2 57	2 31
October	137,680	7,900	29 573	3 08	2 67
November	167,840	20,400	65 214	6 58	5 90
December	104,320	16,300	27,820	2 90	2 52
Per annum	471,700	3,240	32,913	37 06	2.73
1890.					
January	16,300	5,460	9,652	1·01	·87
February	84,000	3,580	38,948	3 68	3·52
March	180,000	16,300	48,920	5 09	4 43
April	59 800	10,500	25,330	2 56	2 29
May	204,700	16,300	56,422	5 26	4 56
June	34,600	13,100	26,553	2 07	1 86
July	24,800	3,000	6,426	67	58
August	24,800	3,000	6,788	·71	·61
September	24,800	3,580	7,913	80	72
October	154,560	5,460	23,616	2 46	2 14
November	16,300	5,460	9,394	·94	·85
December	20,400	4,290	8,457	88	77
Per annum	204,700	3,000	21,368	26 13	1 93
1891.					
January	120,080	7,900	40,710	4 25	3 68
February	173,920	34,600	79,986	7 54	7 23
March	154,560	20,400	59,653	6 23	5 40
April	229 600	10,500	71,444	7·22	6·47
May	29,700	4,290	6,260	65	57
June	104 320	5,460	22,062	2 23	2·00
July	24,800	5,460	11,717	1 22	1 06
August	24,800	3,240	7,102	·74	·64
September	16,300	3,000	6,022	61	54
October	3,580	3,000	3,948	·41	35
November	5,460	3,240	4,546	46	41
December	54,200	3,580	9,682	1·01	88
Per annum	229,600	3,000	26,928	32 57	2·40

Potomac river at Chain bridge, District of Columbia.

[Drainage area, 11,161 square miles]

Month	Maximum	Minimum	Mean	Run off	
				Depth	Per square mile
1892.	*Sec -ft*	*Sec -ft*	*Sec ft*	*Inches*	*Sec -ft*
January	147,200	3,580	30,774	3 18	2 76
February	31,100	5,030	10,190	·98	91
March	143,600	7,250	46,395	4 79	4 16
April	112,300	6,030	35,589	3 56	3 19
May	24,800	4,290	10,920	1 13	98
June	47,200	4,600	13,584	1 36	1 21
July	9,200	2,620	3,419	·35	31
August	7,250	2,200	3,747	39	34
September	31,800	2,460	4,616	46	41
October	5,460	2,050	2,952	31	·26
November	11,150	2,100	3,392	34	30
December	30,400	1,900	5,009	52	45
Per annum	147,200	1,900	14,216	17 37	1 28
1893					
January	9,850	2,800	5,264	54	47
February	69,600	5,460	17,205	1 67	1 55
March	98,000	3,780	26,300	2 72	2 36
April	49,300	2,800	16,064	1 61	1·44
May	198,060	9,200	33,266	3 44	2 98
June	37,400	3,780	10,921	1 10	·98
July	9,850	2,460	4,490	46	·40
August	18,300	2,800	5 527	57	·50
September	43,000	3,410	13,804	1·40	1 24
October	188,200	3,410	30,253	3·14	2 71
November	48,600	2,260	12,373	1·24	1 11
December	22,200	2,390	5,366	·56	48
Per annum	198,060	2 260	15,069	18 45	1·35

From the above table it appears that the maximum flood was that of June, 1889, when the river discharged at the estimated rate of 471,700 second-feet, this being the time when disastrous floods prevailed throughout the Appalachian region. The minimum for the period was about 2,620 second-feet, while the mean discharge by years ranged from 11,880 for 1887 to 32,913 for 1889, the average discharge in two years thus increasing nearly three times, this river, like those of the west, fluctuating within wide limits. Comparing the mean annual discharges for successive years, the following results are shown:

	Second-feet.
1886	12,511
1887	11,880
1888	15,365
1889	32,913
1890	21,368
1891	26,928
1892	14,216
1893	15,069
Average	18,781

There was thus a gradual decrease from 1886 to 1887, a rapid increase to 1889, followed by fluctuations slightly above and then below the average for the whole period. It is interesting to note that while this river, in common with others of the eastern part of the United States, reached a maximum in 1889, many streams in the western half of the United States were about at their minimum. On the other hand, the Potomac reached its lowest point in 1887, one or two years before the western streams reached theirs, and later the floods of the east occurred at the time of greatest suffering from drought in the arid region.

A study of the dependence of river flow upon rainfall was also made by Mr. Babb, in the hope of acquiring data for general use. In a drainage basin of this size, however, composed largely of sparsely inhabited mountain regions, the rainfall measurements are meager and do not fully represent the precipitation upon all parts of the catchment area. Owing to this fact, as well as to variations in the time and duration of the rain storms, the percentage of run-off has been found to be exceedingly irregular. Omitting the comparisons by months, the following table will serve to give the general range of the computations:

Year	Rainfall in inches	Run-off in inches	Per cent
1886	51·10	15·30	30·0
1887	37·03	14·50	39·2
1888	40·99	18·83	46·0
1889	53·80	37·06	68·9
1890	44·92	26·13	58·2
1891	44·34	32·57	73·4

From the above table it appears that the quantity of water in the stream has been from 30·0 to 73·4 per cent of the measured rainfall, the quantity depending largely upon the manner in which the rain fell, whether in heavy showers upon the already saturated soils or in gentle rains distributed throughout the year. The connection between rainfall and run-off is by no means simple, and while there are a few general rules the application of these is subject to so many exceptional cases that they become of little or no value in predicting the probable behavior of any large stream. The fluctuations in quantity of discharge of this and other rivers of the humid regions are far more irregular than those of the streams of the West, exhibited in the diagrams on the preceding pages. The graphic representation of discharge of the Potomac consists of a number of sharp points irregularly distributed through almost every month of the year, instead of presenting the strongly marked May and June rise, so characteristic of rivers rising among snow-covered peaks. Taking the average discharge for the years mentioned, the maximum is found to occur in March and the minimum in August, as shown by the following statement, which gives the discharge by months and in percentages of the whole quantity. With this is also shown distribution of the mean rainfall in percentages of the whole amount:

Month	Average discharge		Average rainfall.
	Second-feet.	Per cent	
			Per cent
January	21,586	9·6	7·0
February	31,817	13·9	7·4
March	36,378	16·0	9·7
April	34,938	15·4	7·6
May	20,949	9·3	11·2
June	18,545	8·1	11·6
July	8,744	3·9	10·7
August	6,932	3·0	8·4
September	9,692	4·2	8·5
October	10,545	4·7	5·8
November	15,738	6·9	6·4
December	11,598	5·0	5·7
	227,462	100·0	100·0

From a study of the above figures it appears that the river discharge, as stated before, increases as a whole until March, then decreases until August, rising again toward winter. On the other hand, the rainfall attains its maximum in June, at a time when the river is rapidly falling, and reaches its minimum in October or December, about a quarter of a year after the period of lowest water. This lack of coincidence of these two phenomena is due mainly to the increase in temperature during the summer months, resulting in greater evaporation and decreased run-off over the drainage basin.

The relation between the average rainfall and discharge per square mile, drained or run off, by months, is best shown by the following table. In two instances, February and April, the discharge from the basin was greater than the recorded amount of rain received. This is, of course, due to storage of the precipitation of former months, either as snow or ice, or as ground water saturating the pervious rocks and soils:

Month.	Average rainfall.	Average run-off	Per cent
	Inches.	*Inches*	
January	3·21	2·09	65·2
February	3·35	3·36	100·1
March	4·39	3·62	82·6
April	3·48	3·51	101·0
May	5·11	2·36	46·3
June	5·25	1·93	36·8
July	4·89	1·00	20·5
August	3·81	·78	20·5
September	3·86	1·06	27·5
October	2·65	1·21	45·7
November	2·88	1·79	62·3
December	2·59	1·32	51·1
Total	45·47	24·03	53·0

Samples of the water of the river have been taken from time to time in order to determine the quantity of sediment carried by the river and to compute, if possible, the rate of erosion and sedimentation. For many years visual tests of the condition of water have been carried on at the head of the Washington aqueduct at Great Falls, about 16 miles above the city. These tests consist in noting the distance at which a small object can be seen horizontally through the water when inclosed in a tube or case with glass ends 36 inches apart. The determination of the exact amount of sediment in the water has served to give approximately the relation between the readings of this visual method and the proportion of fine silt, or mud, making it possible to compute the total amount of solid matter carried by the river in the course of the year.

It has been found that the average amount of sediment is to the water as 1 to 3,575, and assuming that 1 cubic foot of this material weighs 100 pounds, the average amount carried during six years, from 1886 to 1891, was 353 pounds per second, or 5,557,250 tons per year. This would cover 1 square mile to the depth of 3·98 feet, and if spread over the entire drainage area would amount to a thickness of 0·0043 inches. At this latter rate of erosion it would take the river about 2,770 years to remove 1 foot in depth from the whole drainage basin. Comparing, however, the quantity carried by years, as shown by the following table, the great difference in quantity is apparent.

Year.	Rock materials transported.
	Tons.
1886	4, 280, 000
1887	2, 372, 800
1888	4, 996, 800
1889	10, 142, 560
1890	5, 994, 000
1891	5, 544, 300

From an inspection of the above figures it is at once seen that during 1889, with its heavy floods, the erosion and transportation of fine material was over four times as great as in 1887. No account is taken of the heavier sands and gravels partly rolled along the bed of the stream, but merely of the impalpable silt swept seaward and deposited near the mouth of the river.

CONNECTICUT RIVER.

An examination has been made of the material available concerning the fluctuations of this stream, which in many ways is representative of rivers of the northern humid region. The total drainage area is estimated to be 11,083 square miles, of which there are in the Dominion of Canada 156 square miles; in New Hampshire, 2,986 square miles; Vermont, 3,810; Massachusetts, 2,705, and Connecticut, 1,426. All of this country has been glaciated and contains almost innumerable lakes, which tend to equalize the discharge of the stream, reducing the height and intensity of the floods, so that the fluctuations are far less rapid than those of the Potomac, the diagram of river height being similar to that obtained from some of the snow-fed streams of the Rocky mountains.

Along the course of the river are many rapids and a number of falls of great value for water power. Dividing the river into two portions, that above the northern Massachusetts line and that below it, the first is found to have a length of 240 miles and a total fall of 1,830 feet, or an average slope of 7·6 feet per mile. The lower portion, 135 miles long, has a fall of 205 feet, or 1·5 feet per mile. For both parts the average slope is 5·4 feet per mile. Measurements of the discharge of this river were made by the Corps of Engineers of the U. S. Army near Thompsonville, Connecticut, a town a short distance below the Massachusetts line, and also at a few other places along the river, most of these being made during 1874. From these, computations were made of the probable quantity of water at Hartford corresponding to the readings of the height gage at that point. A report upon from the examination and survey of the river was made in 1878,[1] and from the published discharges and information otherwise obtained the following table has been prepared, this being in form similar to that relating to other streams, thus affording means of immediate comparison.

Discharge of Connecticut river at Hartford, Connecticut.

[Drainage area, 10,234 square miles.]

Month.	Maximum.	Minimum	Mean	Run off	
				Depth	Per square mile
1871	*Sec. ft.*	*Sec.-ft*	*Sec.-ft*	*Inches.*	*Sec.-ft*
January	....	....	....	....	....
February	49,350	7,550	18,360	1·87	1·79
March	71,510	19,470	50,240	5·64	4·90
April	38,820	19,420	25,580	2·74	2·49
May	87,460	10,800	30,250	3·42	2·95
June	14,870	6,370	9,140	99	89
July	7,520	5,520	6,185	69	60
August	17,960	5,580	7,150	80	·70
September	20,180	5,880	7,840	85	·76
October	17,100	5,910	9,060	1·02	88
November	43,750	7,910	15,190	1·65	1·48
December	28,370	7,610	12,800	1·44	1·25
Per annum	87,460	5,520	17,433	....	1·70
1872.					
January	20,610	6,470	10,940	1·23	1·07
February	10,660	6,390	7,370	77	72
March	13,610	6,250	8,015	90	78
April	98,100	9,900	50,600	5·50	4·95
May	56,350	16,100	30,740	3·46	3·00
June	63,200	9,370	24,310	2·64	2·38
July	13,800	8,350	10,060	1·13	98
August	48,100	9,740	22,390	2·52	2·18
September	33,300	13,000	20,610	2·24	2·01
October	25,110	10,420	15,650	1·76	1·53
November	51,400	12,500	24,280	2·64	2·37
December	23,750	10,200	17,060	1·92	1·67
Per annum	98,100	6,250	19,335	26·71	1·89

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[1] Report of the surveys and examinations of the Connecticut river between Hartford, Connecticut, and Holyoke, Massachusetts, made since 1867. Appendix B 14 of the Annual Report of the Chief of Engineers for 1878.

Discharge of Connecticut river at Hartford, Connecticut—Continued.

Month	Maximum.	Minimum.	Mean.	Run-off. Depth.	Run-off. Per square Mile.
1873.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*
January	54, 800	14, 110	24, 090	2 71	2·35
February	26, 720	12, 050	18, 700	1·90	1·83
March	34, 900	11, 440	16, 160	1·82	1·58
April	109, 800	35, 260	70, 090	7·61	6·84
May	81, 800	25, 300	51, 850	5·84	5·06
June	21, 670	6, 580	10, 180	1 18	·99
July	7, 970	5, 960	7, 090	·80	·69
August	7, 710	5, 830	6, 450	73	·63
September	82, 000	5, 390	6, 840	·74	·67
October	53, 100	7, 060	24, 950	2·81	2·43
November	27, 620	10, 000	15, 390	1·67	1·50
December	50, 650	13, 720	24, 940	2·81	2·44
Per annum	109, 800	5, 390	23, 061	30·62	2·25
1874.					
January	134, 000	24, 000	50, 680	5·70	4·94
February	58, 250	29, 000	40, 020	4·06	3·90
March	54, 550	13, 700	26, 680	3·00	2·60
April	43, 100	10, 980	23, 960	2·61	2·33
May	71, 900	31, 500	52, 140	5·86	5·08
June	43, 150	15, 140	28, 630	3·11	2·80
July	60, 550	9, 000	20, 600	2·32	2·01
August	15, 110	7, 860	10, 590	1·19	1·03
September	8, 580	5, 910	6, 720	·73	·66
October	10, 100	6, 140	7, 230	·81	·70
November	7, 880	5, 450	6, 120	·67	·60
December	8, 580	5, 210	6, 710	·75	·66
Per annum	134, 000	5, 210	23, 340	30·81	2·28
1875.					
January	7, 520	5, 740	6, 380	·77	·62
February	31, 410	6, 360	11, 190	1·13	1 09
March	28, 800	12, 090	18, 350	2·05	1·79
April	90, 100	29, 800	56, 450	6 14	5·50
May	59, 600	16, 950	41, 630	4·68	4·06
June	30, 250	8, 330	13, 730	1·49	1·34
July	11, 850	6, 540	8, 570	·96	·84
August	27, 000	6, 540	11, 940	1·34	1·17
September	8, 180	5, 700	6, 738	·73	·66
October	13, 050	6, 960	10, 220	1·15	1·00
November	28, 900	10, 340	15, 860	1·72	1·55
December	23, 900	8, 600	16, 310	1·84	1·60
Per annum	90, 100	5, 700	18, 114	23·95	1·77
1876.					
January	46, 800	18, 700	26, 510	2·98	2·59
February	39, 800	11, 500	25, 710	2·70	2·51
March	86, 900	10, 740	35, 090	3·94	3·43
April	120, 800	34, 410	62, 000	6·74	6·05
May	97, 200	24, 150	58, 160	6 54	5·58
June	28, 600	10, 900	15, 830	1·72	1 55
July	11, 000	6, 520	8, 240	·93	·80
August	7, 500	5, 360	6, 230	·70	·61
September	8, 220	5, 510	6, 630	·72	·65
October	7, 460	5, 360	6, 330	·71	·62
November	11, 690	6, 170	7, 820	·85	·76
December	7, 790	5, 410	6, 410	·72	·63
Per annum	120, 800	5, 360	22, 080	29·15	2·15
1877.					
January	7, 950	5, 570	6, 540	·73	·64
February	8, 970	6, 450	7, 650	·78	·75
March	128, 200	8, 140	34, 880	3·91	3·40
April	80, 550	27, 900	42, 660	4·64	4·16
May	36, 800	9, 340	16, 930	1·90	1·65
June	10, 770	6, 600	8, 075	·88	·78
July	20, 000	6, 750	9, 520	1·07	·93
August	13, 740	6, 860	8, 570	·96	·84
September	9, 000	5, 700	6, 980	·76	·68
October	21, 800	5, 630	11, 860	1 33	1·16
November	61, 000	11, 600	29, 220	3·18	2·86
December	38, 100	9, 620	17, 310	1·95	1·69
Per annum	128, 200	5, 700	16, 683	22 09	1·63

Discharge of Connecticut river at Hartford, Connecticut—Continued.

Month.	Maximum.	Minimum	Mean	Run-off	
				Depth	Per square mile
1878.	*Sec.-ft.*	*Sec.-ft*	*Sec.-ft*	*Inches*	*Sec.-ft.*
January	25,520	7,200	14,712	1·66	1·44
February	41,250	11,700	20,003	2·04	1·95
March	59,500	12,750	32,476	3·65	3·17
April	89,350	30,900	47,442	5·15	4·63
May	88,600	10,000	31,748	3·57	3·10
June	26,400	7,600	13,892	1·51	1·35
July	10,800	5,900	7,519	·85	73
August	15,200	7,400	9,706	1·09	·95
September	11,700	5,500	7,748	84	75
October	11,700	5,350	6,849	77	67
November	46,200	5,700	13,362	1·45	1·30
December	139,000	15,000	43,743	4·93	4·26
Per annum	89,350	5,350	20,766	27·51	2·02
1879					
January	19,600	11,700	14,045	1·58	1·37
February	48,850	9,250	21,703	2·21	2·12
March	34,400	13,100	20,292	2·28	1·98
April	115,500	17,200	48,593	5·28	4·75
May	116,400	11,700	46,427	5·21	4·53
June	26,850	8,500	7,257	·79	·71
July	14,000	6,750	9,163	1·03	·90
August	25,050	6,000	9,879	1·11	·96
September	13,800	6,600	7,973	87	·78
October	6,900	5,550	6,387	72	·62
November	24,600	6,300	12,347	1·34	1·21
December	34,400	9,250	22,156	2·49	2·16
Per annum	116,400	5,550	18,852	24·91	1·84
1880.					
January	25,520	7,200	14,817	1·67	1·45
February	41,250	12,400	20,219	2·22	1·97
March	61,300	13,100	26,054	2·92	2·54
April	65,550	14,150	31,786	3·46	3·10
May	36,950	8,750	17,976	2·02	1·75
June	16,800	6,150	8,300	·90	·81
July	9,250	6,150	7,503	·85	·73
August	7,800	5,200	6,229	·70	·61
September	7,200	5,350	6,045	·66	·59
October	12,050	5,200	6,819	77	66
November	17,200	6,750	10,947	1·19	1·07
December	11,100	6,150	7,948	89	·78
Per annum	65,550	5,200	13,720	18·25	1·34
1881					
January	10,800	5,600	7,731	87	75
February	40,700	6,300	17,217	1·75	1·68
March	59,500	15,600	34,747	3·91	3·41
April	72,050	12,050	34,973	3·80	3·41
May	74,000	19,200	42,621	4·80	4·15
June	19,200	6,900	11,498	1·25	1·12
July	11,700	6,150	7,698	86	65
August	9,000	5,400	7,303	82	·71
September	8,750	5,350	7,592	82	74
October	8,750	5,250	6,798	76	66
November	27,900	9,750	15,692	1·71	1·53
December	70,100	9,250	22,461	2·53	2·19
Per annum	74,000	5,250	18,026	23·88	1·76
1884.					
January	16,400	8,750	11,676	1·31	1·14
February	74,700	11,100	34,230	3·60	3·35
March	118,200	17,200	31,939	3·59	3·12
April	120,750	33,900	63,942	6·95	6·24
May	53,600	25,400	38,250	4·30	3·73
June	23,200	7,200	11,058	1·20	1·08
July	8,700	6,750	7,626	86	·74
August	8,250	5,700	6,476	73	63
September	9,500	5,150	6,602	72	65
October	7,400	5,550	6,461	73	·63
November	23,200	6,450	10,715	1·16	1·05
December	38,000	8,500	19,155	2·15	1·87
Per annum	74,700	5,150	19,861	27·30	1·94

Discharge of Connecticut river at Hartford, Connecticut—Continued.

Month.	Maximum	Minimum	Mean	Run off.	
				Depth	Per square mile
1885	*Sec.-ft*	*Sec.-ft*	*Sec.-ft*	*Inches.*	*Sec.-ft.*
January	65, 550	17, 000	34, 661	3 89	3·38
February	23, 200	10, 500	14, 711	1 50	1·44
March	16, 400	7, 600	11, 706	1·32	1·14
April	88, 600	13, 100	26, 250	2 86	2 56
May	63, 700	10, 250	25, 869	2 91	2 52
June	27, 900	5, 800	10, 785	1 28	1·06
July	10, 500	6, 000	7, 909	89	·77
August	18, 000	5, 300	9, 148	1·03	·89
September	13, 100	6, 000	8, 105	·88	·79
October	21, 350	6, 750	10, 084	1·13	·98
November	78, 200	12, 400	33, 067	3 60	3 23
December	35, 400	10, 000	21, 005	2 36	2 05
Per annum	88, 600	5, 300	17, 775	23 45	1 73
1886					
January	....	....	34, 018	3 82	....
February	....	....	36, 112	3 67	....
March	....	....	21, 043	....	....
April	....	....	65, 121	....	....
May	....	....	27, 900	....	....
June	....	....	....	....	....
July	....	....	5, 050	....	....
August	....	....	5, 800	....	....
September	....	....	5, 000	....	....
October	....	....	....	....	....
November	....	....	35, 900	....	....
December	....	....	28, 700	....	....

The above table contains one of the longest records available concerning the fluctuations of rivers of this part of the country. For the later years the accuracy may be questionable, since there have been no means of verifying the computed discharges by the results of actual measurements. The figures are given, however, as being the best obtainable, and as showing the character of the fluctuations of the stream. A somewhat detailed study of the discharge and rainfall data and of the probable relation between these has been made by Mr. Babb for the purpose of obtaining information bearing upon the probable run-off from typical catchment areas. The figures relating to precipitation were obtained from the records of the Signal Service relating to rainfall stations distributed at various points in the area under consideration.

The following table gives for each month the average depth of rain and opposite this the run-off, or quantity of water discharged from the basin, during the month, expressed in terms of the depth in inches which this volume of water would have if spread over a plain of the area of the catchment basin. This depth of run-off is then compared with the depth of precipitation, and the percentage which it bears is placed in the third column.

Connecticut river

Month	1871.			1872			1873.		
	Rain fall	Run-off	Per cent.	Rain fall	Run-off	Per cent.	Rain-fall	Run-off	Per cent.
	Inches	*Inches*		*Inches*	*Inches*		*Inches*	*Inches.*	
January	....	......	.. ...	1·70	1·23	72·5	3·97	2·71	68·2
February	2·60	1·87	72·0	2·10	·77	36·7	2·82	1·90	67·4
March	4·30	5·64	131·1	2·50	·90	36·0	3·81	1·82	47·8
April	3·20	2·74	85·6	1·61	5·50	844·0	1,85	7·61	412·3
May	3·40	3·42	100·0	4·41	3·46	78.5	2·70	5·84	217·0
June	3·50	·99	28·3	5·56	2·64	47·5	1·68	1·18	70·3
July	4·10	·69	16·8	5·49	1·13	20·6	5·28	·80	15·2
August	5·80	·80	13·8	7·91	2·52	32·1	3·15	·73	23·2
September	1·50	·85	56·7	4·33	2·24	51·8	4·63	·74	16·0
October	3·70	1·02	27·6	3·62	1·76	48·6	6·84	2·81	41·1
November	3·00	1·65	55·1	4·47	2·64	59·1	3·52	1·67	46·8
December	2·60	1·44	55·4	3·01	1·92	63·8	3·55	2·81	79·2
Per annum	37·70	21·11	56·2	46·71	26·71	56·6	43·85	30·62	69·9

Month	1874			1875			1876		
	Rain fall	Run off	Per cent	Rain-fall	Run-off.	Per cent	Rain-fall	Run-off-	Per cent.
	Inches	*Inches*		*Inches.*	*Inches*		*Inches.*	*Inches.*	
January	4·21	5·70	135·6	3·24	·72	22·2	2·48	2·98	120·1
February	2·66	4·06	151·6	3·31	1·13	34·2	5·02	2·70	53·8
March	2·17	3·00	138·4	3·77	2·05	54·3	6·77	3·94	58·2
April	6·52	2·61	40·0	2·76	6·14	222·1	3·21	6·74	210·0
May	3·95	5·86	146·9	2·85	4·68	164·5	3·79	6·54	172·8
June	4·76	3·11	65·4	4·44	1·49	33·6	4·44	1·72	38·8
July	6·09	2·32	38·2	3·66	·96	26·2	6·10	·93	15·3
August	3·52	1·19	33·8	6·45	1·34	20·8	1·97	·70	35·6
September	2·74	·73	26·7	3·41	·73	21·4	5·30	·72	13·6
October	2·81	·81	28·9	4·44	1·15	25·9	2·14	·71	33·2
November	2·21	·67	30·4	3·51	1·72	49·0	3·13	·85	27·2
December	1·58	·75	47·6	1·23	1·84	149·5	3·83	·72	18·8
Per annum	43·24	30·81	71·4	43·07	23·95	55·6	48·18	29·15	60.6

Month	1877			1878			1879		
	Rain fall	Run-off	Per cent	Rain fall	Run-off.	Per cent	Rain fall	Run-off.	Per cent.
	Inches	*Inches*		*Inches*	*Inches.*		*Inches*	*Inches.*	
January	2·61	·73	31·6	3·87	1·66	42·9	3·03	1·58	52·2
February	·79	·78	99·0	3·42	2·04	59·6	3·25	2·21	68·0
March	7·02	3·91	55·7	3·10	3·65	117·6	4·69	2·28	48·6
April	2·77	4·64	167·5	6·78	5·15	76·0	3·97	5·28	131·1
May	1·07	1·90	177·6	3·14	3·57	113·8	2·51	5·21	208·1
June	4·64	·88	19·0	5·07	1·51	29·8	5·48	·79	14·4
July	4·76	1·07	22·5	3·72	·85	22·9	4·82	1·03	21·4
August	4·60	·96	20·9	4·80	1·09	22·8	5·77	1·11	19·3
September	1·45	·76	52·5	2·76	·84	30·4	3·37	·87	25·8
October	5·79	1·33	23·0	3·38	·77	22·8	2·22	·72	32·4
November	5·84	3·18	54·5	4·42	1·45	33·0	3·89	1·34	34·5
December	1·58	1·95	123·4	5·74	4·93	86·0	4·24	2·49	58·7
Per annum	42·92	22·09	51·5	50·20	27·51	54·7	47·24	24·91	52·6

Connecticut river.

Month.	1880.			1881.			1884.		
	Rain-fall.	Run-off.	Per cent.	Rain-fall.	Run-off.	Per cent.	Rain-fall.	Run-off.	Per cent.
	Inches.	*Inches.*		*Inches.*	*Inches.*		*Inches.*	*Inches.*	
January	3·58	1·67	46·6	3·82	·87	22·8	3·81	1·31	33·4
February	3·01	2·22	73·8	3·62	1·75	48·3	4·75	3·60	75·9
March	2·63	2·92	111·0	4·41	3·91	88·6	4·56	3·59	78·8
April	2·73	3·46	127·1	1·50	3·80	253·6	2·65	6·95	252·1
May	2·10	2·02	96·3	4·91	4·80	97·6	3·90	4·30	110·4
June	2·79	·90	32·3	3·83	1·25	33·6	2·75	1·20	43·6
July	5·43	·85	15·7	4·05	·86	21·2	5·17	·86	16·6
August	3·60	·70	19·5	3·42	·82	24.0	4·22	·73	17·3
September	4·28	·66	15·4	2·08	·82	39·4	1·80	·72	40·1
October	4·15	·77	18·6	4·17	·76	18·2	3·15	·73	23·2
November	3·15	1·19	37·8	5·13	1·71	33·3	3·56	1·16	32·6
December	2·57	·89	34·6	5·99	2·53	40·6	4·83	2·15	44·4
Per annum	40·02	18·25	45·6	46·93	23·88	51·0	45·15	27·30	60·4

Month.	1885.			Entire period.		
	Rainfall.	Run-off.	Per cent.	Average rain.	Average run-off.	Per cent.
	Inches.	*Inches.*		*Inches.*	*Inches.*	
January	4·14	3·89	93·9	3·27	1·93	59·1
February	2·92	1·50	51·4	3·10	2·04	65·8
March	1·47	1·32	89·6	3·94	3·00	76·3
April	2·79	2·86	102·4	3·26	4·73	145·0
May	2·43	2·91	119·7	3·17	4·19	132·2
June	3·20	1·28	40·0	4·00	1·46	36·5
July	3·56	·89	25·0	4·79	1·02	21·3
August	8·06	1·03	12·8	4·87	1·06	21·8
September	1·84	·38	47·8	3·04	·89	29·3
October	4·72	1·13	24·0	3·93	1·11	28·3
November	5·20	3·60	69·3	3·93	1·76	44·8
December	3·29	2·36	72·0	3·39	2·06	60·7
Per annum	43·62	23·65	54·3	44·69	25·25	56·5

From the above table it appears that the percentage of run-off to rainfall has varied less widely than it did in the case of the Potomac, given on the preceding page. Arranging these in tabular form for convenience of comparison, this fact is more clearly shown.

Year.	Rainfall.	Run-off.	Per cent.
	Inches.	*Inches.*	
1871	37·70	21·11	56·2
1872	46·71	26·71	56·6
1873	43·85	30·62	69·9
1874	43·24	30·81	71·4
1875	43·07	23·95	55·6
1876	48·18	29·15	60·6
1877	42·92	22·09	51·5
1878	50·20	27·51	54·7
1879	47·24	24·91	52·6
1880	40·02	18·25	45·6
1881	46·93	23 88	51·0
1884	45·15	27·30	60·4
1885	43·62	23·65	54·3

SAVANNAH RIVER.

A series of estimates have been made of the discharge of the Savannah river based upon daily observations maintained by the Weather Bureau of the height of the river at Augusta, Georgia, and upon discharge measurements made by the Engineer Corps of the U. S. Army. These cover the period from 1884 to 1891, and without vouching for their accuracy they are presented as affording material for study and comparison. The Savannah river proper is formed by the junction of the Tugaloo and Seneca rivers, the town of Andersonville, Georgia, being located at this point. From here the general course is southeasterly, the total fall of the river in the 106 miles to Augusta being in round numbers 400 feet, or at the rate of nearly 4 feet per mile. The greater part of this fall is between Andersonville and Petersburg, 55 miles below, the rate being 5·25 feet per mile. Below this point the slope is 2·2 feet per mile. The following table gives these computed discharges in form similar to that adopted for other streams.

Discharge of Savannah river at Augusta, Georgia.

[Drainage area, 7,294 square miles.]

Month.	Maximum.	Minimum.	Mean.	Run-off.	
				Depth.	Per square mile.
1884	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*
January	49,670	2,700	10,575	1·67	1·45
February	48,850	4,900	13,307	1·97	1·83
March	65,010	5,260	33,191	5·24	4·55
April	75,890	7,240	18,105	2·77	2·48
May	10,000	4,480	6,541	1·03	·90
June	62,040	3,840	15,073	2·30	2·06
July	25,640	3,600	8,339	1·32	1·14
August	7,060	2,300	4,618	·73	·63
September	3,400	2,060	2,689	·41	·37
October	3,200	1,980	2,370	·39	·32
November	4,900	2,460	2,903	·44	·40
December	41,000	2,860	9,972	1·57	1·37
Per annum	75,890	1,980	10,640	19·84	1·46
1885.					
January	61,050	4,900	22,016	3·48	3·03
February	42,200	7,780	18,661	2·66	2·56
March	22,800	5,800	8,520	1·35	1·17
April	8,500	4,480	5,366	·82	·74
May	19,580	4,200	7,036	1·11	·96
June	22,200	4,080	6,455	·99	·89
July	6,520	3,400	3,886	·61	·53
August	10,400	2,700	3,935	·62	·54
September	45,280	2,460	7,791	1·19	1·07
October	32,960	3,720	11,735	1·85	1·61
November	53,770	6,340	11,608	1·78	1·59
December	34,140	6,340	11,269	1·78	1·55
Per annum	61,050	2,460	9,857	18·24	1·35
1886.					
January	87,900	7,600	23,722	3·75	3·25
February	13,600	7,060	9,011	1·29	1·24
March	96,000	6,340	13,072	2·06	1·79
April	111,320	7,960	21,569	3·29	2·96
May	114,800	8,140	19,562	3·09	2·68
June	36,940	8,500	16,583	2·53	2·28
July	61,710	6,160	19,233	3·04	2·64
August	13,680	5,080	7,250	1·15	1·00
September	12,800	3,500	5,431	·83	·75
October	3,400	3,020	3,251	·51	·45
November	13,900	3,100	5,252	·80	·72
December	13,900	4,200	6,784	1·07	·93
Per annum	114,800	3,020	12,560	23·41	1·72

Discharge of Savannah river at Augusta, Georgia—Continued.

[Drainage area, 7,294 square feet.]

Month.	Maximum	Minimum.	Mean.	Run-off.	
				Depth.	Per square mile.
1887.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Inches.*	*Sec.-ft.*
January	13,460	4,200	6,117	·97	·84
February	31,220	4,900	13,081	1·87	1·80
March	32,660	5,440	9,832	1·55	1·35
April	9,220	4,480	5,653	·87	·78
May	8,140	4,200	4,645	·73	·64
June	29,520	3,400	6,404	·98	·88
July	143,450	3,300	12,162	1·92	1·67
August	120,800	6,700	35,541	5·61	4·87
September	20,100	3,200	4,957	·76	·68
October	14,800	3,300	5,571	·88	·76
November	6,700	3,720	4,305	66	·59
December	23,040	3,600	8,504	1 34	1·16
Per annum	143,450	3,200	9,731	18·14	1·33
1888.					
January	59,400	7,240	16,938	2·68	2·32
February	82,700	6,880	19,881	2·94	2·73
March	117,200	7,240	24,526	3·86	3·36
April	45,660	7,240	14,749	2·26	2·02
May	45,660	7,240	13,788	2 17	1·89
June	28,200	4,900	8,361	1·28	1·15
July	10,000	5,060	5,256	·83	·72
August	12,800	3,500	6,097	96	·83
September	309,930	11,600	46,360	7·09	6·34
October	42,200	6,520	12,659	2·00	1·74
November	57,200	9,220	19,509	2·99	2·68
December	35,500	8,320	12,725	2 01	1·75
Per annum	309,930	3,500	16,821	31·07	2·31
1889.					
January	59,730	11,340	26,885	4·24	3·69
February	119,600	10,200	26,322	3·76	3 61
March	43,000	4,620	15,505	2 45	2·13
April	24,260	7,780	10,652	1·63	1 46
May	9,040	4,620	6,606	1·04	·91
June	21,300	4,480	6,551	1·01	·90
July	26,320	4,340	10,746	1·70	1·47
August	39,000	4,900	16,129	2 55	2·22
September	35,500	4,620	9,471	1·45	1·30
October	7,960	3,960	4,974	·79	·68
November	30,200	4,620	10,061	1 54	1·38
December	7,030	4,760	5,443	·86	·75
Per annum	119,600	3,960	12,445	23 02	1·71
1890.					
January	9,220	4,760	5,076	80	·70
February	46,420	5,260	9,383	1 34	1·29
March	44,520	6,700	12,344	1·95	1 70
April	15,280	5,620	8,335	1 27	1 14
May	27,900	4,900	9,673	1·53	1·33
June	9,220	3,720	5,491	·84	·75
July	33,040	2,700	8,193	1·29	1·12
August	16,780	3,000	6,004	·95	·82
September	55,880	4,200	8,249	1 26	1·13
October	79,600	5,080	19,541	3·09	2·68
November	7,060	4,620	5,370	·82	·74
December	23,760	4,480	7,079	1 12	·97
Per annum	79,600	2,700	8,728	16·26	1·20
1891					
January	44,140	5,420	14,641	2 31	2·01
February	71,620	17,600	34,124	4·88	4·68
March	116,000	14,440	41,631	6·57	5·71
April	52,950	9,220	19,654	3 00	2·70
May	14,440	6,880	8,769	1·38	1·20
June	15,760	4,620	8,646	1·32	1 19
July	16,260	4,080	6,532	1·03	·90
August	60,720	4,200	13,358	2 11	1·83
September	16,000	3,300	5,623	86	·77
October	4,620	3,100	3,494	·55	·48
November	24,780	3,100	6,017	92	·82
December	13,240	5,260	4,591	·73	·63
Per annum	116,000	3,100	13,928	25 66	1·79

The fluctuations in quantity year by year are not as decidedly marked as in cases previously given. The maximum flood noted in the above tables is that of September, 1888, computed at 309,930 second-feet, and the minimum discharge was in October, 1884, when the river shrunk to a trifle less than 2,000 second-feet. The following list brings together the average discharges for the several years:

Years.	Second-feet.
1884	10, 640
1885	9, 857
1886	12, 560
1887	9, 731
1888	16, 821
1889	12, 445
1890	8, 728
1891	13, 928

The character of the discharge of the river differs somewhat from that of the Potomac and Connecticut, the floods as a rule coming earlier in the season and there being a second rise in August or September, due probably to the increased amount of precipitation over the basin. There are few facts available concerning the quantity and distribution of the precipitation, but these have been brought together and comparisons have been made, as in the case of the other streams. Taking the rainfall data for Augusta, Georgia, Mr. Babb has computed the monthly percentage of river flow to rainfall, as shown by the following table. The assumptions in this case are many, affecting both the discharge and the probable precipitation, but until better material is available the probable errors can not be pointed out with certainty:

Month.	Average rainfall.	Average run-off.	Per cent.
	Inches.	*Inches.*	
January	4·34	2·50	57·6
February	3·47	2·59	74·6
March	4·86	3·13	64·4
April	2·08	1·99	95·7
May	4·05	1·51	37·3
June	4·44	1·41	31·8
July	6·46	1·47	22·8
August	4·59	1·96	42·7
September	3·70	1·73	46·8
October	3·03	1·26	41·6
November	1·68	1·33	79·1
December	2·71	1·31	48·1
Total	45·41	22·19	48·9

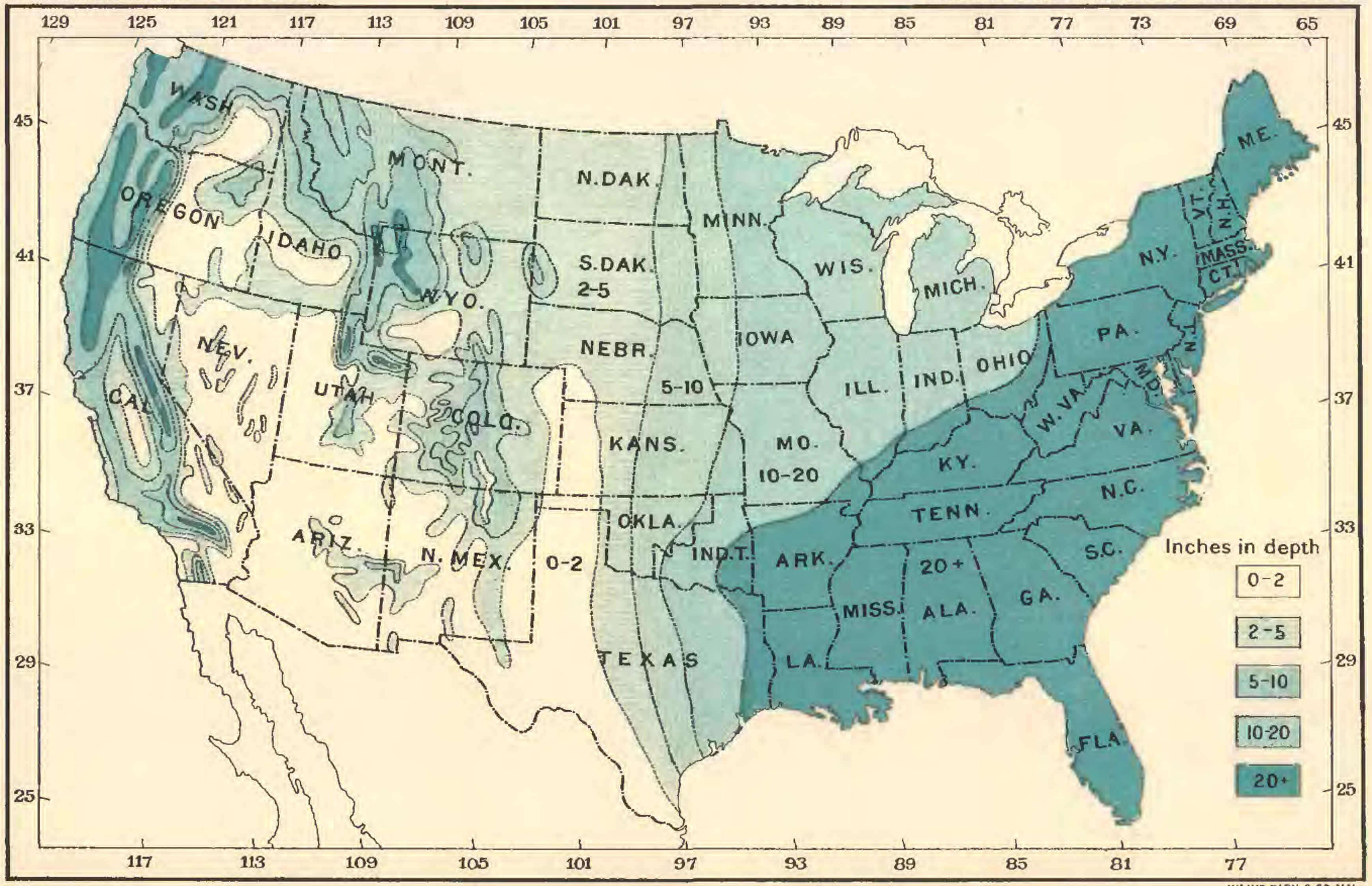
DEPTH OF RUN-OFF.

The run-off, that is, the quantity of water flowing from the land, has been given in the preceding tables, as stated hitherto, in two forms, one as depth of inches over the whole catchment basin; the other as quantity per square mile drained. From these two classes of data some general conclusions can be drawn in a broad way as to the available supply of water in the various large divisions of the country. For instance, the detailed data of depth of run-off can be treated in a manner similar to that in which the data of depth of precipitation is commonly employed in graphic presentations of the distribution of rain; or a few generalizations can be had as to the average quantities of water flowing from areas of certain topographic or cultural types. In the following paragraphs the attempt is made to present these broad views, although as a matter of course the data is as yet somewhat meager and must be supplemented by inferences drawn from general knowledge.

The depth of run-off per year, as obtained at various points along rivers in eastern, central, and western parts of the United States, has been plotted upon a map. This being done, the map has been shaded to indicate in a general way the portions from which the run-off is approximately equal in mean annual depth. In this approximation wide limits have been taken, in order to make due allowance for scanty data. On the accompanying map (Pl. V) four tints, with white, have been used, thus making five classifications of depth of run-off. These are, first, from 0 to 2 inches; second, from 2 to 5 inches; third, from 5 to 10 inches; fourth, from 10 to 20 inches; and fifth, 20 inches and over. A glance at the map is sufficient to show a great difference between the eastern and western halves of the country. Taking the ninety-seventh meridian as the center, it may be said in a general way that east of the line the run-off is from 10 to 20 inches and over in depth, while to the west the run-off is very small, the average being less than 5 inches, and the conditions are quite complicated.

Taking the country a little more in detail, the map indicates that from the eastern coast regions to the valley of the Ohio and down the lower Mississippi the run-off is over 20 inches, while for the lake region and a portion of the upper Mississippi the run-off is less, being from 10 to 15 inches. Going westward, the run-off rapidly diminishes to less than 5 inches, or even to less than 2 inches along the Great Plains, but is increased over the areas covered by the Rocky mountains. Beyond these the run-off is very small, being mainly less than 2 inches, the great interior basin having as a whole no run-off, although it contains or is bordered by areas of mountains from which the run-off is large. Along the Cordilleras and Pacific coast the run-off approaches to that of the Atlantic coast.

For comparison with this run-off map a similar map (Pl. VI) showing the mean annual precipitation is introduced. This has been prepared by Mr. Henry Gannett from data published by the Weather Bureau. The information upon which this map is based is far more detailed than that available for the construction of the run-off map, and therefore limits less wide have been taken for each tint, and more of these tints are employed. These two maps do not coincide in many particulars, although the first has been constructed in the light of general knowledge shed



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by the second. That the run-off is not immediately dependent upon quantity of rainfall has been shown in preceding reports of this Survey as well as by writers in other publications. As a broad statement it may be said that run-off is a function of rainfall and topography, with modifications introduced by various other conditions, such as climate, geological structure, and vegetation. Therefore, the maps showing only depth of run-off and of rainfall can not be expected to coincide, especially where there is great diversity in topography. It is possible, however, with the limited data available, to make broad approximations of quantity of run-off corresponding to certain depths of rain; or, to put the matter in another form, it is possible to use the run-off map to show percentages of rainfall which gathers in streams. For example, where the depth of run-off is from 0 to 2 inches, it is apparent from the data that less than 10 per cent of the rainfall appears in the streams as run-off. Where the run-off is from 2 to 5 inches in depth, this relation is from 10 to 25 per cent; where from 5 to 10 inches, the relation is from 40 to 50 per cent; and where the run-off is 20 inches and over in depth, this represents generally over 50 per cent of the rainfall.

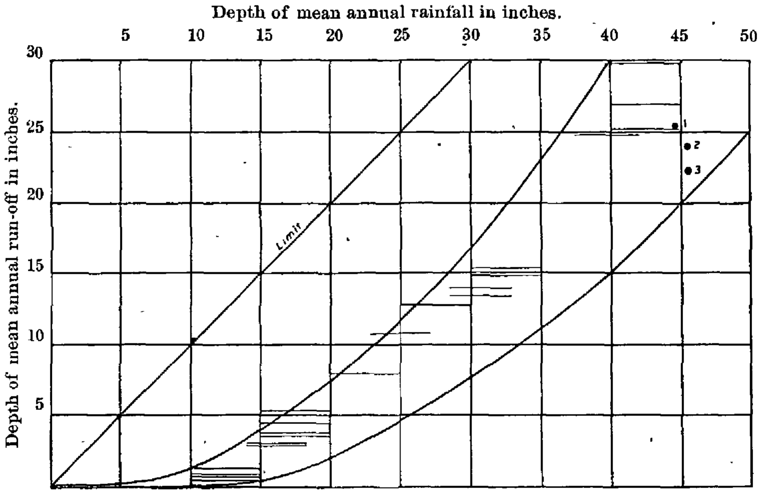


FIG. 24.—Relation of run-off to rainfall.

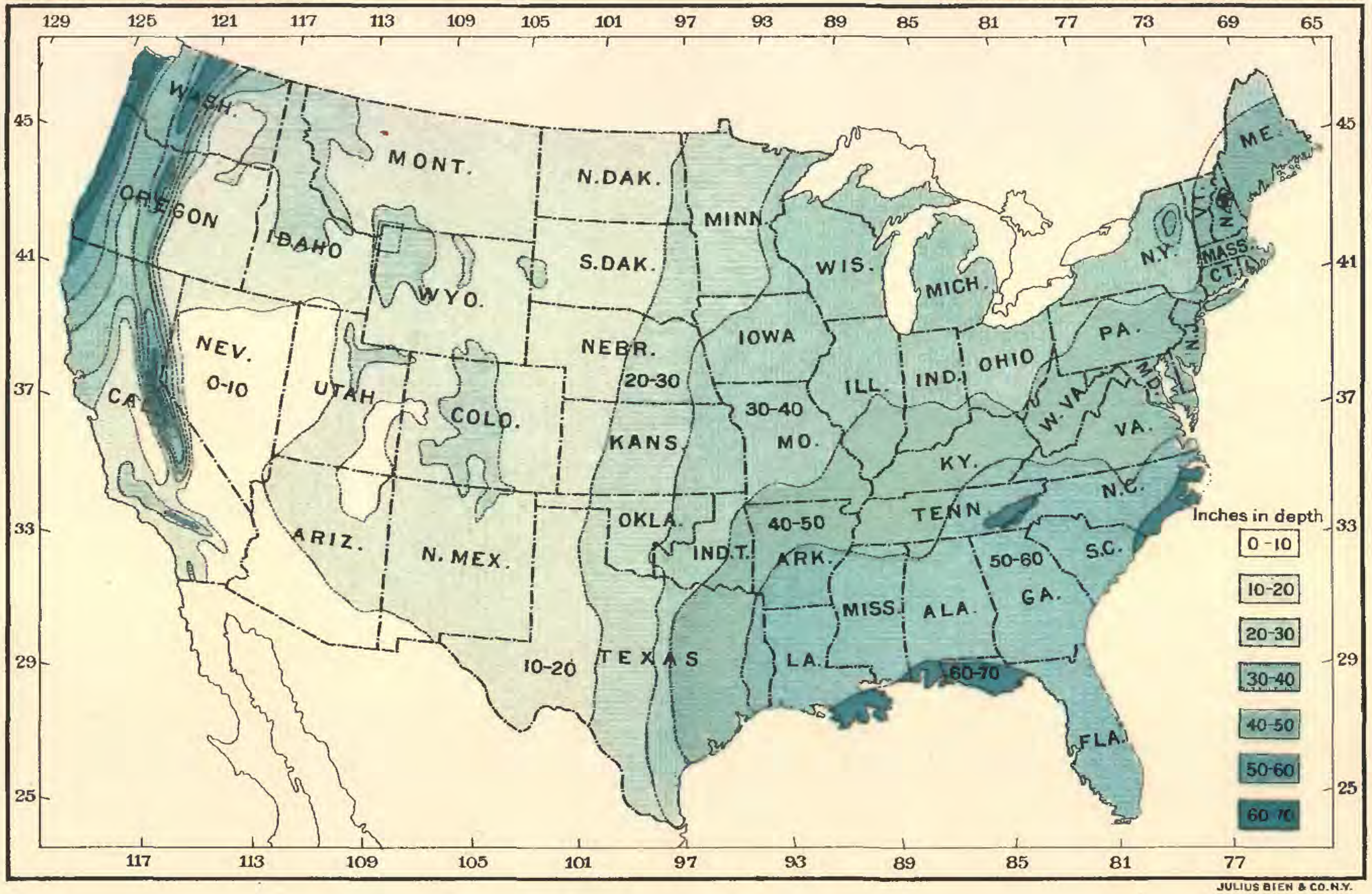
The percentage of rainfall which appears as run-off, as shown in a general way by comparison of these maps, may be represented diagrammatically by making certain assumptions as to character of topography and other modifying circumstances. In the above diagram (Fig. 24) the depth of rainfall in inches is taken as the ordinate, and the depth of run-off, also in inches, as the abscissa. Two curves have been sketched, the upper to represent an average condition of mountain topography, if such a condition can be assumed, and the lower to represent conditions prevailing in a catchment basin of broad valleys and gentle slopes.

The upper curve indicates that where the mean annual rainfall on mountains is 40 inches, the run-off approaches 30 inches; where the rainfall is 25 inches, the run-off is about 12 inches, and where the rainfall is 15 inches, the run-off is less than 5 inches, decreasing rapidly below this point. In the same way the lower curve, that for more open country, shows that where the mean annual rainfall is 50 inches, a run-off of 25 inches may be expected; where the rainfall is 30 inches, about 8 inches of run-off is found; where the rainfall is 20 inches, only about 3 inches gets into the streams, the quantity, as in the other case, rapidly decreasing for less rainfall. These curves should not be regarded as exact expressions of data, but rather as indicating general conditions of relationship, exact plotted points, when determined, falling irregularly on each side of the curves. One notable exception to the rules given above may be mentioned. When the annual precipitation is small, 12 inches or under, the rain usually falls at long intervals and at an excessive rate when it finally occurs, the more arid portions of the country receiving a great part of their precipitation during what are known as "cloud-bursts." In such cases the moisture having little time to penetrate the soil most of the water flows away at once, and the run-off is therefore exceptionally large.

Some of the data upon which these curves have been constructed are shown on the diagram. The dots numbered 1, 2, and 3 represent respectively the relation of run-off to rainfall for the Connecticut, Potomac, and Savannah rivers shown on preceding pages. The short horizontal lines apply mainly to the western rivers. Unfortunately in the case of most of these streams, although the mean annual run-off has been measured, there are few reliable figures for the rainfall, and quantities must be assumed from general considerations. Each of the short horizontal lines indicates by its distance above the base line the depth of run-off, and by its length the probable quantity of rain, this being from 10 to 15 inches or from 15 to 20 inches, and so on. The line lettered "limit" marks the points where all of the rainfall flows from the ground.

RATES OF RUN-OFF.

The average rate at which water is discharged from the different catchment areas has been computed from data previously given and from information obtained from various sources, such, for example, as the report upon water power made by the Tenth Census, and from papers contained in the Transactions of the American Society of Civil Engineers. A comparison of these yields results of immediate utility in estimating the probable discharge from various drainage basins. Accordingly, the following table has been prepared, the streams being arranged in general geographic order from east to west. From an inspection of this table it appears that the maximum estimated rate of run-off was a little over 215 second-feet per square mile, this being from the catchment area of South Fork creek, in southwestern Pennsylvania. This creek is tributary to Conemaugh river, which flows



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into the Allegheny about twenty-five miles above Pittsburg, and is noted from the fact that on the day this extraordinary run-off occurred its waters cut away an earth dam, and overwhelmed Johnstown and other localities. Possibly in the so-called cloud-burts of the arid regions a greater quantity of water may reach the streams, but concerning this there are no definite facts.

Stream	Drainage area	Period	Second-feet per square mile.			Authority
			Maximum.	Minimum	Mean.	
	Sq. miles.					
Merrimac, Mass.	4,599	....	20·87	30	....	Tenth Census, vol 16, p 28
Concord, Mass	361	....	12·30	·17	....	Do
Sudbury, Mass.	76	1875-'90	44·26	·07	1·67	Trans. Am Soc C E, vol 27, No. 547.
Connecticut	10,234	*1871-'85	20·00	·50	1·86	U S Army Eng., 1878, Appen B 14
Croton, N. Y	353	1868-'81	75·22	21	1·65	State Geologist, N J, 1890, p. 154.
Oswego, N. Y	5,013	....	82	23	....	Tenth Census, vol 16, p 28
South Fork creek, Pa	49	1889	215·11	......	.....	Trans Am Soc C E, vol. 24, No. 477.
Tohickon, Pa	102	1884-'91	110·6	03	2·34	Philadelphia water board.
Neshaminy, Pa	139	1885-'91	78·3	03	1·85	Do.
Perkiomen, Pa	152	1885-'91	69·2	·14	1·90	Do
Raritan, N. J	879	1890	27·0	·48	1·72	State Geolog, N J, 1890, p. 207.
Passaic, N. J	773	1888-'90	24·8	·43	2·58	State Geolog., N J, 1890, p. 200.
Paulinskill, N. J	175	1890	16·5	17	1·69	State Geolog, N J, 1890, p 174
Ramapo, N J	160	1890	28·5	25	1·73	State Geolog, N. J., 1890, p. 191
Musconetcong, N J	156	1890-'91	20·3	·39	1·19	State Geolog., N J., 1891, p. 151.
Potomac	11,043	1886-'91	42·6	·17	1·85	Trans. Am Soc C E, vol. 27, No 537.
Savannah, Ga	7,294	1884-'91	41·2	·27	1·64	U S. Army Eng, H R, 51st, 1st, No 213
Kanawha	8,900	....	13·3	·12	......	Tenth Census, vol 16, p 28
Ohio	200,500	1882	6·17	·27	2·10	U. S. Army Eng, 1884, p. 2591.
Upper Mississippi, Grafton, Ill.	164,534	1882	2·38	·19	·90	U. S Army Eng, 1884, p 2673
Lower Mississippi, Carrollton, La.	1,214,000	1882	†1·00	21	50	U S Army Eng, 1884, p 2683
Missouri in Montana	17,615	1890-'91	1·63	·10	·27	U. S G. S., 13th Annual
Missouri at Saint Charles	526,500	1879-'90	·71	·05	‡·18	Army Eng, 1891, p 3826
West Gallatin, Mont	850	1890-'92	8·00	·38	1·13	U S Geol Surv., 13th Annual Report
Madison, Mont	2,085	1890-'92	3·08	51	·93	
Yellowstone, Mont	2,700	1890-'92	5·74	·11	1·09	
Cache la Poudre, Colo	1,060	1889-'91	5·28	03	32	
Arkansas, Colo	3,060	1888-'92	1·55	06	·27	
Rio Grande, at Del Norte, Colo.	1,400	1890-'92	4·24	·14	80	
Rio Grande, at Embudo, N. Mex	7,000	1889-'92	1·22	02	20	
Rio Grande, at El Paso, Tex	30,000	1890-'92	·55	·00	·06	
Gila, Ariz	13,750	1890	·46	·00	04	
Salt, Ariz	12,260	*1888-'91	24·50	03	31	
Truckee, Nev	1,519	1890-'91	4·95	·24	·95	
East Carson, Nev	414	1890-'92	10·26	70	1·78	
West Carson, Nev	70	1890-'91	18·34	50	2·39	
Bear, at Battle Creek, Idaho	4,500	1890-'92	1·33	·06	·33	
Bear, at Collinston, Utah	6,000	1890-'92	1·37	·06	42	
Ogden, Utah	360	1890	6·06	·11	1·84	
Weber, Utah	1,600	1890-'92	3·60	·06	·60	
Provo, Utah	640	1890-'92	3·53	·22	77	
Spanish Fork, Utah	670	1890	1·55	07	26	
Sevier, Utah	5,595	1890-'92	·42	·01	·09	
Falls, Idaho	594	1890-'91	7·46	76	1·65	
Teton, Idaho	967	1890-'92	5·45	41	1·13	
Snake, Idaho	10,100	1890-'92	5·41	20	1·02	
Owyhee, Oreg	9,875	1890-'92	1·82	01	21	
Malheur, Oreg	9,900	1890-'91	·45	·00	05	
Weiser, Idaho	1,670	1890	6·73	05	·73	

* Record broken † For 1890 ‡ Monthly means.

The mean discharge of rivers of small size in the eastern part of the United States is apparently not far from 1·5 second-feet per square mile to 2 second-feet per square mile, while in the Rocky Mountain region the discharge is usually less, being approximately from 1 second-foot per square mile downward. There are within this area, however, a few creeks coming from lofty catchment basins from which the run-off is at a greater rate than 1 second-foot per square mile, but these are apparently exceptional.

EVAPORATION.

The quantity of water evaporated from a surface exposed freely to the sun and wind has been measured at various places within the arid regions, the methods used and the results obtained during 1889 and 1890 having been described on pages 30 to 34 of the Second Irrigation Report. The series of observations at Fort Douglas, Utah, about a mile west of the city of Salt Lake, and at Fort Bliss, Texas, a short distance above El Paso, have been continued with occasional breaks. Owing to the difficulty of securing continuous observations and of protecting the apparatus from storms and from accidental disturbances, the records at best are fragmentary, but they may serve to furnish data for use in computing the probable loss from the surfaces of lakes, reservoirs, or streams. The following table gives in condensed form the average depth of evaporation in inches by months and years.

Evaporation—Fort Douglas, Utah.

Month.	1889.		1890.		1891.		1892.		1893.		Average total.	Signal Service.
	Mean daily.	Total.	Mean daily.	Total.	Mean daily.	Total.	Mean daily.	Total.	Mean daily.	Total.		
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January	......	......	......	......	......	......	......	......	......	......	*1·00	1·8
February	......	......	......	......	......	......	......	......	......	......	*1·50	2·7
March	......	......	......	......	......	......	0·067	‡2·1	......	......	2·10	3·6
April	......	......	0·123	†3·7	0·107	‡3·2	0·075	‡2·3	0·083	§2·5	2·92	7·2
May	......	......	0·133	†4·1	0·153	‡4·8	0·132	†4·1	......	......	4·33	6·9
June	......	......	0·170	†5·1	0·174	†5·2	0·177	†5·3	......	......	5·20	8·9
July	......	......	0·240	‡7·6	0 246	‡7·6	0·211	†6·5	......	......	7·23	9·2
August	0·340	‡10·5	0·210	†6·5	0·210	†6 5	0·235	‡7·3	......	......	7·70	10 7
September	0·190	‡5·7	0·153	†4·6	0·174	‡5·2	0·174	†5·2	......	......	5·18	9·6
October	0·157	§4·9	0·068	†2 1	0·081	‡2·5	0·068	‡2·1	......	......	2·90	6·5
November	0·035	§1·0	0·041	‡1·2	0·047	‡1·4	0·055	‡1·6	......	......	1·30	5·0
December	......	......	......	......	......	......	......	......	......	......	*1·10	2·3
Total	......	......	......	......	......	......	......	......	......	......	42·46	74·4

Evaporation—Fort Bliss, Texas.

January	......	......	0·066	†2·0	0·086	†2·7	0·077	§2·4	0·140	†4·3	2·85	4·0
February	......	......	0·071	†2·0	0·102	†2·9	0·109	†3·2	0·171	†4·8	3·22	3·9
March	......	......	0·226	†7·0	0·177	†5·5	0·194	†6·0	0·130	§4·0	5 62	6·0
April	......	......	0·244	†7·3	0·247	†7·4	0·250	†7 5	0·309	‡9·3	7·88	8·4
May	0·353	†10 9	0·348	†10 8	......	......	0·325	†10 0	......	......	10·57	10·7
June	0·357	†10·7	0·390	†11·7	......	......	0·435	†13·0	......	......	11·80	13·6
July	0·310	†9·6	0·311	†9·6	......	......	0·403	†12·5	......	......	10·57	9·4
August	0·368	†11·4	0·245	†7·6	......	......	0·383	§11·9	......	......	10·30	7·7
September	0·307	†9·2	......	......	......	......	......	......	......	......	9·20	5·6
October	0·219	†6·8	......	......	......	......	......	......	......	......	6·80	5·2
November	0·155	†4·6	0·122	†3·7	......	......	......	......	......	......	4·15	4 6
December	0·092	†2·9	0·098	†3·0	......	......	......	......	......	......	2·95	2·9
Total	......	......	......	......	......	......	......	......	......	......	95·91	82·0

* Estimate.

† Indicates that measurements were continued less than a full month and over twenty days.

‡ Measurements from ten to twenty days. § Measurements less than ten days.

In the above table the figures are in double columns, the first recording the average daily depth of evaporation during days on which observations were successful, and the second column giving this average daily depth multiplied by the number of days in the month. Against these figures are placed small letters signifying the number of days during which the readings were accepted as accurate. Next to the figures on the extreme right-hand side of the table is a column giving the average or estimated average monthly evaporation at the two points, that for Fort Douglas being nearly 43·5 inches in depth and for Fort Bliss a trifle under 8 feet, or over twice as much. In comparison with this is noted the possible depth of evaporation for these localities as computed by the Signal Service.[1]

The Signal Service figures in the above table relate to the year beginning in July, 1887, and ending in June, 1888, and were obtained from observations made at the stations in the cities of Salt Lake and El Paso. The two sets of results are widely discordant, as perhaps might be expected from the difference in methods and surroundings, the figures for Fort Douglas being only 57 per cent of those for Salt Lake City and those for Fort Bliss 117 per cent of the Signal Service total for El Paso.

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[1] Depth of evaporation in the United States, by T. Russell, assistant professor, Signal Service. Extract from Monthly Weather Review, September, 1888.

THE LACCOLITIC MOUNTAIN GROUPS OF COLORADO, UTAH, AND ARIZONA.

BY

WHITMAN CROSS.

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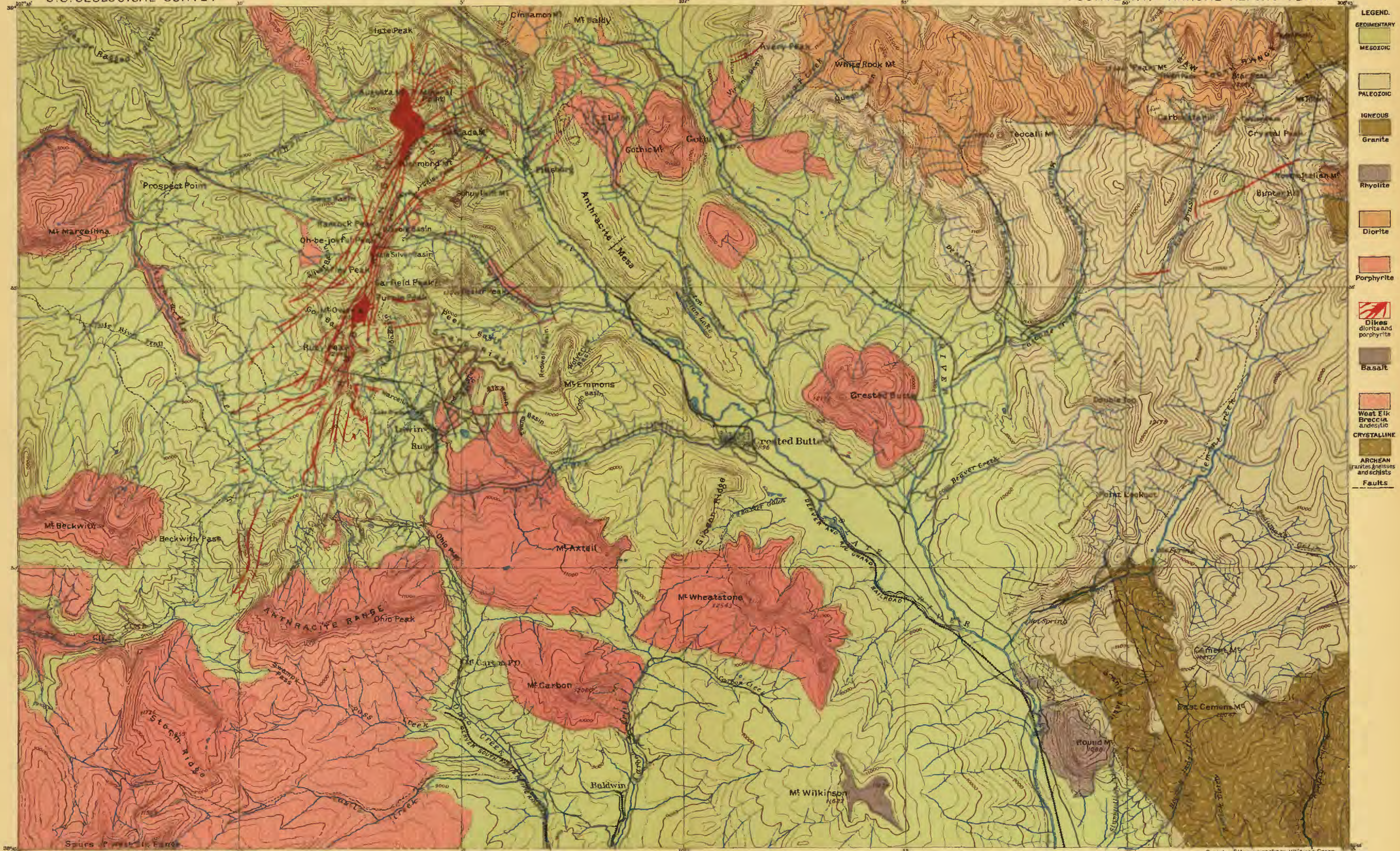
The West Elk mountains—Continued.

ILLUSTRATIONS.



Topography by Anton Karl, W. H. Leffingwell and Laurence Thompson
Surveyed in 1883 & 1888

Geology of Igneous rocks by Whitman Cross
Geology of Sedimentary rocks by G. H. Eldridge.
Surveyed in 1884-88.

GEOLOGICAL MAP OF THE ANTHRACITE AND CRESTED BUTTE DISTRICTS COLORADO.

Scale.

0 1 2 3 4 5 Miles

Contour Interval 200 Feet.

JULIUS BIEN & CO. N.Y.

THE LACCOLITIC MOUNTAIN GROUPS OF COLORADO, UTAH, AND ARIZONA.

BY WHITMAN CROSS.

INTRODUCTION.

The geological investigator in the Rocky mountain area has frequent occasion to observe igneous rocks which have been injected into the sedimentary complex at various geological horizons and at different depths below the surface. These phenomena are so common and their character is placed so completely beyond question by the facts of the excellent natural exposures, that it is difficult for the geologist whose personal experience has been chiefly limited to this region to realize that they belong to a type of eruption not generally recognized elsewhere.

Within the mountain area there are intrusive rocks of various kinds. The laccolites of the plateau country to the west are formed of practically a single rock type, but this is also the most common intrusive of the mountains, and this article is to discuss the general occurrence and character of this type.

It seems desirable to preface the descriptions of some regions where these igneous intrusions are well shown by a partial review of the more recently expressed opinions concerning the general subject of intrusive rocks.

The theory of laccolites: its origin.—In 1877 was issued the "Report on the Geology of the Henry mountains,"[1] and in it is a clear and now almost universally accepted description and explanation of mountain masses owing their elevation to igneous magmas intruded into horizontal strata at considerable depths below the surface. Gilbert's interpretation of the observed facts is that in a plain region underlain by many thousand feet of horizontal sediments molten magmas ascended from unknown depths to various horizons in this complex of strata, where they spread out as sheets or in larger dome-shaped masses, more or

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[1] Gilbert. G. K., a monograph of the U. S. Geog. and Geol. Survey of the Rocky Mountain Region, J. W. Powell in charge, Washington, 4°, pp. 160, Pl. V.

less pronounced, lifting up the load of sediments above them. By expansion or stretching the sediments in some cases remain unbroken above these laccolites, as the dome-like masses were named, while in other cases a rupturing of certain beds took place and the fissures were filled by magmas, forming dikes, usually of quite limited extent.

Preceding the examination of the Henry mountains, Messrs. W. H. Holmes and A. C. Peale had visited and described a number of isolated mountain groups similar to the Henry mountains in origin, but from the reconnoissance character of their work it naturally followed that they could not observe many facts of detail necessary to a satisfactory understanding of the structure of these eruptive masses and to the formation of a consistent theory of their origin. The first of the great intrusive rock masses observed by these geologists were described without special consideration of the novelty of the occurrence, but a comprehensive discussion of the relationships of these mountains was given by Peale in 1877, in a paper entitled "On a peculiar type of eruptive mountains in Colorado."[1]

Peale recognized that the mountain groups of the plateaus consisted chiefly of a certain igneous-rock type, and also that this type occurred in many places in the mountain area of Colorado. He sought to show that the mountains exhibiting this rock are due to its presence and not to orographic movement, and therein is the essential element of his "eruptive mountain" type. It is in place here only to point out that Peale's generalization does not refer to the manner or horizon of intrusion of the magma. Nevertheless the laccolitic groups of the plateaus are the most prominent illustrations of his mountain type.

It is doubtless true that igneous masses have been described in various parts of the world as intrusions of a type more or less allied to that of the Henry mountains, but such descriptions or opinions have not carried weight enough to make them generally accepted. This is made clear by an examination of the chief text books or other comprehensive works on geology published since the Henry mountain report. In all of them great prominence is given to the laccolitic idea of Gilbert, and in many works immediate reference is made to the Henry mountains and allied localities as the most convincing exhibitions known of the actual occurrence of intrusive igneous rocks.

Different views of the laccolitic theory.—To illustrate the manner in which the principle of the laccolitic intrusion has been received by different geologists, it is only necessary to refer to the works of three distinguished geologists of one city, Vienna, namely, Professors E. Suess, M. Neumayr, and E. Reyer.

In his well known work "Das Antlitz der Erde" (1885), Prof. Suess discusses laccolites and intrusive rocks generally under the head of volcanoes. After speaking of the superficial portion of the volcano, he passes to the lower part and finds evidence of lateral injections of mag-

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[1] Bulletin, U. S. Geog. and Geol. Survey, Vol. III, No. 3, pp. 551-564.

mas, producing sheets more or less conformable with sedimentary beds, as instanced in the mass of the old volcano of Monte Venda, near Padua. To explain such phenomena he at once turns to the descriptions of Gilbert, Peale, and Holmes, saying that these American geologists have recently described a remarkable series of mountains characterized by the presence of huge intrusive rock masses. Suess summarizes the facts of observation, cites the conclusions of the authors named, and reproduces their illustrations, showing that these occurrences are to him the most perfect demonstration of principles which he then applies to numerous localities of Europe and elsewhere.[1]

The late Prof. Neumayr, in his "Erdgeschichte" (Vol. I, 1887), discusses laccolites, as did Suess, in direct connection with typical volcanoes and especially in their possible connection with the old theories of craters of elevation. He refers to the phenomena of the Henry mountains as most wonderful, and after summarizing Gilbert's statements as to their character he remarks that there are two possible explanations: one, that the eruptive rocks are surface lavas separated by sediments deposited over them in the intervals between eruptions; and the other, that they are later intrusions. "Unmistakably the first view is a priori by far the more plausible and probable and agrees far better with the ruling ideas of volcanic phenomena and of the dynamics of the earth's interior, while the second borders almost on the impossible and incredible."[2]

Yet he feels forced to accept the intrusive theory because of the stated facts: (1) Eruptive detritus is absent from the sediments above each laccolite or sheet; (2) the "trachyte" is never vesicular or lava-like; (3) tuffs are wanting; (4) the arching of strata over laccolites at high angles could not result from later deposition; (5) cross-cutting arms connect sheets of different horizons, and dikes are abundant above laccolites; (6) contact phenomena occur in strata at the upper contact of laccolites; (7) the igneous rocks of all horizons from the Trias to the Upper Cretaceous are too much alike to represent volcanic eruptions through this long period of time.

Thus Neumayr is forced to the "surprising result" that these igneous masses are actually intrusions of much later age than the sediments surrounding them. He closes with the remark that the observations of Gilbert certainly need confirmation.

A very different view is taken by Prof. E. Reyer in his "Theoretische Geologie" (1888). This author, in treating of volcanoes, remarks that the alternation of eruptive masses and sediments was correctly interpreted by geologists of the last century as due to the extrusion of lavas at intervals during a period of sedimentation, while to-day the view is

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[1] Das Antlitz der Erde, Vol. I, Leipzig, 1885, p. 195.

[2] Erdgeschichte, Band I, Allgemeine Geologie, Leipzig, 1887, p. 180. "Es lässt sich nicht verkennen, dass von vornherein die erste Anschauung bei weitem plausibler und wahrscheinlicher ist und der herrschenden Auffassung der vulkanischen Erscheinungen, ja der ganzen Dynamik des Erdinnern sich weit besser anschliesst, wahrend die zweite fast ans Unmögliche und Unglaubliche streift."

entertained by some authors that the sediments are older than the eruptives, which they consider as intrusive. The latter view is maintained, according to Reyer, because these authors "hold fast to the dogma that in past ages there were no volcanoes."[1] He does not seem to allow for the possibility that an alternation of eruptive and sedimentary masses may arise from different causes in different places. The La Plata mountains of Colorado are specially discussed as an instructive example of the alternation of surface lava flows and sediments, although Holmes, who originally described these mountains, presented evidence of the intrusive character of the eruptive. Some of the facts of the Henry mountains forced Reyer to the conclusion that some of the sheets and dikes are more recent than the sediments, and a hypothesis is framed to explain this, while still assuming that the main laccolites are extrusions.[2] In all his treatment Reyer ignores or distorts the facts of observation, and his hypothesis is sufficiently refuted by reference to the argument of Neumayr quoted above.

Basis of the present discussion.—In connection with the Colorado division of the survey, under Mr. S. F. Emmons, the writer has had opportunities for studying the intrusive rocks of Colorado in detail in three large districts, namely, the Mosquito and the Ten Mile districts, in central Colorado; and the West Elk mountains, on the western slope. He has also availed himself of further opportunities for the examination of many local occurrences in other districts, and through the observations of friends has come to a knowledge of numerous other occurrences. Through the courtesy of Mr. G. P. Merrill, curator of geology in the U. S. National Museum, he has been enabled to study the collections made by Gilbert in the Henry mountains, by Peale in the West Elk mountains, by Holmes in the San Miguel, La Plata, El Late, Carriso, and Abajo mountains—in short, of all the mountain groups which have been compared with the Henry mountains, excepting the La Sal, of which area the specimens have been lost. To Mr. J. S. Diller he is indebted for the loan of thin sections of many of these rocks.

Object and plan of the discussion.—The object of the present discussion is twofold. On the one hand it is desired to establish more clearly than has previously been attempted the various phases characteristic of the intrusion of a certain class of igneous magmas into the sedimentary complex; on the other hand, the rock type produced by the consolidation of these magmas has been found to have characteristics worthy of special note in their bearing upon the principles of petrography.

The plan of presentation will be to briefly review in the outset the facts established by Gilbert in the Henry mountains and to restate the theory of the laccolite as an explanation of those facts. Then the West Elk mountains will be described in some detail and compared with the

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[1] E. Reyer, Theoretische Geologie. Stuttgart. 1888, p. 135.

[2] Op. cit., p. 136.

Henry mountains. The facts known concerning other laccolitic groups can then be concisely reviewed, and the scope of the discussion further broadened by the description of other clearly allied occurrences.

THE HENRY MOUNTAINS.

Position and physiography.—The Henry mountains stand upon the western bank of the Colorado, in southern Utah. They are in the midst of the great desert plateau region, whose scarps and cañon walls are already celebrated the world over for the model-like perfection with which they exhibit the stratigraphical relations of a great series of sedimentary beds. They are 100 miles from the nearest Colorado mountains of the common type of structure.

The mountains are described by Gilbert[1] as follows: "The Henry mountains are not a range, and have no trend; they are simply a group of five individual mountains, separated by low passes and arranged without discernible system. The highest rise about 5,000 feet above the plateau at their base and 11,000 above the ocean. * * * Their extent is small. From Ellen peak to Mount Ellsworth, the two summits which are most widely separated, the distance is but 28 miles, and a circle of 18 miles radius will include the whole group.

"Mount Ellen, which is the most northerly of the group, has an extreme altitude of 11,250 feet, and surpasses its companions in horizontal extent as well as in altitude. Its crest line is continuous for 2 miles with an elevation varying little from 11,000 feet; from it there radiate spurs in all directions, descending to a series of foot hills as conspicuous in their topography as they are interesting in their structure.

"Mount Pennell is a single peak rising to an altitude of 11,150 feet. On one side its slopes join those of Mount Ellen in Penellen pass (7,500 feet), and on the other those of Mount Hillers in the Dinah creek pass (7,300 feet).

"Mount Hillers is more rugged in its character, and although compact in its general form is carved in deep gorges and massive spurs.

"Mount Ellsworth (8,000 feet) and Mount Holmes (7,750 feet) stand close together, but at a little distance from the others. The pass which separates them from Mount Hillers has an altitude of 5,250 feet. They are single peaks, peculiarly rugged in their forms and unwatered by springs. They stand almost upon the brink of the Colorado, which here flows through a canyon 1,500 feet in depth."

For maps and views of the Henry mountains the reader must be referred for the most part to the admirably illustrated monograph by Gilbert. The general position of the group, relative to the other isolated groups of the plateaus, is shown in Pl. XII, a reproduction of one of Holmes's remarkably expressive sketches. Pl. XV*a*, represents the

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[1] Geology of the Henry mountains, pp. 2, 3.

Henry mountains as seen from the Abajo mountains, 55 miles to the east, another sketch by the same master hand.

Gilbert's monograph.—The Henry mountains were made the subject of detailed investigation by G. K. Gilbert, of the Powell Survey, in 1875 and 1876, the same years in which Holmes and Peale were most hurriedly examining the other similar mountain groups of the plateau country. He was able in two months' time, thanks to the excellent natural exposures, to establish by many details of observations that the Henry mountains present a practically new type of mountain structure. It will be impossible in this place to do more than summarize the facts concerning the relationships between sedimentary and igneous rocks, and to state the theory formulated by Gilbert for their explanation. In doing this the plan of the monograph will be followed and the author's words used wherever possible.

Structure of the group.—The strata of the plateau about the Henry mountains have a uniform dip of 45′ to the northwest, and the nearest of the great flexures traversing the plateaus is 15 miles westward. At the base of the mountains on all sides the strata are upturned, slightly or abruptly, and on all the slopes dip away from the center. In some peaks, as at Mounts Ellsworth and Holmes, the sedimentary beds are seen to arch completely over the crest; at others erosion has cut through the strata and revealed one or more great masses of igneous rock, of uniform type, which appear to be the sole cause of the disturbance of the beds.

These eruptive bodies are large or small, thick or thin. Some of them are huge, flat, dome-shaped masses; others are sheets; and dikes frequently occur. The disturbance of the strata is regular, as a rule, because the eruptive rock has been intruded at definite stratigraphical horizons, effecting markedly only the beds above. Erosion exhibits the size, form, and relationships of the rocks in all degrees of clearness. To explain this mountain structure, Gilbert at once formulates his theory as to the intrusion of the magmas.

The laccolite.—It is first pointed out that mountains of igneous rock are usually formed by magmas, coming from unknown depth, traversing the entire intermediate series, and accumulating upon the surface of the earth. "The lava of the Henry mountains behaved differently. Instead of rising through all the beds of the earth's crust, it stopped at a lower horizon, insinuated itself between two strata, and opened for itself a chamber by lifting all the superior beds. In this chamber it congealed, forming a massive body of trap. For this body the name of *laccolite* (*λάκκος*, cistern, and *λιθος*, stone) will be used. * * * The laccolite is the chief element of the type of structure exemplified in the Henry mountains."

Fig. 25 is a reproduction of Gilbert's ideal cross section of a laccolite. "Associated with the laccolites of the Henry mountains are *sheets* and *dikes.* The term *sheet* will be applied in this report to broad, thin, stratified bodies of trap, which have been intruded along the partings between sedimentary strata, and conform with the inclosing strata in dip. Dikes differ from sheets in that they intersect the sedimentary strata at greater or less angles, occupying fissures produced by the rupture of the strata. * * * Between the sheet and the laccolite there is complete gradation. The laccolite is a greatly thickened sheet, and the sheet is a broad, thin, attenuated laccolite."

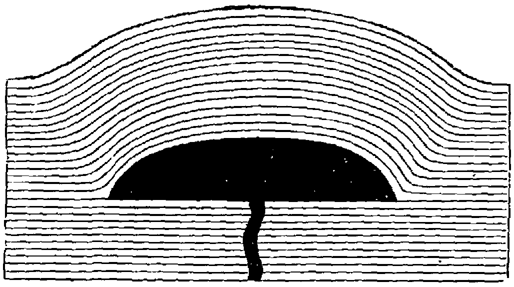

Fig. 25.—Ideal cross section of a laccolite.

In the Henry mountains "the laccolite is usually, perhaps always, accompanied by dikes and sheets. There are sheets beneath laccolites and sheets above them. The superior sheets have never been observed to extend beyond the curved portion of the superior strata. Dikes rise from the upper surfaces of the laccolites. They are largest and most numerous about the center, but, like the superior sheets, they often extend nearly to the limit of the flexure of the uplifted strata." Fig. 26 represents the ideal relationship of laccolite, sheets and dikes, as given by Gilbert.

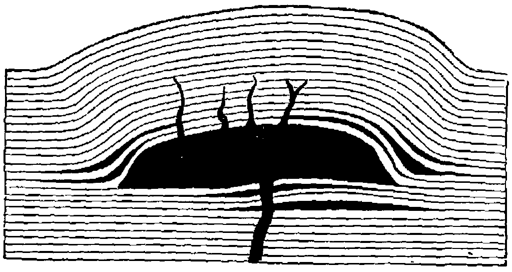

Fig 26.—Ideal cross section of a laccolite.

In both horizontal and vertical distribution the laccolites of the Henry mountains are very irregular. Fig. 27 is Gilbert's ideal cross section of a group of laccolites. If to these be added sheets and dikes corresponding to Fig. 26, it is clear that erosion will display very different phases of this structure in different stages. "In one place are seen only arching strata; in another, arching strata crossed by a few dikes; in another, arching strata filled with a network of dikes and sheets. Elsewhere a portion of the laccolite itself is bared, or one side is removed, so as to exhibit a natural section. Here the sedimentary cover has all been removed, and the laccolite stands free, with its original form; there the hard trachyte itself has been attacked by the elements

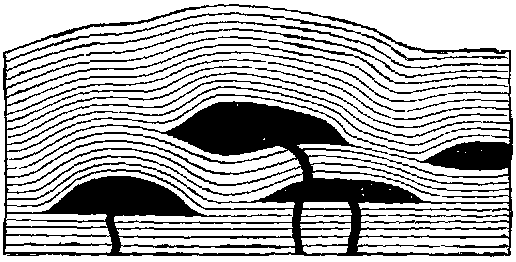

Fig. 27.—Ideal cross section of grouped laccolites.

and its form is changed. Somewhere, perhaps, the laccolite has been destroyed and only a dike remains to mark the fissure through which it was injected."

Summary of facts.—With the theory of the laccolite in mind, the facts of observation can now be briefly summarized. Firstly, as to the *intrusive* origin of the igneous masses, the facts brought forward by Gilbert are the following: (1) "No fragment of trachyte has been discovered in the associated strata." (2) "The trachyte is in no case vesicular, and in no case fragmental." These negative proofs are sufficient to demonstrate that the rocks are not surface lavas, especially in view of other characters of the rocks to be brought out later on. (3) The strata arch over many laccolites too regularly, and at too great dip angles—in many places between 45° and 80°—to have been deposited in this position by sedimentation. (4) Sheets are occasionally found breaking across from one horizon to another. (5) The strata above laccolites are metamorphosed in degree and manner as are those below them. To these may be added the fact pointed out by Neumayr, that (6) the laccolites occur at various horizons from the Carboniferous to the upper Cretaceous, and but one rock type is represented; no known volcano has produced a single type of lava for any such length of time. These holocrystalline rocks have a granular groundmass, practically the same in sheets, laccolites and dikes, and do not show the structure characteristic of andesites, their equivalent lava forms. Both the uniformity and character of the rock structure show that the masses of varying size consolidated far below the surface, where size was a comparatively unimportant element in determining the conditions of cooling. Many minor points appear throughout the descriptions, which are incompatible with the idea that the bodies are surface extrusions, and none of the facts point to such a conclusion.

Secondly, the facts of observation dependent on *extent of erosion* may thus be grouped: (1) "There are seven laccolites which lie so far above the local plain of erosion that they are especially exposed to denuding agents. They have no enveloping strata, and their only associated sheets lie in the strata under them. Their original forms have been impaired or destroyed by erosion." (2) "There are two laccolites so nearly bared that their forms are unmistakable, which are still partially covered by arching strata, and which have associated sheets and dikes." (3) "There are five supposed laccolites situated where the erosion planes are inclined, which run under the slopes and are covered at one side or end, and at the other project so far above them as to have lost something by erosion. These are accompanied by overarching strata and by sheets and dikes." (4) "There are seven or eight supposed laccolites, of which only a small part is in each case visible, but which are outlined in form by domes of overarching strata. Their bases are not exposed. Associated with them are dikes and sheets." (5) "There are five domes of strata accompanied by dikes and sheets, but showing no laccolites." (6) "There are nine or more domes of strata with no visible accompaniments of trachyte."

Thirdly, as to the observed *forms of laccolites.* "As a rule laccolites are compact in form. The base, which in eleven localities was seen in section, was found flat, except where it copied the curvature of some inferior arch. Wherever the ground plan could be observed it was found to be a short oval, the ratio of the two diameters not exceeding that of three to two. Where the profile could be observed it was usually found to be a simple curve, convex upward, but in a few cases * * * the upper surface undulates. The height is never more than one-third of the width, but is frequently much less, and the average ratio of all the measurements I am able to combine is one to seven."

The Mount Hillers laccolite.—It seems desirable to give some of the details concerning the Mount Hillers laccolite, the largest of the Henry mountains, and the one with which it will be instructive to compare certain other masses that are to be described. Fig. 28 is Gilbert's cross section of the mountain, with ideal representation of the underground structure.

The depth of the laccolite "is about 7,000 feet, and its diameters are 4 miles and 3¾ miles. Its volume is about ten cubic miles. The upper half constitutes the mountain, the lower half the mountain's deep-laid foundation. Less than one-half has been stripped of its cover of overarching strata. The remainder is still mantled and shielded by sedimentary beds and by many interleaved sheets of trachyte." The uncovered part is "scored so deeply that not less than 1,000 feet of its mass are shown in section."

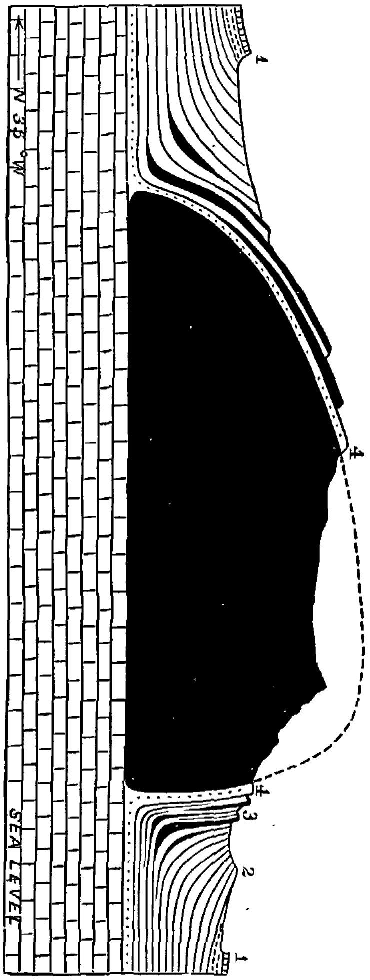

FIG. 28.—Ideal cross section of Hillers laccolite.

The strata at the southern base have a dip of 80°; on the east and west the dip is about 60°; and on the north it is still less. "It would appear that the laccolite was asymmetric. * * * By a reference to the section it will be seen that the sedimentary strata of the north flank stretch quite to the summit of the mountain. The same beds which form the revet crags on the southern base constitute also some of the highest peaks. Since these rest directly upon the laccolite, it is assumed that the next lower beds of the stratigraphic series form its floor; and the base of the laccolite is drawn in the ideal section on the level which the Shinarump group holds where it is unaffected by the displacement of the mountain."

"It is noteworthy that wherever the sedimentaries appear upon the mountain top they are highly metamorphic. But in the revet crags there is very little alteration."

Distribution of the laccolites.—The sedimentary section of this region may be summarized as follows:

	Feet.
Cenozoic: an unknown but great thickness.	
Mesozoic:	
Cretaceous	3,500
Jura-Trias	2,930
Paleozoic:	
Permian and Permo-Carboniferous	854
Carboniferous	3,252
Devonian	100
Silurian	785
Cambrian	459
	11,880

The Mesozoic divisions are here assigned the thickness given by Gilbert for this vicinity; the Paleozoic is that given by Walcott for the Colorado canyon country, to the south.[1]

According to Gilbert, "the range of altitudes at which laccolites have been formed is not less than 4,500 feet, and neither the upper nor the lower limit is known. The highest that are known are near the base of the Blue Gate shale [Middle Cretaceous], but it is quite possible that higher ones have been obliterated by erosion. The lowest that is known was intruded in the Shinarump shale [base of Juratrias], but it is known of the invisible Ellsworth laccolite that upper Carboniferous strata lie above it, so that its horizon of intrusion must be still lower."[2]

The greater number occur in the Lower Cretaceous or in the Upper Jura-Trias.

As regards the rocks in which the laccolites occur Gilbert remarks that "all the determined laccolites are inclosed by soft beds. They have been intruded into the shales but not the sandstones. They cluster about the Henry's Fork conglomerate [base of the Cretaceous], but none of them divide it. This selection of matrix is confined, however, to the laccolites and is not exercised by sheets and dikes."[3] Important sandstone banks separate the shale formations in which lie the laccolites.

Questions of cause, condition and age.—It is the object of this article

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[1] Personal communication.

[2] Henry Mountains, p. 56.

[3] Op. cit., p. 58.

to assemble the known facts concerning the occurrence and character of a large group of igneous rocks rather than to discuss the abstract questions of their origin. In a later section, however, the general bearings of observations will be considered, and to that place may profitably be assigned a review of Gilbert's conclusions. It is well to bear in mind, that the theory of Gilbert requires the assumption that several thousand feet of strata existed above the highest laccolite now seen in the Henry mountains at the time of its intrusion. Such a condition places the age of the laccolitic eruption in Cenozoic time, and the occurrences of the West Elk mountains demonstrate the correctness of this conclusion.

The rocks.—The igneous rocks of the Henry mountains are called "porphyritic trachyte" by Gilbert, in accordance with the determination of Capt. C. E. Dutton, who examined a considerable number of them under the microscope, and whose report upon them is contained in Gilbert's monograph. That this determination is incorrect has already been stated by the present writer in connection with a description of similar rocks from the Mosquito range, in Colorado.[1] At that time only a few of the hand specimens, the original thin sections, and a few new ones, were available for examination. Now, however, the writer has studied the entire collection, reexamined the original sections and a suite of excellent new ones, and can state the character of the Henry mountain eruptives with much greater positiveness.

In describing these rocks, and, indeed, those of several other mountain groups, it will be necessary to use a nomenclature almost entirely different from that adopted by Gilbert, Dutton, Holmes and Peale. That this is true is not a reflection upon these able geologists, for the modern science of petrography was unknown in this country at the time their work in these regions was done. Few of the specimens collected by them had been examined microscopically or chemically when the published reports were written, and it is usually stated in those reports that the names used are adopted provisionally. It is probably true that the terms "trachyte" and "rhyolite," most commonly used, have conveyed to European geologists an incorrect idea as to the character of the rocks constituting the remarkable masses described, and may have caused some to hesitate in accepting the ideas advanced regarding their origin. The sections studied by Capt. Dutton are so thick as to render their examination very unsatisfactory even with the best of microscopes.

The rock collection made by Gilbert is now represented in the U. S. National Museum by specimens from about thirty different masses. They represent large and small laccolites, sheets and dikes, and come from all parts of the group. As a rule but one specimen was collected from each mass, but the uniformity of these rocks is so great that in

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[1] Monograph XII, U. S. Geol. Survey. Geology and Mining Industry of Leadville, Colorado, by S. F. Emmons, Appendix A; Petrography, by Whitman Cross, pp. 359–362.

most cases the average of the mass is no doubt fairly represented by the single specimen.

As was indicated by Dutton's examination, there is practically but a single rock type. It is a holocrystalline porphyry, characterized by phenocrysts of plagioclase, with hornblende or augite, and by a granular groundmass consisting chiefly of orthoclase and quartz. Its granular equivalent would be a quartz-bearing diorite, and its lava form would be andesite, approaching dacite in some cases. The rock is what has hitherto been called porphyrite by American petrographers and by some Europeans.

The group is especially characterized by its uniform porphyritic structure. Among the phenocrysts plagioclase is always the dominant mineral. It occurs in stout crystals, usually between 1 and 4 millimeters in length with a few somewhat larger ones. Occasionally the average size is nearly 5 millimeters, but more frequently it is less than 3 millimeters. Hornblende and augite are smaller than the plagioclase in general, with a tendency of the former to develop here and there in prisms 1 centimeter or more in length.

Nearly all of the rocks are hornblendic without either augite or biotite. In four of them augite replaces most of hornblende, and in two others is present in subordinate amount. Biotite is a minor constituent of a single rock.

Quartz phenocrysts, always more or less rounded by resorption, were observed in eight rocks, and are no doubt sporadically present in nearly all of them. Orthoclase phenocrysts are developed sparingly in two rocks, but these are not to be compared with the large crystals occurring in some types to be described from other groups. Garnet appears scattered irregularly through two of the specimens.

The plagioclase seems to be oligoclase or andesine in most cases. The albite twinning appears alone in a majority of rocks, but the Carlsbad and the pericline laws are sometimes shown in addition. A faint zonal structure is common, and inclusions are, as a rule, not abundant. The hornblende is yellowish brown or sometimes green. The augite has a very unusual clear green or yellowish green color. $\mathfrak{a}$=strong yellow green; $\mathfrak{b}$=dark grass-green; $\mathfrak{c}$=grass-green. A colorless kernel was seen in a few crystals. Small grains of augite, which, with magnetite, result from the resorption of hornblende in the augite-porphyrite, have the same peculiar color as the phenocrysts. The usual crystal form, cleavage and extinction angle characterize the mineral as augite

The groundmass is typically granular in the great majority of cases, and consists most naturally of quartz and orthoclase. As quartz decreases the evenness of grain diminishes, and in the feldspathic rocks the grains are elongated instead of exhibiting even dimensions. If plagioclase enters into the groundmass it is in microlitic form. The quartz is clear and distinct from the more or less clouded orthoclase, except in the finer grained rocks. A tendency of the quartz to form rude dihexahedral crystals is often seen. Micropegmatitic structures are entirely absent. In two cases a patch or micropoikilitic structure is imperfectly developed.

The average size of the groundmass grains is between 0·02 and 0·04 millimeter for more than half the rocks. In another large division the groundmass is cryptocrystalline, though never far below the limits of probable identification. The average grain rises above 0·04 millimeter in but three rocks, and never reaches 0·1 millimeter.

The microscopic accessory constituents are apatite, magnetite and zircon, in the usual development; titanite, very characteristic of a large number; and allanite, seen sparingly in five rocks. Magnetite often occurs in two generations—in large phenocrystic grains, and in minute ones belonging to the groundmass.

Distribution of types.—The different mountains and different kinds of occurrences are quite evenly represented in the collection. Eight are from large laccolites, three from small ones, eight from sheets, and nine from dikes.

The augite-porphyrites are all from Mount Pennell or Mount Hillers, but hornblendic rocks apparently predominate in both mountains. The augitic types are mainly from sheets, but it is possible that the main Hillers laccolite is of this rock.

As to the grain of the rocks—the cryptocrystalline forms are all from dikes, mainly in Mounts Ellsworth and Holmes. The average grained rock occurs in laccolites, sheets and dikes. The three coarser grained ones come from dikes or sheets in different mountains.

The observations then confirm the conclusions of Dutton that these specimens indicate no differences of composition or structure corresponding either to geographical or geological distribution, or to the size or form of the intruded masses. The collection is of course not large enough to permit of a positive statement that no correspondence between occurrence and characteristics of any kind exists in the Henry mountains, but it does clearly prove that certain generalizations can not be made.

WEST ELK MOUNTAINS.

GENERAL DESCRIPTION.

Introductory.—The West Elk mountains, in Colorado, were the first to be examined of the groups under consideration, and also the first to be reexamined in some detail. They are taken up next in order because the recent investigation of them contributes materially to a knowledge of certain phases of laccolitic intrusion not emphasized in the Henry mountains, and because one can then proceed to review the other mountain groups of allied character from a broader standpoint.

Their geographical position contrasts with that of the Henry mountains in that they seem at first to be merely the outliers of the great mountain region of Colorado. But even an average observer must quickly notice that they are very distinct in character from the ranges to the east.

Relation to the Elk mountains.—To the west of the Sawatch range in Colorado lie the Elk mountains, a group of high and rugged peaks which have already been made classic ground by the work of Holmes and Peale of the Hayden survey. The entire sedimentary section from the Upper Cambrian to the Dakota Cretaceous is represented in the Elk mountains. Several dynamic movements of importance have occurred, the most important of which is the Elk mountain fold-fault, worked out by Holmes. In intimate connection with the latter came a great eruption of diorite, but there are other diorite masses not directly related to this movement. Metamorphism by aqueous agencies accompanying the diorite eruptions has hardened the sediments and made them capable of forming high and rugged mountains. Ore deposition has also taken place in many parts of the Elk mountains.

Adjoining the Elk mountains on the southwest is a group of mountains differing markedly in topographic forms, as a result of different origin. The sedimentary rocks of this area are of Cretaceous age and the many isolated mountain masses are due to huge intrusions of igneous rocks, to surface volcanics, or, in a very minor degree, to metamorphism of Cretaceous shales. The markedly differing character of these two mountain groups was at once appreciated by Holmes, who designated the latter group the West Elk mountains. The two areas meet on the line where the lower Cretaceous strata are upturned at the west base of the Elk mountains.

The reports of Holmes and Peale.—The descriptions of Holmes and Peale concerning the Elk and West Elk mountains were published in the annual reports of the Hayden Survey for 1873 and 1874. At that time the laccolitic idea had not been advanced and the true character of the occurrences described was but imperfectly realized. Holmes examined but one of the masses properly belonging to the West Elk mountains, namely, Ragged mountain, the most northerly of the group, and as it happens the one where the relationship between igneous and sedimentary rocks is most clearly visible. He approached it, too, from the most favorable direction to see its structure and in his sketch, reproduced below (Fig. 29), he shows the true structure of the mountain, interpreting the great central body as "a wedge-like mass of intrusive rocks."[1]

All the other mountains in the West Elk group were examined by Peale, who states that they consist of great masses of a uniform igneous rock, generally called "trachyte," and are surrounded in the main by Cretaceous strata. Certain points were observed where the eruptives cut across or appeared as a sheet between strata, but evidence was nowhere found which led Peale to conclude that the large masses were

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[1] Hayden, Ann. Rep., 1873, p. 64.

ever wholly covered by sediments. After the experience of the next few years in the laccolitic groups of the plateaus, Peale published his paper, "On a peculiar type of eruptive mountains in Colorado," and included the West Elk mountains in the list.

Recent investigations.—The Colorado division of the Survey has now completed two atlas sheets of this region. The Crested Butte sheet is traversed diagonally from northwest to southeast by the line between the two mountain groups. On the northeast is the southern ending of the great Elk mountain fold-fault and of the associated diorite mass, while on the southwest it embraces two of the typical mountain masses of the West Elk mountain group.

The Anthracite district, adjoining the Crested Butte on the west, lies entirely in the West Elk area and contains seven large mountain masses characteristic of the group.

The Elk mountain diorite mass not a laccolite.—Before proceeding to a description of the West Elk laccolitic masses it is desired to correct an impression entertained by some that the main diorite mass of the Elk mountains is a laccolite. This is directly stated by Gilbert,[1] in his Henry mountain report, and Peale[2] discusses it with the other masses, treating it as identical with some of them as to character of the rock, and expresses the belief that they are from the same immediate source. Suess refers to this mass as considered to be a laccolite by American geologists.[3]

As regards the form of the mass, the view above mentioned seems to come from a misinterpretation of Holmes's stereogram representing the Elk mountain fold-fault. To produce the desired effect Holmes has pictured the folding of a single stratum, but does not say that everything below this stratum is eruptive, yet this has been assumed by Suess, and hence the implication that the eruptive is intruded at a given horizon. The descriptions of the region and the drawing of the Hayden map controvert this idea. As shown at the southern extremity, in the Crested Butte district, this great diorite mass is a huge cross-cutting body sending arms in all directions across the entire Carboniferous section.

The rock was called "granite" by Holmes. It is in fact a very fine and even grained diorite, characterized by nearly equal development of hornblende and biotite, and has some quartz. Pale-green augite is locally intergrown with the hornblende, and in parts of the mass a distinct augitic facies is developed. It is ordinarily a strongly plagioclastic rock, but has pegmatitic or feldspathic veins in some parts. The structure is typically granular, and even in small dikes it does not develop the porphyritic structure. While its chemical and mineralogical composition is similar to that of some of the laccolitic rocks, the

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[1] Henry mountains, p. 70.

[2] On a peculiar type of eruptive mountains in Colorado, Bull. U. S. G. and G. S., Vol. III, p. 555, 1877.

[3] Das Antlitz der Erde, Vol. I, p. 214.

marked differences in structure show that these magmas were erupted and consolidated under different conditions.

The marked metamorphism of the sedimentary rocks in a broad contact zone about most of the Elk mountain diorite bodies proves that these magmas contained, or were accompanied by, mineralizing agents, not associated with any of the laccolitic magmas. And this, also, suggests that the magmas of the two types of intrusion belong to different periods of eruption.

The eruptive mass of Mount Sopris, at the northern limit of the Elk mountains, is described by Holmes[1] as upturning the Paleozoic beds, as if it were a true laccolitic intrusion. The few specimens collected by Holmes representing this mass have been examined by the writer and found to be quartz-diorites, similar to the main Elk mountain diorite. Present knowledge does not show whether the Sopris mass is a granular member of the main laccolitic series of intrusions, or whether it belongs with the other diorites in period of origin.

General character of the laccolitic mountains.—The accompanying map (Pl. VII) shows the forms and relationship of the nine laccolitic mountain masses of the Crested Butte and Anthracite districts. The subdivisions of the sedimentary formations have been for the most part omitted as unessential and obscuring, and many of the smaller intrusive sheets have also been left out. For these details the reader is referred to the atlas sheets now in course of final publication.

Each of the large igneous areas of the map is composed of a single and usually homogeneous body of porphyrite, which rises as a mountain mass. These great masses lie in the comparatively soft Cretaceous strata, and erosion has removed the overlying sediments entirely or in great part and has cut down into the strata below them in several places. To convey an adequate idea of these masses it may be well to give their average dimensions. From the average elevation of the contact to the mountain summits is usually 2,000 to 3,000 feet, while the horizontal extent is from 2 to 4½ miles. The thickness now seen in no case represents the original vertical dimension of the mass.

The upper portion of each of these mountains is above timber line and hence displays the bare rocks. The outlines are rugged and the slopes usually very abrupt to the line of contact. Great amphitheaters excavated in the solid rock of the summits form a characteristic feature of several mountains, as in Mount Wheatstone, the Anthracite range, and Mount Beckwith. It is noticeable that these amphitheaters are always on the northern or eastern slopes.

The contact line is almost always well marked by the change from the steep to a more gentle slope. As a rule the shaly slopes are covered by a dense timber growth, but another cause operates still more effectively to conceal the exact contact line. This is the immense amount of débris washed down from the higher slopes. This talus

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[1] Ann. Rept. of Hayden Survey for 1874, p. 61.

often covers the contact continuously for miles. In spite of this obscuring of the contact, sufficient data were obtained in favorable localities to place the character of these masses beyond question. These data will be given for some of the principal masses.

RAGGED MOUNTAIN.

Position and structure.—Ragged mountain is the most northern and also one of the largest of the West Elk group, and in it can best be seen the upturning of the sedimentary rocks about the igneous core. Its southern slopes extend into the northwestern corner of the Anthracite sheet.

The mountain is a series of pointed peaks above 12,000 feet in height, with high, sharp, connecting ridges suggesting its name. Its greatest length is abut 8 miles. On the east and northeast the rough contour of the upper part is increased by a number of deep, broad amphitheaters or basins excavated in the eruptive and separated by jagged ridges. On the west is a very abrupt wall more than 2,000 feet in height, presenting an unbroken front for nearly 3 miles.

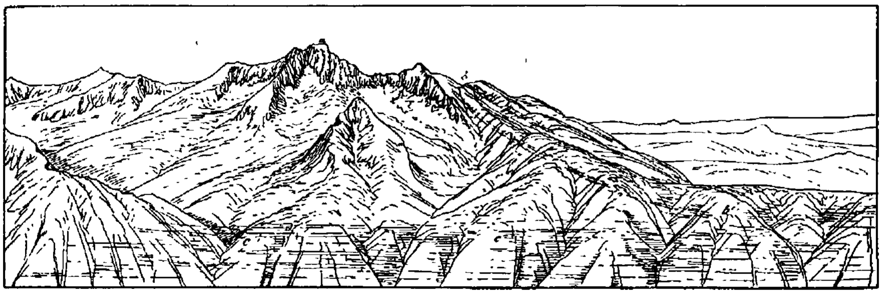


FIG. 29.—Ragged mountain, West Elk mountains, showing upturned strata on laccolite.

The ridges extending out from the center on the north, east, and south, show strata belonging to the upper part of the Montana and the lower part of the Laramie Cretaceous, reaching far up on the mountain by reason of a dip of from 25° to 45° away from the eruptive center, and some of the outer summits of the group at nearly 12,000 feet elevation are made up of Montana shales. In the gorges between ridges one can see that the strata rest upon the uniform eruptive mass whose upper surface is seen to be approximately conformable with the stratification.

At the northern end of the mass the valley of Rock creek has cut down sufficiently to show, according to Mr. Holmes, that the eruptive is "a wedge-like mass" splitting open the strata at a certain general horizon, below which the beds run nearly horizontally under the mountain. On the east and south erosion has not yet cut deep enough to show this.

Fig. 29 is the sketch of the mountain made by Holmes. The structure exhibited by this sketch, and the other facts, show the Ragged mountain mass to be in this part at least very much like the typical laccolite of the Henry mountains. The resemblance is heightened by the occurrence of two or three large intrusive sheets in the shales resting upon the eruptive, one of which extends into the Anthracite district, here dipping southwesterly, thus taking part in the syncline which appears east of the mountain. Dikes have not been observed.

No observations known to the writer indicate the relations to sedimentary rocks on the western slope of the mountain. The abrupt face suggests that there is a line of fracture similar to that to be described in other mountains of the group.

The rock.—The rock of the Ragged mountain core has received several designations. Holmes called it "rhyolite," while Peale refers to it as "trachyte," and upon the final map it is called "eruptive granite." Holmes collected from the central summit specimens which are identical in character with the southeastern part of the mass seen by the present writer. The rock is characterized by numerous distinct phenocrysts of plagioclase, orthoclase, hornblende, biotite, and quartz, which lie in a coarse-grained granular mass of quartz and orthoclase. The prominent feature of the rock, seen in mass, is the development of huge orthoclase crystals, often more than 3 inches in diameter, and exhibiting most beautifully a silvery luster parallel to a steep orthodome. These large crystals are irregularly scattered through the rock, and plagioclase—probably oligoclase—is still the dominant feldspar. The rock is, therefore, a porphyrite of the type common in these intrusive masses.

The outlying sheets are of similar rock with much smaller orthoclase phenocrysts and a finer grained groundmass.

MOUNT MARCELLINA.

Position and physiography.—Mount Marcellina is one of the most interesting isolated laccolitic mountains of the West Elk group. It lies a few miles south of Ragged mountain, in the northwestern part of the Anthracite district, and is encircled on the east, north, and northwest by the deep canyons of Anthracite creek. (See Pl. VII.) To the west is a low plateau country, and on the south a broad, timbered divide.

Pl. VIII shows the peculiar form of the mountain as seen from the southeast at a distance of about 3 miles. Its highest point (11,349 feet) is at the southern extremity, and below it on the south is a great cliff of glaring white rock with gothic pinnacles, and at its base an enormous talus slope now largely timber covered. North of the summit is a broad central hump or shoulder, from which there is a comparatively gentle descent northward to the brink of Anthracite canyon. On the east is a high cliff facing that part of the canyon, and on the west a steep slope, precipitous in places.

MOUNT MARCELLINA, WEST ELK MOUNTAINS; AN ASYMMETRIC LACCOLITE.

The line of Anthracite creek before reaching the mountain is rather indistinctly shown in Pl. VIII by a line ascending from left to right across the middle ground of the picture. Near the center of the view are seen the vertical columns of the upper part of the west wall of a minor canyon, where the stream has cut through a small laccolite, indicated on the map. Near the right hand or eastern extremity of the Marcellina mass the main canyon begins, passing between the bare face of the mountain and the light-colored ridge whose crest is marked by a line of trees. About on the border of the view the canyon turns at right angles and passes behind the mountain. The canyon has very abrupt walls and an average depth of 1,000 feet near the mountain. Its bed at the northwest base is 4,550 feet below the summit. The length of the mountain as seen in Pl. VIII is nearly 3 miles. It is hoped that these statements will have given some idea of the great mass of homogeneous eruptive rock, typical of many whose origin is to be discussed.

Structure.—On the canyon sides of the mountain the geological structure is very plain; on the others it is obscured by talus and vegetation. Dr. Peale was able to examine the mountain only at the northwestern base, where he found the Laramie strata, "tipped up, dipping to the northwest 15° to 20°." Here also he observed finger-like arms of the eruptive extending up into the strata a short distance. This structure extends along the entire northern base of the mountain, the north wall of the canyon showing in its upper part a band of Laramie sandstones dipping gently northward and resting on the eruptive. According to Mr. Eldridge, a layer of Montana shales is shown between the eruptive and the Laramie along a part of this canyon wall; thus the plane of intrusion is here at or near the base of the Laramie.

Approaching the northeast extremity of the mass the strike of the beds swings gradually around to north-south, with a steepening in the dip. That the upper surface of the eruptive is nearly conformable to the sediments is shown in the walls of Dark canyon, which enters the Anthracite from the east at the great bend, the form of the eruptive body at this point as shown on the map being due to an easterly dip of the contact plane.

Prospect point, in the angle between Anthracite and Dark canyons, exhibits the structure east of Marcellina. Its summit, and the crest of the ridge leading south, the descending line of which is shown in Pl. VIII, are made up of Laramie sandstones and shales. At the summit the dip is about 60° east, and the eruptive contact is found about 450 feet down the steep western slope, still conforming in general to the stratification.

The ridge southward from Prospect point descends to the level of Anthracite creek at the head of the main canyon; that is, where the stream passes into the eruptive. The dip of the Laramie beds increases in the descent of the ridge, but abruptly changes to a slight southerly dip near the stream level, and on the western bank strata in nearly horizontal position visibly approach close to the cliff of eruptive which rises as shown in Pl. VIII; that is to say, at the southeastern corner of the Marcellina mass there is clearly a sudden change in the character of the contact between eruptive and sedimentaries. The latter have been dipping away from the Marcellina masses all along the northern and eastern sides, with the eruptive under them as the apparent cause of the dip. From this point westward, all along the steep southern face of the mountain (see Pl. VIII), the strata seem to abut against the eruptive under the great talus slopes.

In the several miles between the northern and southeastern limits of the eruptive exposures along the canyon walls the contact plane has gradually cut across the stratification from a horizon near the upper limit of the Montana to one well up in the Laramie, probably 1,000 feet higher geologically, and on the south face of the mountain the Ruby beds, a Post-Laramie formation, to be more closely defined below, come in contact with the eruptive.

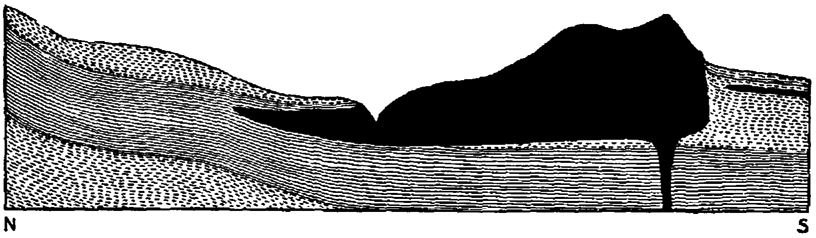


FIG. 30.—Profile section through Mount Marcellina, natural scale.

The profile section.—Fig. 30 represents a north-south profile through Mount Marcellina, drawn to natural scale, expressing the facts given and the deductions as to the probable form of the mass. On the north the dip toward Mount Marcellina is undoubtedly due to the great intrusive mass of Ragged mountain. The outlines of the Marcellina mass below the surface are drawn to accord with the theory that the strata pass under the eruptive practically undisturbed. The location and form of the conduit through which the magma ascended are entirely hypothetical. As will be shown hereafter, there are several masses in this region whose forms are very similar to that of Marcellina, and the discussion of the origin of such a mass will be deferred until the facts of other occurrences have been presented.

The rock.—The Marcellina massive is composed of a porphyritic diorite, consisting essentially of plagioclase, orthoclase, hornblende, biotite, and quartz. It is a fine-grained, grayish rock, the dark silicates being subordinate, and seems at first glance evenly granular. Plagioclase, hornblende, and biotite appear in small crystals, averaging 1 to 3 millimeters in length, and a hand lens shows that these crystals are embedded in a feldspathic groundmass, which also contains very minute but distinct quartz grains. The microscope shows this matrix to be properly a groundmass of quartz and orthoclase, corresponding in composition to that of many porphyrites of the region, but of unusual structure and grain. As a rule in similar rocks quartz and orthoclase form a fine, evenly granular mass, quite distinct from the phenocrysts, but here a coarser grain and a remarkably uniform development of quartz in rude dihexahedral crystals, 0·2 to 0·5 millimeters in size, produces a very interesting and significant transition stage between the porphyritic and granular structures.

Specimens collected in Anthracite canyon north of the mountain, at the southwestern base, and by Dr. Peale at the northwestern base, are identical in structure. The rock was called "trachyte" or "porphyritic trachyte" in the Hayden reports, and "eruptive granite" on the final map.

The small laccolite of Anthracite creek.—The smaller laccolite or thick sheet, cut into by Anthracite creek southeast of Mount Marcellina (see Pl. VII), may be here described as contributing data of importance in the discussion of the larger body. For 2½ miles the creek cuts through a porphyrite mass whose form and dimensions can be inferred only from this exposure. In the space between this body and the Marcellina mass the uppermost strata of the Laramie and the lower part of the Ruby beds run along the smooth sides of the gulch in nearly horizontal position. At the north end of the laccolite the Ruby strata, and about 20 to 30 feet of the Laramie, arch up over the porphyrite and thence are seen at the top of the canyon wall, resting on the eruptive to its southern end, where they curve down again, resuming their normal position. The contact of the eruptive passes gradually up, cutting out the thin Laramie layer, and the line between the Laramie and the Ruby is thus practically the horizon at which this body has been injected. The canyon cut across it is 400 to 600 feet deep, and as seen from several points at the top of the walls the eruptive does not seem to have been cut through. The Ruby beds conceal the eruptive on either side of the canyon, but a sheet of similar rock very near the upper limit of the Laramie, exposed 3 miles eastward, on the slope of the Ruby range, may very possibly represent the eastward extension of the body in question. It may also extend westward south of the Marcellina.

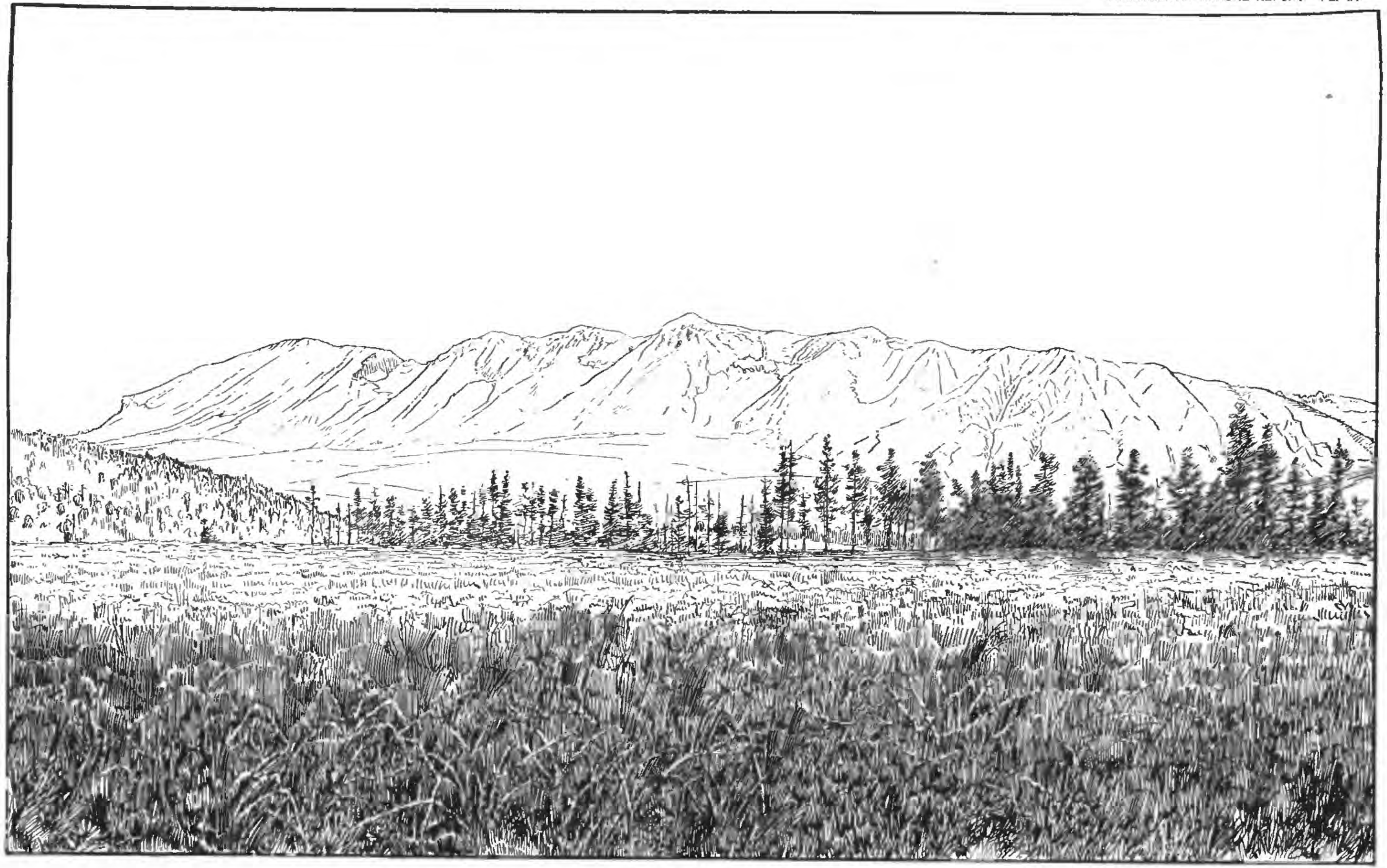
Known evidence does not show whether the Marcellina mass or the smaller body is the older. They would certainly have been connected on the line of Anthracite creek if actually contemporaneous. But if the smaller body is older than the other its presence may have helped in causing the form of the later body. The rock is a hornblende-biotite-porphyrite, with a few small quartz phenocrysts and a fine grained groundmass of quartz and orthoclase.

THE ANTHRACITE RANGE.

Position and physiography.—Near the center of the Anthracite district is a porphyrite mass bearing some marked resemblances to that of Mount Marcellina. As shown by the map it is one of a group of eruptive masses approaching very near each other, but clearly independent as geologic bodies. The range is 4 miles long from east to west, and quite narrow, possessing a rather sharp crest with several peaks, the highest of which has an elevation of 12,251 feet. To the south this range presents an abrupt face for its entire length, as seen in Pl. IX. The average height of this steep front is from 1,500 to 2,000 feet. The view is from a photograph taken at a point about 4 miles southeast of the range. A very different configuration is presented on the northern slope of the range. Here are four large amphitheaters whose glacial polished floors have an altitude of nearly 11,000 feet. Between them are ridges extending northward for 2 or 3 miles, separating gulches which drain the amphitheaters. At the west the range ends abruptly in a ridge curving to the north. On the east the crest divides, and between the two sharp forks is a remarkable large amphitheater, below which is a very steep descent of 500 feet.

Structure.—The Anthracite range is a single mass of porphyrite surrounded by sedimentary or pyroclastic rocks and bearing to them structural relationships strikingly similar to those observed about the Marcellina mass. This eruptive body may be compared to a great wedge whose thick base is represented by the southern cliff and whose edge is inserted at a horizon just below the coal measures of the Laramie Cretaceous, to the north of the range.

The precipitous face of the range shown in Pl. IX is entirely of porphyrite. Below this is a long densely wooded slope where outcrops are rare, but it is known from occasional exposures that beneath the talus heaps at the base of the cliffs are the tuffs and breccia of the pyroclastic "West Elk breccia" formation. This is the northern limit of this great volcanic formation, whose distribution is shown by the Hayden maps. The material is dark hornblende-andesite and pyroxene-andesite, very different in composition from the porphyrite and of entirely different origin. The loose and friable tuff has a nearly horizontally bedded structure. Below the pyroclastic material comes the Ohio formation, a post-Laramie series of friable sandstones, grits and fine conglomerates of non-igneous materials. About 300 feet in thickness is known in the valley of Ohio creek, which rises in the gap at the east end of the Anthracite range. These beds are nearly horizontal and approach very near to the porphyrite without signs of disturbance by it. Beneath the Ohio beds appears the Laramie, in a thickness of about 1,000 feet. According to Mr. Eldridge the upper half has been removed by erosion in the interval between the two formations. No evidence was found that any of the formations named



ANTHRACITE RANGE, WEST ELK MOUNTAINS; SHOWING THE ABRUPT SOUTHERN FACE.

occur at the south base of the Anthracite range. They must abut more or less sharply against the eruptive as at the southern base of Mount Marcellina.

The northern slope of the range is as different from the southern in geological structure as in topography, for the latter is due to the former. Pl. X gives a view of the range as seen from Scarp ridge, at a distance of 6 miles a little east of north. The timbered ridges are made up principally of Laramie strata with a northerly dip of 25° to 35°, resting on the eruptive, whose contact is approximately the base of the formation. The gulches cutting through the strata into the eruptive furnish good exposures, and the fact that the coal occurring in the Laramie at 50 to 100 feet above the eruptive is of the finest quality of anthracite has led to most thorough exploration of the relationship between the eruptive and sedimentary rocks. The contact is irregular in minor details, but is probably nowhere more than 100 feet below the coal at any point on the northern slope, and comes close to it in places.

The Laramie strata contain numerous smaller porphyrite masses, some of which are sheets, others dikes, and the principal body is partly one, partly the other, as indicated by the form given it on the map. As a sheet, 400 to 500 feet thick, it is very regularly intercalated in the strata for some distance, its northerly dipping outcrop being very marked in Pl. X. Many smaller bodies, whose forms can not be closely determined, are shown by natural exposures or have been cut by the diamond drill in the course of exploration for coal. The similarity of the rock in these bodies to that of the main range shows that the strata above this great mass were much fractured in their elevation, and that magma was injected into the fissures.

The dip of the strata continues for nearly 2 miles northward and then rapidly decreases to zero.

A north and south section through the Anthracite range is shown in Fig. 31, the form of the eruptive mass corresponding to the writer's interpretation of the facts given. It is seen to be similar to that of the Marcellina mass, and the origin of such forms is to be discussed in a later section.

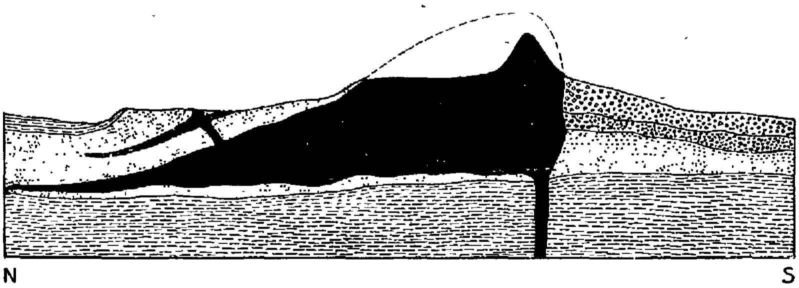


FIG. 31.—Profile section through Anthracite range, natural scale.

Approaching the western end of the range the Laramie strata and the ruby beds above are steeply upturned, and change in strike to northeast southwest. They do not visibly wrap around the abrupt end of the porphyrite mass because they have been eroded away from the higher slopes and their edges are concealed below by the débris and forest growth.

The manner in which the structure of the northern slope is united with that of the southern, around the ends of the mass, can best be considered after a description of the porphyrite body of Mount Axtell, which approaches close to the east end of the Anthracite range. It is evident that a rupturing of the strata took place, and the reason for it appears in the presence of the other mass.

The rock.—The average rock of the Anthracite range mass is a quartz-hornblende-mica-porphyrite bearing large orthoclase phenocrysts in variable abundance. Some crystals were seen 2 inches in length. The groundmass is a granular mixture of quartz and orthoclase of varying grain in different parts of the mass.

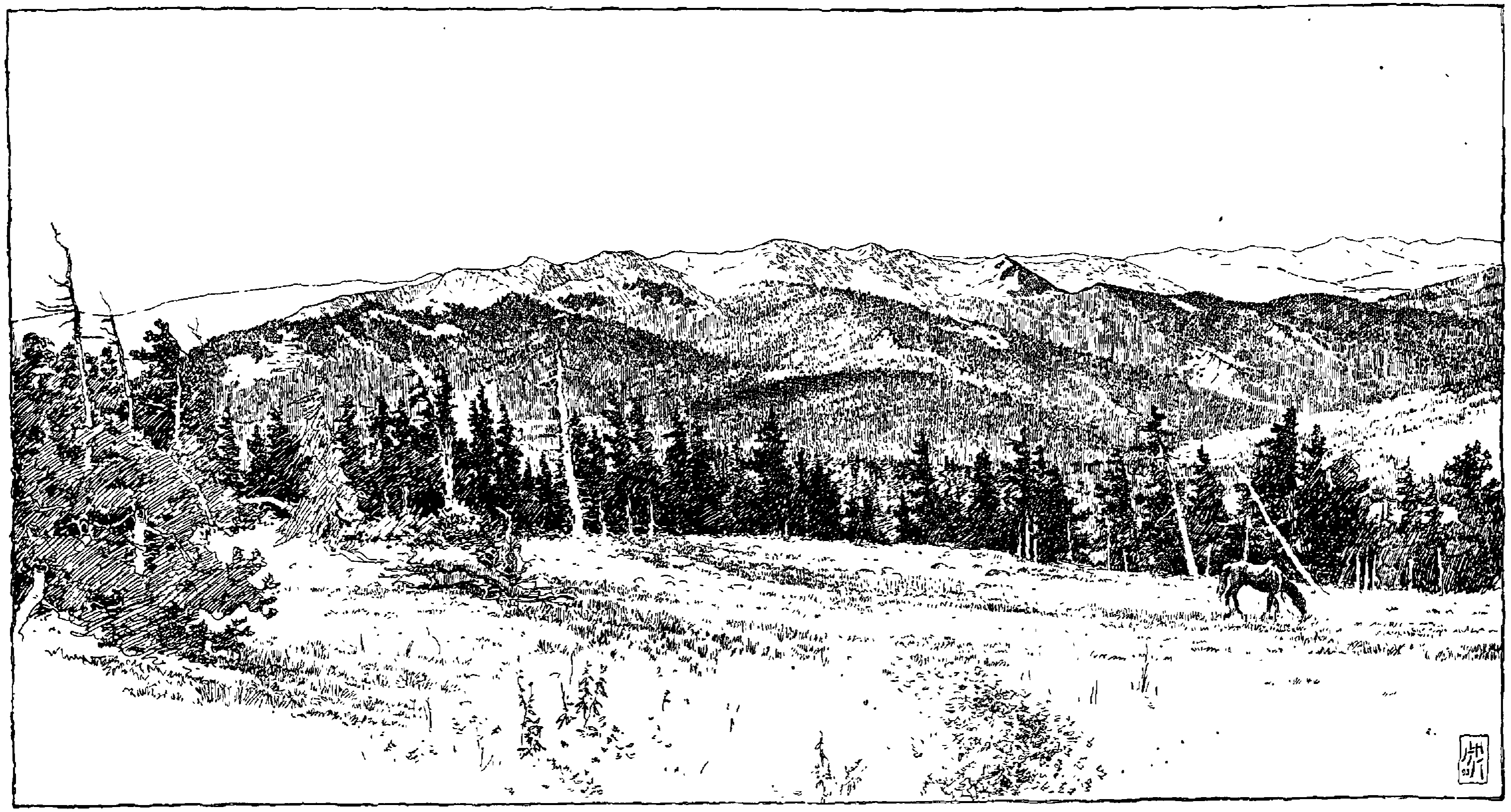
Near the contact with the Laramie on the northern slope of the range the rock sometimes has a slightly pinkish tinge, is finer grained than usual, without orthoclase phenocrysts, and the microscope shows a slight development of hypersthene or augite among the small phenocrysts. The groundmass is of the usual composition.

The variations in composition are not great enough to indicate different eruptions in this mass, though such may be the case. No sharp lines between different facies were noticed.

THE MOUNT AXTELL MASS.

Position and form.—Directly east of the Anthracite range is a large porphyrite body, whose relationship to the strata below it are better exposed than in any other important mass of the district. This is partly due to intrusion at a higher geological horizon and partly to the original form of the body, which is intermediate between a sheet and the typical dome-shaped laccolite. The mass does not build up one central mountain, for the highest part, Mount Axtell, is a ridge with several peaks situated on the eastern border. Below this summit is a cliff facing northeast which descends to the contact with the underlying sediments. To the west there is a more gradual slope to a broad, densely wooded plateau, below which succeed rather abrupt slopes on the south and west. To the north the eruptive extends across the valley of Coal creek.

Structure.—At the eastern base of Mount Axtell, on the western border, near Ohio pass, and at several other places, the lower contact of the eruptive body is seen to be an almost uniform horizon in the Ruby beds, at less than 100 feet above the Laramie. Northward the contact descends with the strata in a gentle syncline, rising again beyond Coal creek to the southern slopes of Scarp ridge, northeast of Irwin. The latter is a remarkable ridge, presenting a vertical cliff several hundred feet high to the northeast, while on the southwest is a smooth, gentle



ANTHRACITE RANGE, WEST ELK MOUNTAINS, FROM THE NORTHEAST.

slope in which a series of small basins have been excavated. As the strata rise on the north flank of the syncline the porphyrite body thins out, and along a certain line its original character as a sheet 200 to 300 feet thick, intercalated in the Ruby beds, becomes evident, for strata appear resting upon the eruptive in the ridges between basins. Passing farther up the slope the porphryite thins until it becomes a sheet less than 50 feet in thickness, and as such is seen in the walls about the basins, and at its present northern limit it appears in the northeast scarp of the ridge near the top, as a regular sheet 30 feet or less in thickness. The adjoining Fig. 32 is a reproduction of a view published by Peale, showing this scarp with the porphyrite sheet regularly interbedded in the Ruby sandstones. In the section of this cliff given by Peale he states the thickness of the sheet at 18 feet. It is here about 100 feet above the Laramie.

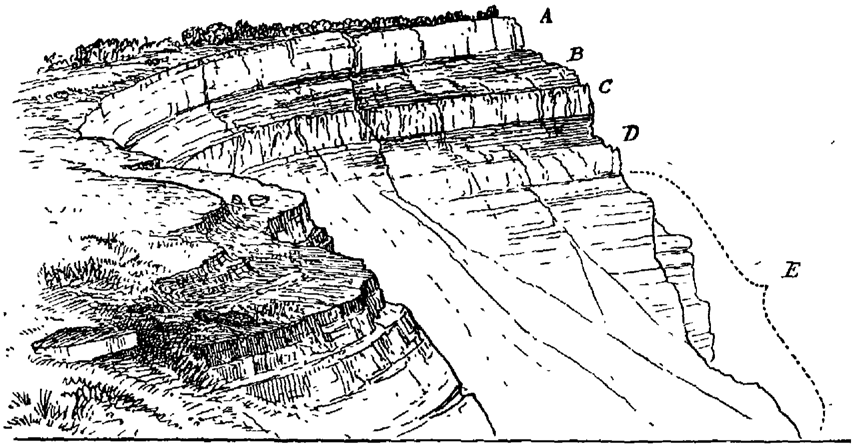


FIG. 32.—Cliff face, scarp ridge.

A number of small faults emphasize the regularity with which this sheet is intruded. They are perfectly distinct, of course, in the cliff face, or in the walls of the small basins on the south slope of the ridge, but produce a very puzzling structure in the lower wooded slopes about Irwin. The actual continuity of the eruptive sheet with the great body south of Coal creek is made perfectly plain by continuous exposures along the banks of Elk and Evans creeks, northern tributaries of Coal creek, draining basins of the same names.

The north and south extent of this porphyrite mass is 6½ miles, and for 2 miles it appears as a sheet between stratified rocks. Its width is 3 miles. Its lower contact, wherever seen, is in the Ruby beds or at the very top of the Laramie. Its greatest known thickness, in Mount Axtell, is 1,200 feet.

Profile section.—The accompanying section, Fig. 33, exhibits the structure which has been described. Although this body corresponds to those of Mount Marcellina and the Anthracite range in thinning out northward, and although the thickest part was undoubtedly near the southern limit, there seems no reason to doubt that the strata once arched over the entire mass without any line of fracture. The former maximum thickness of the body is a matter of conjecture, but considering the great erosion of some of the adjacent laccolites and the fact that the Axtell mass, by virtue of its higher geological horizon, must have suffered still more than the others, it seems necessary to assume that it had a thickness of more than 2,000 feet. The dotted line of the figure indicates the form in cross section which it seems to the writer reasonable to assume was possessed by this body. It is that of a sheet greatly thickened near one extremity.

Relation to the Anthracite range.—Referring to the map, it is seen that the eruptive masses of Mount Axtell and of the Anthracite range are represented as coming close together at Ohio pass, and it is possible that they may come in contact at some point. The valley of Ohio creek south of the pass is plainly excavated in soft Laramie sediments, and on the east the band of purple shales of the Ruby beds appears below the Axtell mass. On the west débris covers the contact.

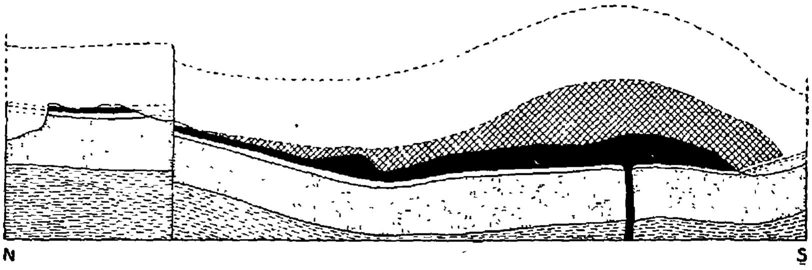


FIG. 33.—Profile section through Mount Axtell, natural scale.

The rocks of the two masses are sufficiently distinct to confirm the indications of structure to the effect that the two masses do not belong to the same injection of magmas. They are, then, probably not contemporaneous, and it is evident that the earlier body must have affected the relationship of the sedimentary rocks to the later eruptive. The Axtell mass has a simple relationship to the strata as far as known, while the Anthracite range body has very irregular position, and the complexity seems to be just what might be expected were the latter the younger.

As has been shown, the Anthracite body is intruded near the base of the Laramie. If the magma were injected at the side of the already consolidated Axtell mass the latter, by its comparative inflexibility, would hinder the adjacent strata from conforming to the shape of the newer injection, and a rupturing parallel to the line of resistance thus afforded would naturally take place. The east end of the Anthracite range mass is probably a fracture plane whose displacement corresponds to the side of the wedge.

The rock.—The porphyrite of this mass has in general a finer grain than is usual in the large laccolites. Small phenocrysts of plagioclase, hornblende, and biotite, less than 0·5 centimeter in size, are the rule, and both quartz and orthoclase are very variable in development. The orthoclase particularly is lacking over probably the larger part of the mass, but large crystals are found in a part of the rock of Mount Axtell and in the thinner parts of the sheet in Scarp ridge.

The groundmass has an even-grained structure, but the grains of quartz and orthoclase almost always interlock very intricately, and even produce the patchy or micropoikilitic structure through the inclusion of the feldspar by the quartz. This interlocking causes the groundmass to assume macroscopically a very dense appearance.

Hornblende has been much resorbed, producing augite and magnetite, and chlorite and calcite have replaced much of this augite. The rock is more decomposed than that of the adjacent bodies of Mount Carbon or the Anthracite range.

The rock of the sheet part of the mass has about the same phenocrysts as the thicker portion, but the groundmass is finer grained. Decomposition has naturally affected this part more than the thicker mass of Mount Axtell. In general the rock of Scarp ridge is almost identical with that of numerous small sheets and dikes of the region, and shows the effect of conditions of consolidation on the smaller mass.

The contrast in size and character of phenocrysts, in structure of groundmass, and degree of decomposition, distinguishes the rocks of the two masses either side of Ohio pass, though they probably agree closely in chemical composition.

MOUNT CARBON.

Position and structure.—To the south of Mount Axtell rises another mountain mass of porphyrite, known as Mount Carbon. It was called Ohio peak on the Hayden map, but this name is now applied to the highest point of the Anthracite range. The mountain is a single mass of eruptive rock which rises from 2,000 to 3,000 feet above the contact with the surrounding Laramie strata, and has a length of 3 miles by a breadth of 2 miles. Steep cliffs mark the southern and eastern upper slopes, while long ridges extend to the northwest. A growth of spruce covers the gentler slope almost to the summit.

The exact character of the relationships of this mass to the sedimentaries is obscured on most slopes by the talus and timber growth, or, as on the east side, by Pleistocene drift, but the body is plainly an intrusion into Laramie strata, which has broken irregularly across the stratification except on the west side. Here the Laramie beds, in a thickness of 1,200 feet, and the overlying Ohio beds, are found dipping westward at about 45°. The Coal-measures are found in this upturned section and the porphyrite contact is thus known to be at or very near the base of Laramie. At the northwest base of the mountain the strata dip northwesterly. The influence of the Mount Carbon eruptive is hardly visible west of Ohio creek, where the dip angle is only about 5°.

On the east side of the eruptive, in the bank of Carbon creek, the coal strata with a slight southwesterly dip are seen to be sharply cut off by the eruptive, and no upturning of the beds, indicating intrusion parallel to the bedding, is noticeable on either the northern, eastern, or southern sides of the mountain, although exposures were seen at short distances from the contact.

This mass seems therefore to have expanded irregularly in the shaly beds of the Laramie. The relation to the Axtell mass is unfortunately not visible, but there is a band of Laramie shown in certain places in the depression between the mountains, although the two eruptives may touch at some points. Following the line of thought presented in discussing the mass of the Anthracite range, it seems probable that the Axtell mass is older than that of Mount Carbon, and that its presence may have been the chief factor in preventing the strata from adjusting themselves with the usual regularity about the younger body.

The rock.—The porphyrite of Mount Carbon varies but slightly from those previously described. It contains prominent orthoclase phenocrysts, with plagioclase, biotite, hornblende, augite, and quartz. The dark silicates are less abundant than usual; the biotite equals hornblende in amount, and the latter has been much resorbed, yielding unusually coarse grains of augite and magnetite. Augite also appears in a few prisms not of secondary origin. The groundmass is very distinctly granular, consisting chiefly of quartz and orthoclase with some plagioclase. A quantitative analysis of this rock is given in the general discussion of rock types.

MOUNT WHEATSTONE.

Position and structure.—Mount Wheatstone lies adjacent to and east of the masses of mounts Axtell and Carbon, and is on the eastern border of the West Elk mountain group. At its eastern base is the valley of Slate river, which here marks very sharply the line between much folded and faulted strata on the east and the comparatively undisturbed shales on the west.

This porphyrite mass is the largest of the district studied in detail. Its length is 4½ miles, the breadth from 2 to 3 miles, and the summits are 3,000 feet above the eastern sedimentary contact. Pl. XI gives a good idea of the northeastern face of the mountain for a distance of about 3 miles. The view is from the bank of East river at the south base of Crested Butte mountain, looking across the broad bottom of Slate river valley, which is hidden by the further bank of East river. The characteristic topography of these great masses of homogeneous rock is very clearly brought out in this view, which is from a photo-

MOUNT WHEATSTONE, WEST ELK MOUNTAINS.

graph taken just after a light snowfall. The elevated amphitheaters and the general character of the ridges between them, the precipitous slope with straggling tree growth reaching up to more than 11,000 feet, and the densely wooded lower slopes underlain by the Cretaceous shales, all are plainly brought out by the illustration.

The great accumulation of talus and the timber growth make exposures of the contact line rare, but the united observations of various members of the party show that the strata about this mass are nowhere upturned, and are apparently unaffected in their structure by the porphyrite body. The eastern base of the eruptive marks the line between the Montana and Laramie formations, as nearly as can be determined. At the south end of the mountain the eruptive seems to have cut up somewhat into the Laramie, for good exposures show a coal bed with the prevalent slight dip to the northwest, a few feet below the porphyrite. From both the southern and northern limits of the eruptive to the western point the contact seems to gradually cut up across the Laramie to the base of the Ohio formation. The thickness of the Laramie is probably considerably less than 1,000 feet at the western extremity, owing to the erosion preceding the deposition of the Ohio beds.

The available data thus give little ground upon which to reconstruct the former shape and relationships of this mass except by analogy, and by application of the laws deduced from the consideration of the characteristics of the group to which this mountain belongs.

The rock.—The porphyrite of Mount Wheatstone is very much like that of the Anthracite range and Mount Carbon. It has the large orthoclase phenocrysts scattered in variable abundance through the mass. Hornblende is more abundant than biotite and has been much resorbed in most cases, with the usual product of augite and magnetite. Quartz phenocrysts are quite numerous and have often been much rounded and reduced in size by resorption. The groundmass is an even granular mixture of quartz and orthoclase with some plagioclase in microlitic form.

CRESTED BUTTE.

Position and structure.—Crested Butte is the easternmost mountain of the West Elk group, situated in the angle between Slate and East rivers. About it are the almost undisturbed Montana shales, while less than 1 mile from its eastern base begins the complicated structure pertaining to the Elk mountain uplift.

Plate XII represents the mountain as seen from the south. The summit (12,172 feet) is 3,200 feet above the valley bottom of Slate river, the length of the eruptive mass is 2¾ miles, and the breadth nearly 2 miles. As seen in Pl. XII the western and southwestern faces of the mountain are very precipitous, the cliffs of bare white rock rising more than 1,000 feet at several places. On the other side of the mountain there is a bench line at about 1,000 feet above the adjacent valleys, and this bench marks the elevation of the contact line of eruptive rock and shale, for on the slope below it outcrops of the latter are frequent. At the junction of the bench line with the steeper mountain slopes there are commonly large débris piles, but the first outcrops above this line are always of porphyrite. At a corresponding level at the base of the western cliffs the contact is shown in several places. It is a nearly horizontal plane with minor irregularities. In the eruptive there is a contact zone a few feet in width within which the rock grows denser approaching the actual contact, and the shales are baked for a corresponding distance from the porphyrite.

Above the contact line all is massive porphyrite; below it are the shales with a very gentle dip to the westward in no way disturbed by the eruptive. The mass, therefore, seems to be a huge block of porphyrite resting on shales, erosion having removed all traces of strata from the sides and obliterated all evidence of the manner in which the eruptive was once covered by them. The present outline indicates that the original mass was much greater than at present, and it may well have had the dome shape of the typical laccolite. The general horizon of the contact is somewhat above the middle of the Montana shales, the lowest horizon at which porphyrite masses occur in this part of the group except at Gothic mountain.

At the western base of the mountain is a cluster of small irregular dikes in shale, the rock being very much like the contact zone of the mass above. Larger dikes occur in the ridge between Crested Butte and Gothic mountain, and here the rock contains a few large orthoclase phenocrysts and approaches the rock of the larger body in structure. None of these dikes connect visibly with the laccolite, but they suggest the character of the conduit probably situated below the latter.

The rock.—The porphyrite of Crested Butte represents the extreme development of alkali feldspar noticed by the writer in any of these masses. Great glassy crystals of sanidine-like feldspar are very abundant in many parts of the mass, and orthoclase would certainly seem to predominate locally, but in all other respects the constituents are as in the other orthoclase-bearing porphyrites. Plagioclase, hornblende, and biotite are developed as usual, but quartz is somewhat more abundant. The groundmass is coarsely granular, and composed of quartz and orthoclase. In short, the rock might well be called granite-porphyry except that it is evidently near the line and its associations are with the large group of porphyrites.

GOTHIC MOUNTAIN.

Position and structure.—Gothic mountain, like Crested Butte, lies on the very border of the mountain group to which it belongs, and only 3 miles away from one of the great diorite masses of the Elk mountains. In this interval are found the steeply upturned strata of the Maroon formation (Upper Carboniferous), the Jura, and the Dakota and Colorado Cretaceous. On about the line of East river the beds

CRESTED BUTTE, WEST ELK MOUNTAINS.

become nearly horizontal, and on the Montana shales of the west bank of the stream rests the laccolitic mass of Gothic mountain.

The mountain is smaller than any so far discussed. Its summit is, however, 3,200 feet above the bed of East river, reaching an elevation of 12,646 feet. Great amphitheaters have been scored out of its eastern face, and the cliffs are steep on all sides. The gothic form of the pinnacles and projections on certain faces, especially on the southeast gave rise to the name.

The structure of the mass is almost exactly like that of Crested Butte. A great mass of porphyrite of uniform character rests with somewhat irregular contact upon the Montana shales, which do not seem to be disturbed by the eruptive. The contact is plainly seen at intervals all along the eastern face, the slope being too steep to permit the accumulation of débris. On the south, west, and north, the immediate contact is concealed. On the ridge leading northwest toward Mount Baldy it is shown again, but local faults obscure the original structure.

The east face of the mountain was examined by the geologists of the Hayden Survey and sketches illustrating the nature of the contact were published in the reports for 1873 and 1874.[1]

The earlier observations and those of the present writer agree in showing that the contact plane follows the stratification approximately for a considerable distance and that the shales undoubtedly pass under the eruptive mass. Parallel to the main contact and about 150 feet below it is an intrusive sheet of porphyrite, similar to the rock of the mountain, but finer grained. This sheet begins on the south about opposite the town of Gothic and runs for 5 miles northward, occupying very nearly the same horizon. Its average thickness is 150 feet on the slope of Gothic mountain and it forms a cliff on the steep slope. Both contacts may occasionally be seen. Their character is like that of the main mass.

At one point in the eastern face of the mountain a band of black shales appears as an inclusion in the main porphyrite mass, running parallel to the contact. This is represented in the sketch accompanying the Hayden report for 1874, mentioned above.

Character of the contact line.—As this eastern face of Gothic mountain affords the best opportunity known to the writer for studying the lower contact of a large laccolitic mass it may be well to give some details concerning it. Fig. 34 represents a profile section of the mountain face near the contact, as it may be seen at several points. Above is the cliff of massive porphyrite, below which the contact plane is sometimes well exposed by the weathering away of the shales. These are commonly somewhat hardened by heat for a foot or more from the eruptive, but are quite soft and friable beyond that limit. They dip very slightly southwest or west. At some places the shales have worn away so that one can examine the under surface of the porphyrite for

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[1] Hayden, Ann. Rep. 1873, fig. 12, facing p. 60. Ibid., 1874, Pl. XIV., facing p. 54.

2 or 3 feet from the edge Vertical joints in the eruptive cause great slabs of the cliff to fall before this undermining can proceed far, and the great débris piles below fresh white cliffs testify to the frequency of this occurrence.

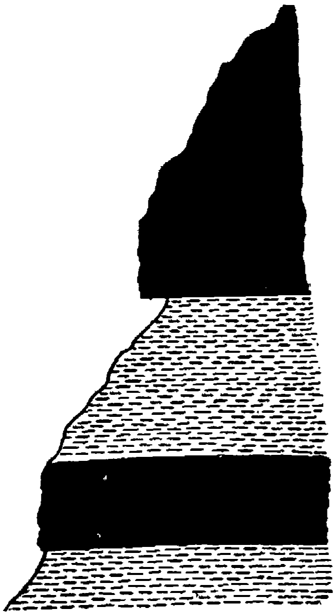
FIG. 34.—Profile to illustrate lower contact of laccolite, and sheet below it; east face of Gothic mountain.

East river has cut its valley so close to the mountain that, were it not for the porphyrite sheet whose position is shown in Figs. 34 and 35, the shales below the laccolite would be removed still more rapidly. The presence of this sheet protects in a measure the shales between the two eruptives, but still this part of the slope is in several places so steep that débris from the cliff above can scarcely lodge upon it.

The details of the main laccolitic contact may be represented by Fig. 35. The line is undulatory or even jagged in places.

Toward the southern part of the eastern mountain face the shales assume a more decidedly southwesterly dip, while the eruptive contact rises, and thus cuts diagonally across the bedding. It seems to rise nearly a thousand feet to the horizon at which it crosses the southern face of the mountain. Fig. 36 shows the character of this part of the contact. The offshoots noticed do not seem to develop into sheets of any extent at this place. A similar cross cutting

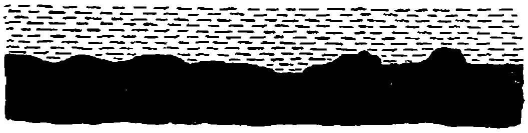
FIG. 35.—Sketch to illustrate irregularities of contact between laccolite and shale, Gothic mountain.

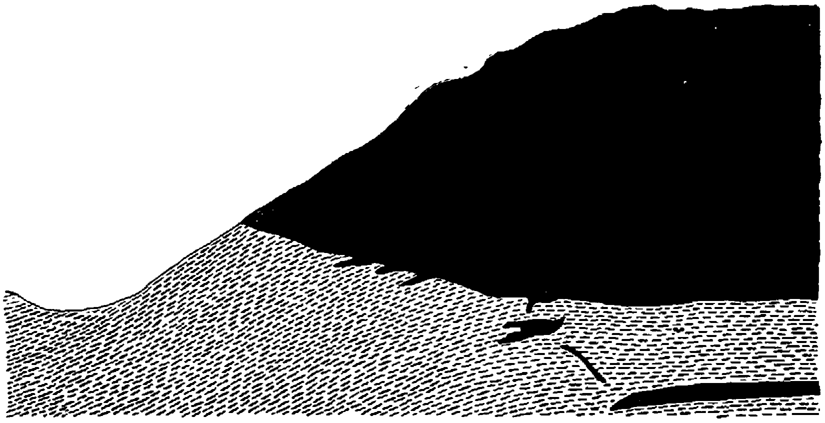
FIG. 36.—Sketch of contact between laccolite and shales, south end of Gothic mountain.

must take place also to the northward, for the eruptive line passes well up on the slope, although its exact position can not be seen.

The porphyrite is finer grained, both as to phenocrysts and groundmass, in the zone within a foot or two of the contact, and a banding or fluidal structure is sometimes noticeable.

To the northwest of Gothic mountain are three large sheets of porphyrite in the Montana shales. Two of them approach close to the main porphyrite mass of the mountain, but several faults here complicate the structure to such an extent that it was impossible to determine whether they were once actually continuations of the main body or not. It seems more probable that they are geologically distinct.

The rock.—The Gothic mountain porphyrite is so much like that of Mount Wheatstone, Mount Carbon, and Crested Butte that details are not necessary. Large orthoclase crystals occur all through it, and in smaller size are present in the sheet below. Chemical analysis has not been made, but it must have a composition near that of the Crested Butte rock.

STORM RIDGE.

General sketch.—Southwest of the Anthracite range and surrounded for the most part by the West Elk andesitic breccia is a large porphyrite mass of whose relationships but little is known. It is not indicated at all on the Hayden map and the present writer visited it late in the season, after a heavy snow fall, which doubtless prevented the discovery of significant outcrops.

It is known that the mass of Storm ridge is a single body of porphyrite, and that the outline given upon the map is approximately correct, but no contact was actually seen. The formation surrounding it for the most part is the more or less plainly bedded andesitic breccia or tuff referred in describing the Anthracite range. At first sight it would seem most probable that the breccia surrounded the older mass, but the porphyrite seems to cut through the breccia of the sharp ridge running north from West Elk peak, near the southern boundary of the Anthracite sheet. This line was seen from a distance and the apparently vertical contact of the two formations may be due to faulting.

The mass is spoken of here because the rock indicates that it belongs with the series of eruptions under discussion. The rock is a very fine grained porphyrite whose phenocrysts, usually less than 1 millimeter in diameter, are as follows: Plagioclase, biotite, hypersthene, hornblende, augite and quartz, named in the order of their importance. The groundmass is a very subordinate mixture of quartz and orthoclase. Although the list of constituents sounds different from that of the other rocks, the mass is really closely allied to some phases of the Anthracite range body. The phenocrysts have the same general character, and the bulk analysis given in the petrographical discussion proves a close connection between this magma and the others. No large orthoclase phenocrysts were observed, but they may well be present locally.

MOUNT BECKWITH.

General sketch.—Mount Beckwith is a large porphyrite mass on the western border of the Anthracite district and is surrounded by the Ruby beds. At its western base a high saddle separates it from another very similar peak, and both are usually included under the one name, as West and East Beckwith. Only the eastern peak was visited, and very few data were obtained bearing on the actual character of the contact plane between eruptive and sedimentaries. As in many other masses it is plain that all is porphyrite above a certain undulatory line which corresponds in general to the change from steep to gentle slopes.

As far as observed the Ruby beds dip very gently away from the mountain on the northern and eastern sides. The southern slope is like that of the Anthracite range—a very steep wall—and at its base the enormous accumulations of talus and the timber growth obscure everything. Great amphitheaters characterize the northern face.

In the narrow saddle at the west, which has an elevation of about 10,500 feet, the Ruby beds are seen on either side dipping at 15° to 20° toward the saddle, i. e., resting on the porphyrite masses of the respective mountains.

According to the observations of Mr. R. C. Hills, kindly communicated to the writer, the rock of each of these masses is practically identical with the prevalent type of the bodies described in greater detail above.

THE WESTERN LACCOLITIC MASSES.

General physiography.—The western peaks of the West Elk mountains, lying beyond the limits of the Anthracite district, were not visited during the recent survey, and the following statements are mainly taken from Peale's report upon them. Referring to the Hayden map (Sheet XIV of the atlas) it is seen that southwest of Mount Beckwith there is represented to be a large irregular mass of "porphyritic trachyte," in various portions of which are the peaks Mount Gunnison, Mount Guero, Mount Lamborn, and Land's End, the last named being the westernmost peak of the group. The summits reach heights varying between 10,000 and 13,000 feet, and are in part connected by high ridges. Mount Lamborn and Land's End are sharp peaks with very steep slopes westward for from 3,000 to 4,000 feet.

As seen from the peaks of the Anthracite district these mountains seem to be very similar to those described above. A few smaller masses lie to the west of the main peaks.

Peale's description.—Peale[1] states that these mountains are made up in their upper portions of massive "porphyritic trachyte" and that they are surrounded by strata of the upper and middle Cretaceous. But he gives no details as to the relationship between the eruptive and

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[1] Hayden, Ann. Rep., 1874, pp. 167, 168.

inclosing sedimentaries, and apparently saw no contacts. Supposing that these masses are similar to those already described, there are still no statements from which one can infer whether any of the strata rest in upturned position upon the eruptive, whether they abut against it or pass beneath it. For the westernmost peaks, whose lower slopes for 2,000 feet or more are of Cretaceous shales, it seems most probable that the eruptive mass, like that of Crested Butte or Gothic mountain, at the same geological horizon to the east, rests upon the shales, which pass under it undisturbed. But Peale, in illustrating the stratigraphy to the west of Land's End, gives a profile section in which the eastward dipping shales are represented as abruptly cut off by the eruptive.

It would seem probable that several intrusive masses exist in the area in question, with shales occupying some of the lower saddles.

South of Land's End is Saddle mountain, described by Peale as "a double-topped hill of trachyte rising about 1,000 feet above the Cretaceous rocks that surround it."

A still smaller body of trachyte to the west of Saddle mountain is the lowest geologically of any of these masses in the West Elk mountains. It seems to occur on the contact between the Dakota and the Benton shales. A finger-like projection or neck of "trachyte," mentioned by Peale as between Lands End and Saddle mountain, may represent the character of the conduits to be assumed as present beneath the laccolites.

The rocks.—The specimens collected by Peale from Mount Lamborn, Land's End, and the small mass in contact with the Dakota, have been examined by the writer. They are hornblende-porphyrites with a little biotite and augite, without the large orthoclases common to the east, and seldom showing quartz phenocrysts, but possessing a granular groundmass principally composed of these two minerals. According to Mr. R. C. Hills (in a private letter) the rock of Mount Gunnison is almost identical with that of Ragged mountain or the Anthracite range, less the great orthoclase phenocrysts.

These data show that the rocks of these large masses are very much like the ones more fully described above, and they also closely resemble those of the isolated mountain groups to the southwest.

THE RUBY RANGE.

General character.—The Ruby range is a chain of peaks extending in a nearly straight line for about 8 miles through the northern half of the Anthracite district, with a trend nearly north and south. The summits are between 12,500 and 13,000 feet high, and the connecting ridges rarely sink below 12,000 feet.

This range is geologically of very different origin from the mountain type under special discussion and is unique among the mountains of western Colorado. The sedimentary rocks represented in this range embrace, by virtue of a southwesterly dip, the upper 1,000 feet of the

Montana, the Laramie (2,000 feet), and the Ruby beds (2,500)—in all, 5,500 feet of strata, and they are here preserved through the metamorphosing and protecting influence of a great series of intrusive sheets and dikes of porphyrite. Neither sheets nor dikes show evidence of any direct connection with the laccolitic eruptions, although the rocks are in great degree identical in composition and sometimes even in detail of structure. From this juxtaposition and identity of characteristics important evidence is to be drawn concerning the conditions attending the intrusion and consolidation of the laccolitic bodies, and hence a brief description of this interesting occurrence is here in place.

The intrusive sheets.—At the northern end of the Ruby range, on both slopes, many thin sheets of porphyrite are found in the Montana shales; a less number occur in the Laramie, and only a few in the Ruby beds at the south. These sheets are usually less than 50 feet thick and many are less than 25 feet. They generally occur quite regularly intercalated at a given horizon, but on tracing them out they are often found to cut across from one plane to another, to fork, or to be offshoots from some dike. Some extend for 4 or 5 miles.

The rock most common is a hornblende-mica-porphyrite, quartz phenocrysts appearing in some cases, and the groundmass is finely granular or cryptocrystalline. Decomposition has ordinarily destroyed the hornblende, with chloritic and other customary products. Some of the sheets are white quartz-porphyry.

The dike system.—Far more important than the sheets are the dikes of the Ruby range, a few of which were represented upon the Hayden map. There are probably more than 100 of these dikes, with a general trend between north-northeast and south-southwest (see map, Pl. VII). At the north end of the range, at and south of Augusta mountain, is a great central eruptive channel or conduit, and a small one is situated at Mount Owen, near the south end. Connecting these points, which may be compared with the ganglionic centers of nerve systems, are several great dikes, and beyond each center is a radiating series of dikes, confined chiefly to the respective octants, north to northeast and south to southwest.

The main dikes are from 50 to 150 feet wide, nearly parallel, and of remarkably straight courses, considering the rocks they cut. A branching and reuniting is common, however, and numerous smaller arms occur. From the rock varieties represented in these dikes and the corresponding evidence in the channels, it appears that there have been successive periods of eruption here, each taking place through a system of fissures along the same general course.

The dikes cut the sheets above mentioned, as a rule, only occasionally connecting with contemporaneous ones. The heat from the network of dikes, and the accompanying thermal waters, have metamorphosed the shales and sandstones penetrated, hardening them and even producing an adinole-like rock in some places. The range is entirely due to the dikes and the hardened condition of the strata, there being no evidence of any underlying laccolitic mass.

The rocks.—The rock of the principal dike system is a porphyrite identical in composition and structure with the prevalent type of the laccolitic masses described above. Its large orthoclase phenocrysts are perhaps not so large as in the laccolites, and there is a slightly sharper contrast between phenocrysts and groundmass. Following dikes of this character away from the main axis or center of eruption they are commonly found to lose their large orthoclases.

A finer grained hornblende porphyrite constitutes another set of dikes, and there are a few of quartz-porphyry like the sheets mentioned.

In the conduit near Augusta mountain occur coarse granite porphyry, diorites of various textures, and porphyrites of several varieties. The intricate relationships of these rocks present a very interesting petrographical problem which can not be enlarged upon here, but the simple facts stated have evidently direct bearing upon the laccolitic question. This dike system cuts the uppermost known beds referable to the Cretaceous; namely, the Ruby beds. They are thus unquestionably of Tertiary age, for their structure indicates that they must have consolidated at some distance from the surface, and it therefore seems necessary to assume that Tertiary formations once extended over this district, confirming the conclusions reached independently from a consideration of the laccolites. These arguments will be reviewed in the general discussion.

REVIEW.

The igneous masses.—The individual mountain masses of the West Elk group are due to huge bodies of homogeneous igneous rock. Erosion has in many cases destroyed nearly all evidence of the former relationship to sedimentary beds, but in other cases the proof is clear that the masses are intrusive. Strata rise nearly to the summit of Ragged mountain, resting upon the eruptive, with a steep dip, while at Mount Marcellina and the Anthracite range the strata are somewhat upturned by the intrusive rock.

The larger masses are much like the laccolites of the Henry mountains, and they are sometimes accompanied by sheets and dikes of the same eruptive rock. The large mass of Mount Axtell is seen to pass into a sheet on the north, and several small masses appear to be intermediate between the sheet and the laccolite in form.

The intrusive rock.—The character of the rock forming these mountain masses is a most convincing proof that they are practically identical with the Henry mountain bodies in mode of origin. Some of the masses consist of a hornblende porphyrite almost identical with the prevalent type of the Henry mountains, but the magmas here were, as a rule, somewhat richer in alkalies and silica, and this difference often manifests itself under the conditions of consolidation in a development of large orthoclase phenocrysts.

The structure of the rocks is that found in the Henry mountain laccolites and implies a deep seated site of consolidation. In both regions the large and small masses are of nearly the same character, varying only in grain.

Geological horizons occupied.—All the masses of porphyrite are intruded into Cretaceous beds—assuming the Post-Laramie Ruby beds to be referable to that series. The lowest intrusion is that represented by Peale at the top of the Dakota, and the highest is probably that of Mount Beckwith, in the Ruby beds. Seven thousand feet is a moderate estimate of the sedimentary section between these extremes.

The larger number of intrusions have been in the middle Cretaceous shales, but several are in the sandstones of the Laramie or Ruby beds. As in the Henry mountains the rock structures developed are practically the same whatever the horizon, indicating that even the highest bodies were so deeply buried that relative distances from the surface had no perceptible effect upon the course of consolidation.

Age and load of sediments.—The Post-Laramie Ruby formation is either the highest Cretaceous formation known, or it belongs to the Eocene. The intrusive masses in this formation, whether laccolites, sheets, or dikes, possess the same structures as masses injected at the base of the Cretaceous or, as will be shown later on, in Paleozoic horizons. The conclusion is indisputable that the intrusions are of Tertiary age, but the only known element of evidence as to how recent they may be is that derived from the requirements of load. The laccolitic theory is based upon the assumption that a great weight of superincumbent beds existed above the highest laccolite, and the structure of the rocks themselves implies a depth sufficient to produce a slow rate of cooling. How great a depth is necessary for either of these factors is quite unknown.

The Eocene formations of the Colorado plateau are several thousand feet in thickness. The southwestern edges of the Wasatch (1,000 feet) and the Green river (1,200 feet) formations are but 15 to 20 miles northwest of Ragged mountain, and the Ruby beds are known to pass under the former at a point on Grand river north of that mountain. It is entirely natural to assume that these formations, at least, once extended over the area of the West Elk mountains, and very possibly other Tertiary formations did the same.

As has been mentioned, it is not clearly established whether the West Elk andesitic breccias are older than the intrusions or not, or to what Tertiary period they belong. They may have existed over this area in considerable thickness at the time of the intrusion of the other rocks. It is to be plainly understood that no evidence suggests any connection between the eruptions.

Comparison with the Henry mountains.—The great similarities in the intrusive rocks of the West Elk and Henry mountains and in their general occurrence are very obvious, and it remains to consider the meaning of the differences in details of occurrence. Gilbert represents that the formal relationships between intrusive and sedimentary rocks in the Henry mountains are very regular. As observed by him the uplifting of the strata by each laccolite is quite uniform except where preexisting bodies interfered. Mount Hillers is not quite symmetrical, but nothing approaching to the irregular form exhibited by the Marcellina or Anthracite range bodies is described.

It is plausible that the position of the Henry mountains far from the mountain areas of orographic disturbance would allow regularity of development in the intruded mass not attainable where other factors entered into the section, as must be the case in a region of folded and faulted strata already containing earlier intrusions of various shapes and sizes.

THE SAN MIGUEL MOUNTAINS.

Position and general character.—The San Miguel mountains lie about 70 miles southwest of the West Elk group. Like the latter they are outliers of the great mountain system of Colorado. To the east are the rugged volcanic mountains of the San Juan while westward stretches the great barren plateau of Colorado and Utah, scored by deep canyons and otherwise diversified by the remarkable mountain groups whose description will follow.

In order that the reader may most readily comprehend the form and relationships of the interesting mountain groups of the plateau, a number of the remarkably effective sketches by Holmes are here reproduced. They give an idea of the broad structural significance of the form and position of these groups which can scarcely be adequately conveyed in words.

Pl. XIII[1] gives a bird's-eye view of the area containing the San Miguel, La Platà, Carriso, El Late, Abajo, La Sal, and Henry mountains, from a point above the Carriso mountains in northeastern Arizona. Mount Wilson, the highest peak of the eastern subgroup in the San Miguel mountains, reaches an altitude of 14,280 feet. The central cluster seen in the sketch is about Dolores peak (13,600) and on the extreme west is Lone Cone (12,761).

The Hayden map represents the upper portions of the San Miguel mountains as made up of masses of "hornblendic trachyte," while the lower slopes are Cretaceous shales.

Holmes's description.—The San Miguel mountains were visited by W. H. Holmes in the summer of 1876, and are described by him in the Hayden annual report for that year.[2] He was able to give but two or

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[1] From Pl. XXXVI of the Hayden Report for 1875. Profile sections of the same plate illustrate Holmes's idea of the eruptive masses of the mountain groups.

[2] Hayden Ann. Rep., 1876, pp. 193-195.

three days to their examination, but his previous experience in the neighboring groups of the plateau region enabled him to quickly grasp the main features in the occurrence of the eruptive masses. He describes only the peaks west of Mount Wilson, the eastern part having already been visited by Endlich, who did not, however, distinguish between these eruptive masses and the volcanics of the San Juan.

Speaking of the western part of the Mount Wilson group Holmes says: "All that portion of the summit that rises above 11,200 feet is of trachyte. This is underlaid by Cretaceous shales in a horizontal position. Interbedded with the shales are a great number of sheets of trachyte. These are somewhat variable in thickness and manner of occurrence and seem to decrease in number and importance in descending from the main trachyte mass.

"The divide between the eastern (Mount Wilson) and middle (Dolores) groups has an altitude of 11,500 feet, and seems to be preserved at its present height only by a heavy bridge-like mass of trachyte, which connects across from group to group and prevents the degradation of the valleys north and south of this divide. There is a succession of irregular shelves or steps produced by outcropping edges of sheets and masses of trachyte."

The Dolores or middle group is said to be identical in geological structure with the Mount Wilson group.

As to Lone Cone, the western outlier of the whole group, Holmes says: "The pyramidal part is a bare mass of grayish trachyte which rests on a base of horizontal shales." These shales were found to be somewhat metamorphosed, "and there is doubtless considerable interbedded trachyte," but timber growth obscures the lower slopes. The sketch in Fig. 37 shows the cliffs of the summit eruptive, with which the lower slopes of shale contrast so markedly.

Concerning the peak southeast of Lone Cone, he remarks that the summit is of "trachyte," but the contact line with the shales was not observed. The map represents a large eruptive mass of irregular relationship to the strata, but the report shows that this outline is conjectural, and it is quite likely that several masses at different geological horizons are present. "In the ridges or saddles which connect this point with the Dolores group and Lone Cone there are occasional outcrops of shales and trachytes, as in the saddles between the Dolores and eastern groups."

Holmes's summary as to the nature and origin of these masses is as follows: "Thus it appears that the San Miguel mountains comprise at least five distinct masses of trachyte, four at least of which rest upon horizontal Cretaceous shales, and at a uniform level above the sea. It seems probable, therefore, that they all belong to the same flow, which flow may have had its source far to the east. There seems at least to be no evidence of vertical flow or intrusions in the western portions of these mountains." Holmes does not mean surface flow in this case, but merely that the isolated masses were connected once and constituted one great intrusive body. But in his profile section through the group he represents eruptive conduits beneath each large "trachyte" mass, similar to those assumed for the other eruptive groups of the plateau.

The rocks.—Three specimens collected by Holmes, two from Lone Cone, the other from the unnamed peak southeast of that point, were found in the U. S. National Museum. The two from Lone Cone are of a fine grained greenish gray rock, containing a very scanty groundmass of quartz and feldspar, and numerous small phenocrysts of plagioclase, augite, hornblende and biotite. Augite is much more abundant than hornblende, and biotite is quite subordinate. The small plagioclase crystals have strong zonal structure, some are filled with inclusions, and the extinction angle is often large enough to show that labradorite or some variety even richer in the anorthite molecule is present. The augite occurs in small, pale green, irregular prisms and grains, and contains a few inclusions of glass, magnetite, apatite and biotite. Hornblende and biotite are dark brown. The groundmass is locally so scanty as to barely make a connected matrix for the phenocrysts. The rock is thus a porphyritic augite-diorite.

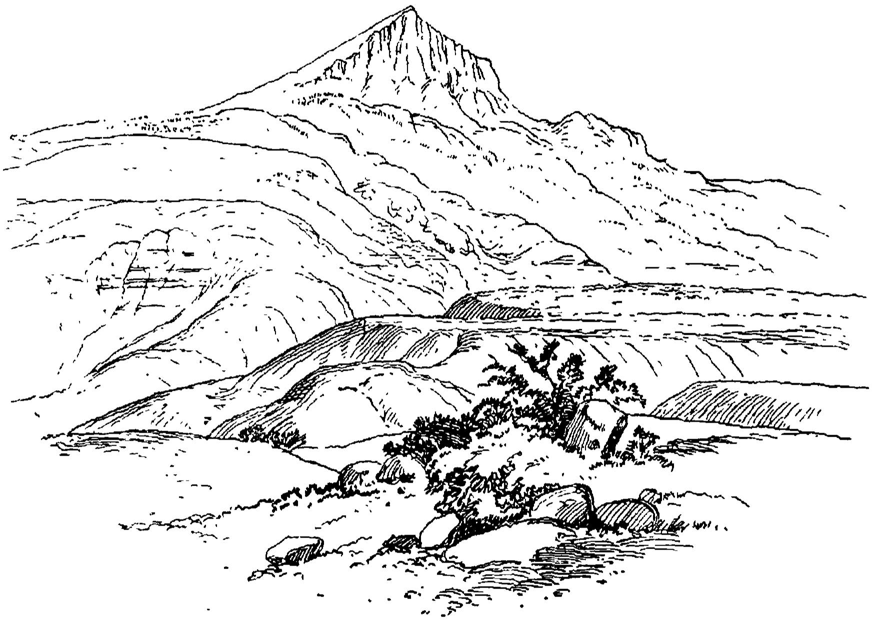

FIG. 37.—Lone Cone, San Miguel mountains. Remnant of a laccolite on horizontal Cretaceous shales.

The other rock has a very similar structure to that of Lone Cone, but hypersthene is here more abundant than hornblende, and the latter than augite.

These two rocks are intimately related to certain granular rocks of the same general mineral composition which occur at the eastern base of the Mount Wilson group, and a few miles further east in Silver mountain, north of Ophir. These rocks were kindly sent to the writer by Mr. George E. Kedzie, of Ouray, Colorado, and concerning one of them Mr. Kedzie makes the note that it is older than the andesitic breccia of adjacent exposures. Still other allied rocks are known to the writer from various parts of the San Juan, where the relationship to surrounding andesites is unknown.

Review.—The San Miguel mountains are caused by great masses of nearly granular dioritic rocks. Erosion has here been very great, and sheets below the larger bodies afford the only definite evidence of the former relationship to sedimentary beds. From the presence of these sheets, the character of the eruptive rock, and the general position and character of the mountains, it appears probable that they are due to laccolitic masses very similar to those of Gothic mountain and Crested Butte in the West Elk mountains. In the absence of any detailed observations it is useless to speculate as to the degree of regularity in form once possessed by these masses, but the general conditions of their origin seem clearly indicated. It is obvious that Holmes did not entertain the laccolitic idea of intrusion at great depth while describing these mountains.

The geological horizon occupied by these masses is apparently in the upper or Montana division of the Cretaceous shales, and corresponds to that of the western peaks of the West Elk group, and of Crested Butte and Gothic mountain.

LA PLATA MOUNTAINS.

Position and general character.—About 25 miles south of the San Miguel mountains is another still more remarkable mountain group. Situated at the extreme southwestern limit of the high mountain area of Colorado, this small cluster, scarcely 10 miles square, includes a number of very rugged peaks, some of which are nearly 14,000 feet high. The general position is shown in Pl. XIII, and the detailed character of this group in the panorama by Holmes reproduced in Pl. XVI *b*, from Sheet XX of the Hayden Atlas, and by the sketch of Fig. 38.

Referring to the Hayden map it is seen that the center of this mountain area is an uplift of what are called "Metamorphic Paleozoic" rocks. This core is exposed in the deep valley at the head of the La Plata river. Around this center is a rim of ragged peaks of "hornblende trachyte," while outside of this rim are the Cretaceous and Lower Mesozoic strata on the south, west and north, and Carboniferous on the east.

Holmes's description.[1]—As to the "Metamorphic Paleozoic" formation of the La Plata mountains, it is sufficient to point out that the nature

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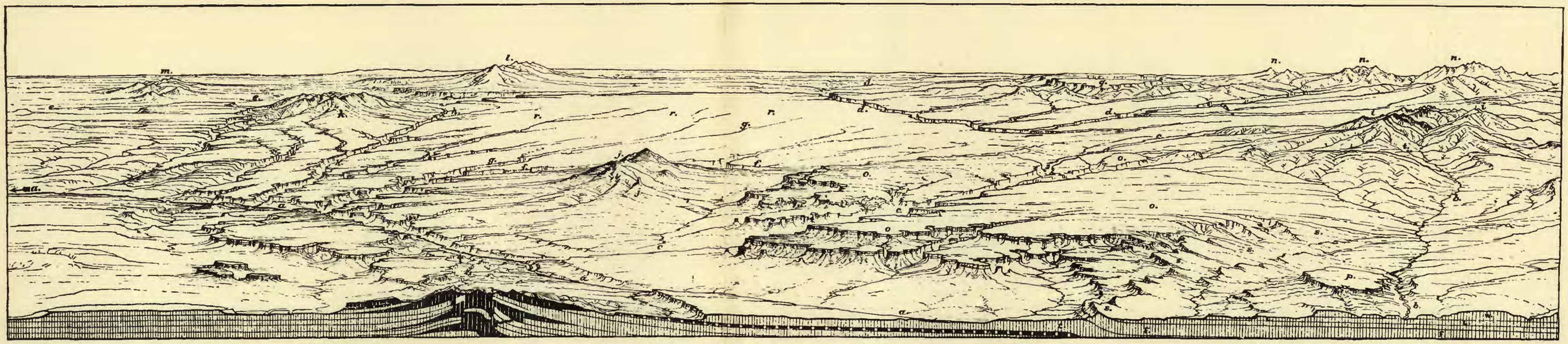
[1] Hayden Ann. Rep., 1875, pp. 268-272.



West. *m.* Henry mountains. *k.* Abajo mountains. *l.* La Sal mountains. *j.* El Late mountains. *n.* San Miguel mountains. *i.* La Plata mountains. East.

e. Colorado canyon. *a.* San Juan river. *h.* Montezuma creek. *g.* Hoven-weep creek. *f.* McElmo creek. *c.* Mancos river. *d.* Dolores river. *o.* Mesa verde. *b.* La Plata river.

BIRD'S-EYE VIEW OF LACCOLITIC MOUNTAIN GROUPS IN THE PLATEAU COUNTRY.

Looking northward from a point above the Carriso mountains, which are shown in profile section in foreground.

of the metamorphosis which they have undergone and of the agencies accomplishing the change were not ascertained by Holmes, and, while he suggests that the intrusive rocks may have caused the alteration, he does not fail to observe "that in the neighboring groups of mountains of trachytic origin there is little or no metamorphism apparent." In the absence of further facts bearing upon this point the present review may be confined to the association of igneous and sedimentary rocks in the high peaks of the group and on the outer slopes.

The peaks encircling the metamorphic area are mainly made up of an igneous rock, but other high points on ridges extending out in various directions are in certain cases made up of an alternation of sedimentaries and eruptive banks. Mount Hesperus (13,159 feet) is the most striking instance of alternation. Its structure is illustrated by the sketches reproduced, and is described as follows by Holmes:

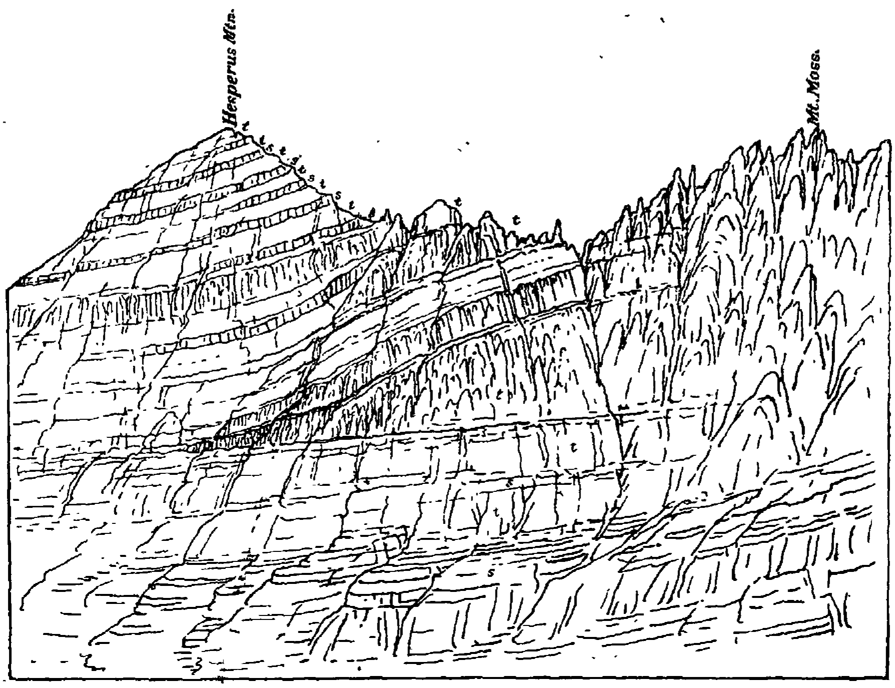


FIG. 38.—Mount Hesperus, La Plata Mountains. Shows intrusive sheets and laccolite.

"The intrusion of sheets and wedges is most strikingly illustrated in Mount Hesperus. Between timber line and the summit there is an alternation of trachytic sheets with shales in such regular succession that until closely examined I imagined the whole to consist of the sandstones of the Upper Cretaceous. In the upper 1,500 feet there are 12 distinct layers of trachyte, some having a thickness of from 30 to 40 feet, others of not more than a few inches." Adjacent to Mount Hesperus, toward the center of the group, is Mount Moss, a solid mass of eruptive rock weathered into most rugged forms. On the ridge between these two peaks one can see that "a succession of wedges of the former (trachyte) penetrate Mount Hesperus, while the included layers of shale extend into the west wall of Mount Moss. There is a sort of dovetailing produced that might be illustrated by setting together two combs so that the teeth should alternate."

Dikes and the cross-cutting of a sheet from one horizon to another are mentioned, and the various horizons occupied by these sheets in the mountain group extend from the Carboniferous through the Trias and Jura to the Middle Cretaceous shales. As cited in the introduction, Reyer has taken the occurrences of the La Plata mountains as typical of the alternation of sediments and surface lava flows, a view possible only by practically ignoring all the facts of observation except that of alternation of materials at certain places, a relationship which certainly might be produced in various ways.

The rocks.—Three igneous rocks collected by Holmes from the La Plata mountains have been examined. Two of them are from Mount Aldrich, a peak of massive rock near Mount Hesperus. These are coarse grained orthoclastic rocks, evidently facies of the same mass, whose predominant character is, of course, unknown One type may be called an augite-syenite. It is a strongly feldspathic rock with orthoclase predominant, both feldspars in irregular tablets, augite in pale green rudely prismatic grains, and no other constituent of importance except titanite, which must form 2 or 3 per cent of the mass.

The other type from Mount Aldrich is an augitic granite-porphyry. There is here a very irregular, coarse grained groundmass of quartz and orthoclase, while the phenocrysts are similar to the minerals of the preceding facies. The groundmass is quite subordinate in amount, and it may be more appropriate to call the rock a syenite-porphyry.

The third rock, the exact locality of which is not given, though the type is said to "occur for miles," is a quartz-bearing hornblende porphyrite, much decomposed, but showing distinct phenocrysts of plagioclase, hornblende and a few of quartz in a granular groundmass of quartz, orthoclase, and a little plagioclase. The type is a common one among the intrusives under discussion.

The distribution of these types being unknown it is sufficient to point out that they can not be called trachytes, but possess appropriate structures for intrusive masses.

Review.—It is clear that the igneous masses described by Holmes are intrusive and to be compared with the other occurrences under discussion. But, with so few detailed facts, and with a metamorphic core to the group whose character is almost entirely unknown, a comparison with the laccolites of the Henry or West Elk mountains is possible only in a most general way. Fig. 39 is the ideal section through the mountains given by Holmes. It is interesting in its evident close relationship to the laccolitic representation, and suggests a kind of intrusion which may possibly take place under certain conditions. As drawn, this intrusion implies a considerable absorption or assimilation of strata, for which no evidence is given, and which is entirely improbable.

The syenitic rocks of Mount Aldrich differ somewhat from any others of similar occurrence known to the writer, but they are not sufficiently removed from the common laccolitic type to cast doubt upon their real identity of origin. They seem to be simply a variety rich in potash and poor in silica. The specimens collected may possibly not represent the average magma of these mountains, but they do seem to indicate a differentiation stage allied to rocks known to the writer from other parts of the San Juan from masses surrounded by andesitic breccia.

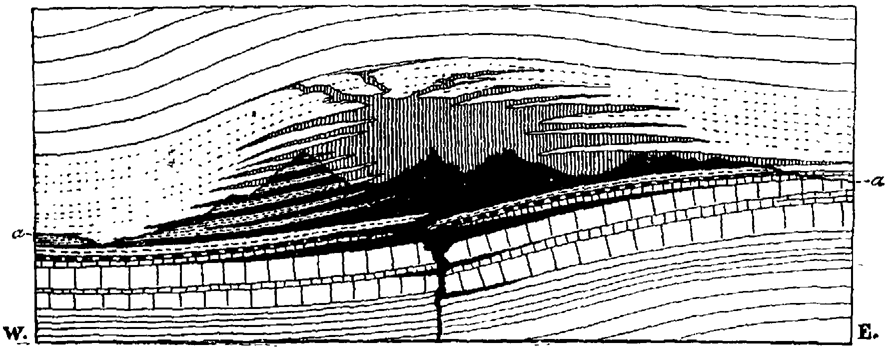


FIG. 39.—Ideal cross section through La Plata mountains, to illustrate theory of their origin.

THE CARRISO MOUNTAINS.

Position and general character.—The group known as the Carriso mountains lies in the extreme northeastern corner of Arizona, about 65 miles southwest of the La Plata mountains. (See Pl. XIII.) It differs from the other groups of the plateau country described in being itself rather a remnant of an isolated plateau than a cluster of peaks. The average elevation of the table-land is about 9,000 feet and Pastora peak, the highest point, reaches but 9,420 feet. The area is about 50 square miles, but it is deeply cut into by gulches on all sides. There are abrupt slopes on nearly all fronts for 1,000 feet or more.

In Pl. XIV *a*, is reproduced Holmes's sketch of the group as seen from the north. The plateau character is not prominent here owing to the low point of view, but it is indicated by the outlying mesas or flat topped shoulders in the sketch.

The Carriso group was examined by Holmes in 1875. He found the mountains due to the intrusion of igneous magmas into the sedimentary series, but in apparently more regular bodies and also at somewhat lower geological horizons than in the other similar groups. These facts explain the topography and allow a more direct comparison with the Henry mountain structure.

Holmes's description.—According to Holmes[1] the igneous masses of the Carriso mountains are much more clearly intrusive than in the El Late, Abajo, and San Miguel groups. He studied only the northern part, and while he observed several distinct sheets or thick laccolites separated by sedimentary beds he was not able to outline them upon the map, which therefore does not express his observations. He says: "The masses of trachyte were not poured over the surface of the country but lodged between the sedimentary strata, producing a more or less symmetrical doming of those beds that were not penetrated. Beyond the immediate vicinity of the trachytic masses the strata remain comparatively undisturbed."

Outlying mesas on the north and west are capped by thick sheets of "trachyte," resting on sandstones which are upturned in the interval between the mesas and the central mass of the mountains. Holmes speaks of this indication that the strata once arched over the entire central part, but says "unfortunately my observations could not be carried to the southern and southeastern slopes of the mountains, and it is impossible to say whether the arch has been continuous and symmetrical or not."

In gulches on the north and northeastern slopes Holmes observed several thick, eruptive sheets between steeply upturned red sandstones, and remarks that "the red sandstones appear also in a number of places in the midst of the higher regions of the eastern part of the group, interbedded with sheets of trachyte."

"This suggests the possibility of a sort of dome within dome structure, such as would be produced by the uplifting of a series of beds in which there had been horizontal intrusions of trachytic sheets, or even by the intrusion of such sheets into a series of already uplifted sedimentary strata." "I am not inclined to think, however, that the movements of the volcanic matter have been systematic or the results highly uniform, as accidental causes—such as unevenly yielding strata, diversity of dips, and presence of previously deposited volcanic matter—must often greatly influence, if not wholly govern, the direction of the flows, the thickness of the sheets, etc. At the same time there are doubtless laws that in general govern the movements of the volcanic products and tend to produce uniform results, but I shall not attempt their discussion here." It is clear that had Holmes discussed those laws at this time, a theory closely akin to the laccolitic idea of Gilbert would have been evolved.

The rocks.—Three specimens from the Carriso mountains, collected by Holmes, have been examined by the writer. They are all hornblende-porphyrites, almost identical in character with those of the El Late group. There are abundant phenocrysts of black hornblende and plagioclase, 1 to 5 millimeters in length, in an even grained ground mass, chiefly made up of quartz and orthoclase. Biotite is rare or

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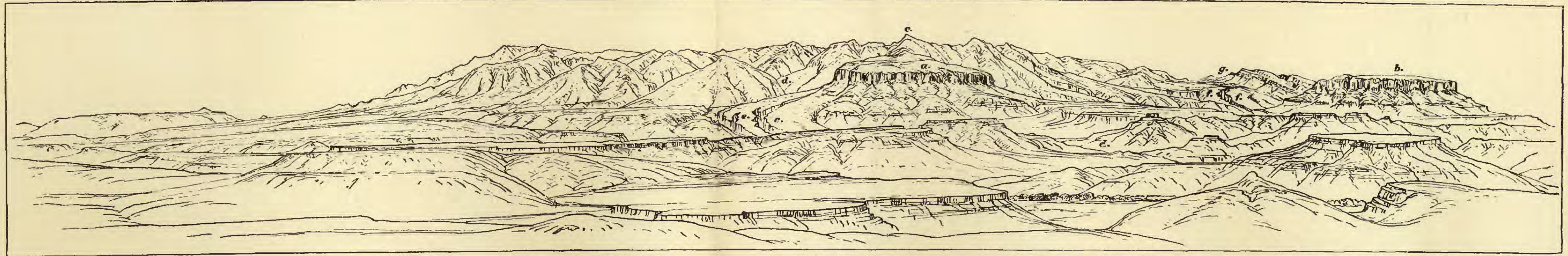
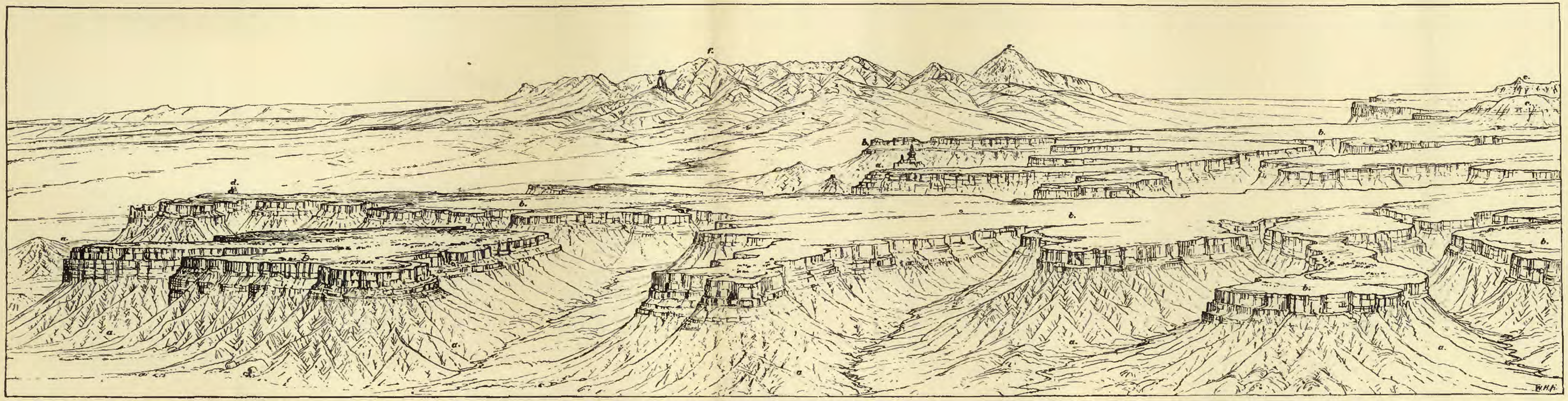
[1] Hayden Ann. Rep., 1875, pp. 274-276



East — *a.* North mesa. *b.* West mesa. *c.* Pastora peak. *d.* Navajo creek. *e f.* Canyons cut in porphyrite sheets. *g.* Cretaceous strata. — West.

A. PANORAMA OF CARRISO MOUNTAINS.



South. — *a a.* Slopes of Middle Cretaceous shales. *b b.* Lower escarpment sandstone. *d.* Jackson butte. *e.* Ute peak. *f.* Hermano peaks. *g.* Sentinel rock. — North.

B. PANORAMA OF EL LATE MOUNTAINS.

wanting. Quartz phenocrysts were not seen. One of the specimens greatly resembles a type common in the intrusive sheets of the Ten Mile district, Colorado.

Comment.—The igneous masses of the Carriso mountains are evidently very closely allied to those of the Henry mountains. They are apparently thick sheets rather than laccolites, and this form is no doubt connected with their occurrence in sandstones in the Trias or Jura,—that is, in firm, bedded rocks, under a greater load of sediments than was sustained by the masses of the El Late or other groups. Holmes gives few data concerning the interior of the group, and it must remain for future exploration to show the number, size and form of the igneous bodies which it may be inferred make up the larger part of the mass. Apparently the exposures are here quite favorable for a study of the phenomena of intrusive rocks, and the group is much more easily accessible than are the Henry mountains.

EL LATE MOUNTAINS.

Position and general character.—In the southwestern corner of Colorado, 25 miles northeast of the Carriso mountains and 48 miles southeast of the Abajo mountains, rise the El Late, another isolated mountain group in the plateau country. Their relative position is shown in Pl. XIII, and a view of the group from the southeast, looking over the Mesa Verde, by Holmes, is given in Pl. XIV *b*. Fig. 40 is a sketch, after Holmes, of Ute peak, the most prominent summit.

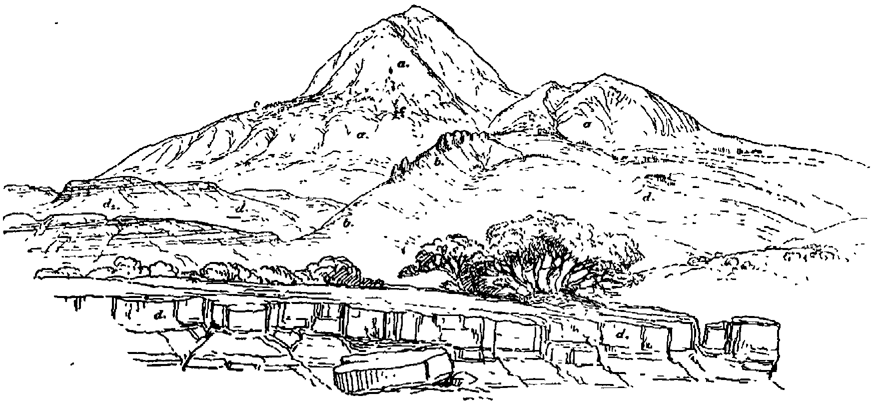


FIG. 40 —Ute peak, El Late mountain, a laccolitic peak.

These mountains were examined by Holmes in 1875. In his report upon them is contained the following general description:

"The area occupied by this group is not more than 40 square miles, and the highest summits do not reach 10,000 feet. Viewed from all sides it appears to be a cluster of rounded and, for the most part, gently sloping hills, from which rise two or three steeper cone-shaped points."[1] The Hermano peaks at the southern end and Ute peak at the northern are the principal summits, the latter reaching 9,884 feet. The general base of the group is between 6,000 and 7,000 feet above the sea.

The plateau country about the mountains has a floor of the Dakota sandstone, upon which are varying remnants of the Colorado shales. The strata are practically horizontal beyond the base of the mountains, but are upturned on their slopes, and the core of the mountains proper is an igneous rock closely allied to that of the Henry and Carriso mountains.

Holmes's description.[2]—The Hayden map represents this mountain group as made up of a single mass of "hornblendic trachyte," the outline of which follows the 7,000-foot contour quite closely, except for a large dike cutting down at the north base. It is evident from Holmes's description that this outline is incorrect, but that data were not obtained from which to draw it more accurately. The description of the group records few details of observation, but there is an interesting discussion of the probable method of intrusion of the igneous magmas.

"The bulk of the mountain mass is composed of trachyte, of which there are a number of varieties. When viewed more critically this mountain group does not seem closely compacted, as if formed of a single mass of trachyte, but rather as if formed of a number of distinct bodies that had reached their present horizon through closely associated vents. That the various masses of trachyte came from sources located directly beneath is evident from the fact that the sedimentary rocks are frequently bent up at a high angle around the borders. The upturned strata include the lower part of the Middle Cretaceous shales and portions of the Dakota sandstones.

"On the north side of Ute peak a large vertical dike cuts through the Jura-Trias and Lower Cretaceous sandstones, and connects, apparently, with the trachytic mass of a northwest spur. On the north face of Ute peak there is a heavy horizontal bed of trachyte that falls off in rounded bluffs. It seems to be interbedded between the Dakota sandstones and the Middle Cretaceous shales, and rests upon the upper surface of the former." Fig. 40 shows Ute peak from the north as sketched by Holmes, indicating the dike and general structure just described.

Holmes's theory of intrusion.—Holmes follows up the suggestion that several distinct bodies of eruptive rock are present in these mountains with some theoretical considerations which it is interesting to compare with the laccolitic idea of Gilbert. He says:

"It is a fact worthy of notice that in all parts of the trachytic mass there are fragments of Cretaceous shales which have been caught up in the rising mass and distorted and metamorphosed, but that no other

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[1] W. H. Holmes, Hayden Annual Report, 1875, p. 272.

[2] Hayden Ann. Rep., 1875, pp. 272-274.

rock appears similarly situated. This fact would seem to have an interesting bearing upon the question of the manner in which the volcanic matter reached the position now occupied by it. It does not seem possible that any considerable bulk of pasty or even fluid matter could rise through the sedimentary crust without carrying up quantities of fragments. The absence of all fragments, excepting those of the shales, goes to prove that the ascent of the molten material up to the base of the shales has been through narrow, firm walled crevices, and that the lateral spreading out and consequent stoppage of the great bulk took place when the horizon of the yielding shales was reached. So far as my observations go the trachyte does not seem to have been deposited as a single compact mass, as though on reaching the shale horizon it had opened for itself a great cavity, with the firm sandstone as a base, and an unbroken arch or dome of the entire series of superincumbent strata above, but rather as though it had broken irregularly into the yielding shales, pushing them back upon themselves, penetrating them first in one direction and then in another, with a sort of irregular radiation of masses from the mouths of the vents—not at once, perhaps, but with a rapidity depending upon the size of the vents and the character of the forces beneath. By such a method of intrusion numerous masses of the shales would be surrounded and held suspended in the mass of plastic material or sandwiched between masses proceeding from distinct flows. In no case did I notice any symmetrical arch of strata over the trachytes, but my observations all tend to show that there has been a sort of absorption, so to speak, of the shales, and that at least half of the space through which the trachyte is distributed is occupied by the crushed and metamorphosed fragments of shale. As a consequence the height of the arch—such as may once have existed—would not be equal to the height of the trachytic mass, as only the higher layers of the shale extend entirely over it, the lower layers having been absorbed by it and really forming a part of it." Holmes illustrates his ideas by figures, of which the above, Fig. 41, is one.

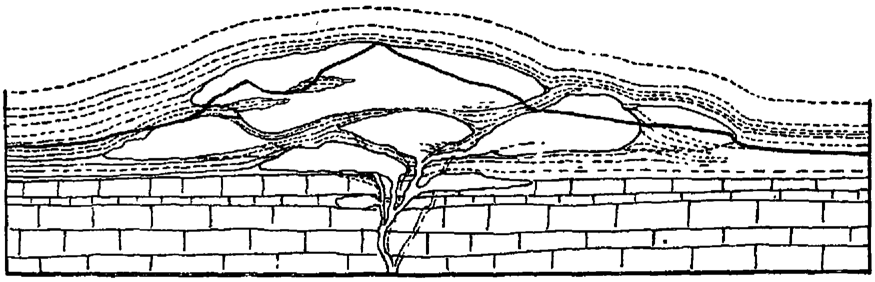


FIG. 41.—Ideal cross section through El Late mountains, illustrating their structure.

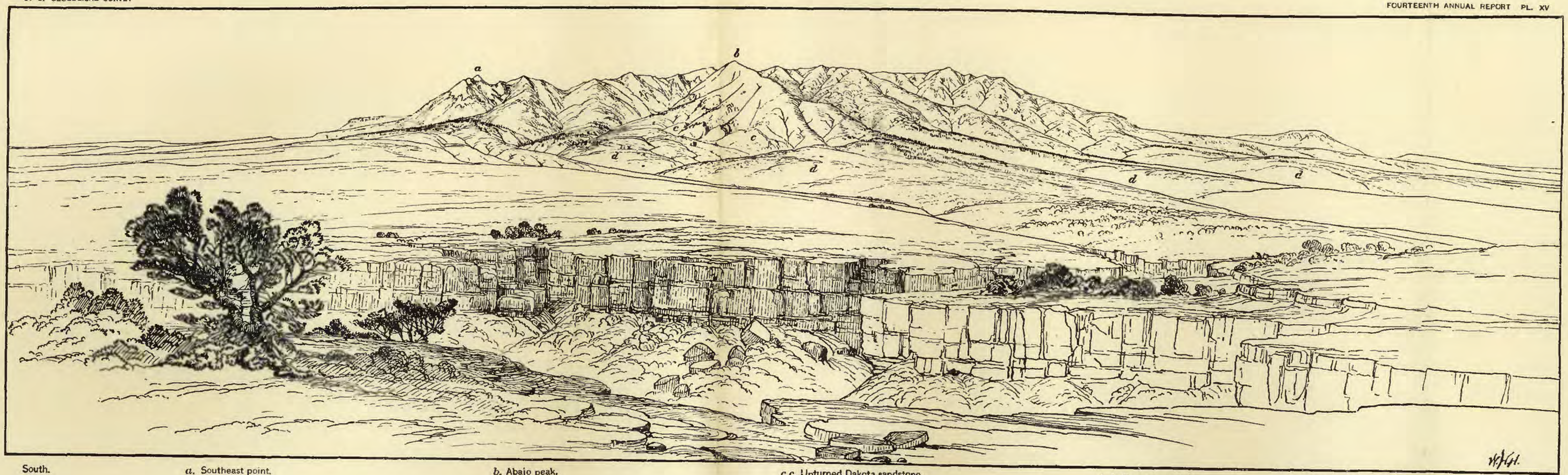
Comment.—Holmes's idea resembles that of Gilbert, but does not consider the effect of a great load of sediments, nor, indeed, various of the physical conditions brought into the theory of the laccolite. The "absorption" of the shales is not by fusion, but in any case the displacement of strata by Holmes's intrusions must be in the aggregate equal to the amount of magma injected, less any contraction of which the shales are capable, and a doming up of the higher unbroken layers must result. But the suggestion of Holmes that the soft shales of a great complex into which magmas are intruded would naturally be disrupted and crumpled rather than displaced in the regular manner assumed by Gilbert for all kinds of sediments, seems quite in accord with the observed facts of various occurrences. The data given for the El Late mountains are entirely inadequate, however, to demonstrate the actual relationship of the strata and the intrusives in that region.

As in the Abajo mountains, the Dakota and some lower beds are said to be upturned at the foot of the mountains, yet Holmes assumes that the intrusive rocks are in the Middle Cretaceous shale horizon. On the laccolitic idea the upturned beds are above the horizon of intrusion, and Holmes neither gives evidence for the Cretaceous age of the shales in which he assumes the intrusion to have taken place, nor explains what becomes of the lower upturned beds.

From the study of the rocks it appears that the igneous masses of the El Late group are intrusives, practically identical in character with those of the Henry mountains, and that they must have consolidated under the same general conditions. Whether the intrusive bodies structurally resemble the laccolites and sheets of the Henry mountains or represent much more irregular masses, as conceived by Holmes, is not determinable from his observations.

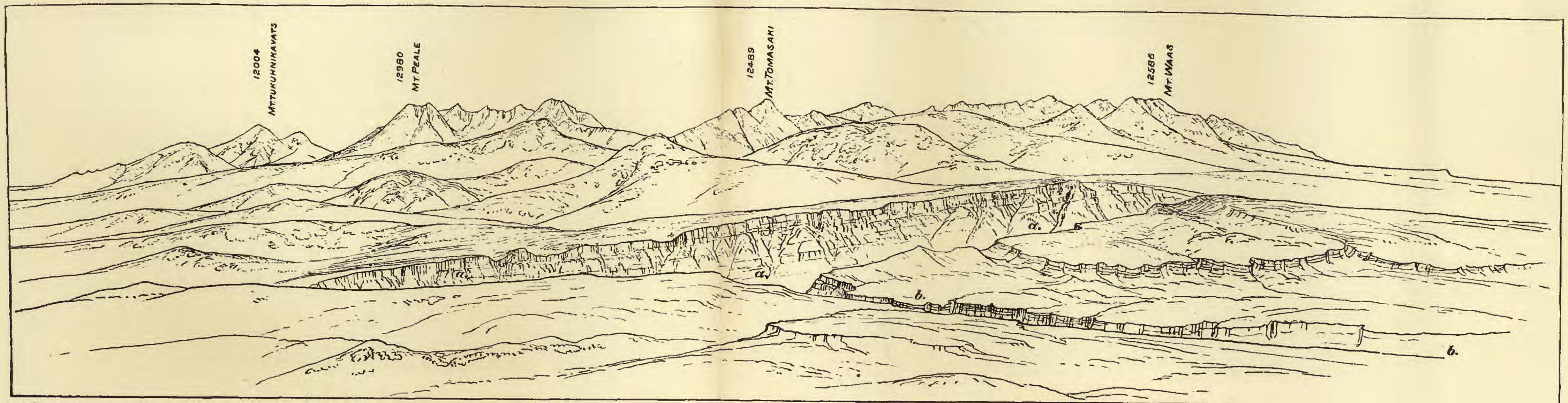
The rocks.—In speaking of the "trachyte" Holmes says that: "Ordinarily it is composed of a dark gray microcrystalline feldspathic paste, with many acicular crystals of hornblende and a little sanidine porphyritically embedded." Except that the phenocrysts of feldspar are plagioclase, and not sanidine, this description applies very well to the 5 specimens from the El Late mountains examined by the writer. They are all hornblende-porphyrites of the type prevalent in these isolated mountain groups. Hornblende predominates strongly, there being but a very little biotite or pale green augite. Quartz is rare, in rounded phenocrysts, and the groundmass is not rich in this mineral, although it is never wanting. The grain of the groundmass varies in the 5 specimens from cryptocrystalline to coarsely granular, and one has a micropoikilitic structure. Two of the specimens are from the Ute peak and 3 from the Hermano peaks.

The perfect agreement in composition and details of structure between these rocks and the intrusives of the Henry mountains is strong evidence as to the character of the eruptions themselves.



South. *a*. Southeast point. *b*. Abajo peak. *c c*. Upturned Dakota sandstone. *d d*. Cretaceous shales. Montezuma canyon in foreground. North.

A. PANORAMA OF ABAJO MOUNTAINS.



South. *a a*. Sinbads valley. *b b*. Salt creek. North.

B. PANORAMA OF LA SAL MOUNTAINS.

ABAJO MOUNTAINS.

Position and general character.—The next of the mountain groups of the plateau country to be compared with the Henry mountains is the Abajo in eastern Utah. The bird's-eye view of Pl. XIII shows its position relative to the other groups. It is 55 miles directly west to the Henry mountains and the same distance east to the San Miguel group in Colorado. To the north some 35 miles are the La Sal mountains, and 48 miles to the southeast rise the peaks of the El Late group.

The physiography of the Abajo group is well illustrated by Holmes's sketches, reproduced in Pl. XV *a* and *b*, the latter portraying the character of the plateau and showing the Henry mountains and the L Sal mountains in the distance.

The group is smaller and more compact than the Henry mountains, there being 8 or 10 peaks exceeding 11,000 feet in altitude within a circle having a radius of 3 miles. As shown by the sketch from the summit of Abajo peak, the group is broken into several clusters of peaks separated by deep gulches. The main passes are at an altitude of nearly 10,000 feet, and the average elevation of the base of the mountain is between 7,000 and 8,000 feet.

The Abajo group was visited in the summer of 1876 by the combined topographical and geological party of the Hayden survey. Unfortunately their work was practically limited by storms and the exigencies of a reconnoissance trip to a single day. The map naturally does not give accurate detail, and Holmes, who ascended Abajo peak after a heavy snowfall, was able to recognize the general features of the geology only through his previous experience in similar neighboring groups. He found the Dakota sandstone which forms the floor of the surrounding plateau steeply upturned at the eastern base of Abajo peak, as shown in Pl. XV *a*, and that the peaks themselves, as far as examined, were made up of an eruptive rock recognized as similar to that of the El Late and other groups. All that is known as to the structure and constitution of these mountains is contained in the following abstract from Holmes's report:

Holmes's description.[1]—"The Sierra Abajo consists of a number of small groups of volcanic summits. The trachyte of which they are formed seems to have reached its present place through a number of channels, although probably from the same nucleus. The masses now exposed were doubtless forced up through narrow crevices or apertures until yielding formations of the Middle Cretaceous were reached, where the melted material spread out to the right and left in great masses and sheets. The shales are still found in all parts of the group, caught up in a manner identical with that observed in El Late and Carriso mountains, and the low saddles between the summits are invariably of these shales. All along the east and south bases of the mountains the

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[1] Hayden Ann. Rep 1876, pp. 189–193

sandstones of the Dakota group are turned up at high angles." In one place "they are somewhat metamorphosed and have a dip of 45°" away from the mountains. Above these outcrops of Dakota sandstones "in a number of places there are outcrops of variegated shales and slates." After referring to the uniform height of several summits and the flat tops of some of them, Holmes remarks: "As their general height above the surrounding floor of the Dakota sandstones represents so nearly the thickness of the Cretaceous shales, the idea is suggested that possibly the great mass of trachyte did not penetrate the very massive sandstone of the Upper Cretaceous, which at that time must have covered the whole region."

Review.—The last quoted sentence shows that Holmes's conception of these igneous masses is that they are intrusive in the general horizon of the Cretaceous shales, while the overlying sandstones were probably not very much elevated or disturbed. This involves as a physical necessity the assimilation of shale by the magma, and such is plainly Holmes's meaning, though not explicitly stated in this connection.

Fig. 42 is a reproduction of Holmes's section through the Abajo mountains, taken from a profile in Pl. XXXVI of the Hayden report for 1875, accompanying a discussion of other laccolitic groups. It was drawn after the season of 1876 and illustrates his idea of the probable structure. It is to be noted that although the lower intrusive body of the section is like the typical laccolite in that it domes up the strata regularly, the surface masses of the mountains are of very irregular relationship. The idea of the laccolite was evidently not applied by Holmes to any of the exposed mountain masses of eruptive rock.

The meagre facts now known concerning the Abajo mountains do not warrant any more than the most general comparison with the Henry mountains. It is known that the rock is very similar in composition and structure to the laccolitic type, that the general geological structure and conditions are mainly the same in the two mountain groups, and, in detail, that the strata are upturned on certain slopes, and that some of the large eruptive masses are separated by shale outcrops. The form of the eruptive bodies is unknown, as is the character of the contact planes, and while there may be dikes and sheets no evidence of it has been given.

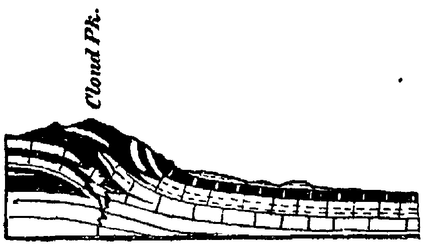

FIG 42.—Ideal cross-section through Abajo mountains, illustrating their structure.

It can be said that the intrusions were doubtless nearly contemporaneous with those of the Henry mountains, at about the same geological horizon, and presumably under similar conditions in other respects. But there seems to be no definite ground for the inference

Henry mountains in distance. La Sal mountains.

A. PANORAMA FROM ABAJO PEAK.

Mount Moss. Hayden peak.

B. PANORAMA FROM MOUNT HESPERUS, LA PLATA MOUNTAINS.

that the masses possessed the regular and symmetrical relationships to the strata of the typical laccolite rather than an irregular form, such as is expressed by Holmes in some of his profile sections. Applying the laccolitic idea, it seems from the upturned strata on Abajo peak that the horizon of intrusion there is that of the variegated shales below the Dakota sandstone (Jura?), rather than of the Middle Cretaceous shales, as assumed by Holmes.

The rock.—Two specimens of the Abajo rocks seen by the writer are hornblende-porphyrites, almost identical in appearance with those of the Carriso and El Late mountains. Plagioclase and hornblende are the only abundant phenocrysts, quartz appearing sporadically. In the only one examined in thin section the groundmass is composed chiefly of quartz and orthoclase, with a development of a patchy or micropoikilitic instead of the common evenly granular structure.

LA SAL MOUNTAINS.

Position and general character.—About 35 miles north of the Abajo mountains rise the southernmost peaks of still another peculiar mountain group, surrounded by a desert plateau deeply scored by numerous canyons. The La Sal group is in Utah, close to the Colorado line, and is included in the Hayden map of Colorado. The general position of the mountains is shown in the sketches of Pl. XIII and Pl. XVI *a*, while a nearer view of the eastern front, given by Peale in his report, is reproduced in Pl. XV *b*. The mountains were hurriedly examined by Peale in the season of 1875, and his description of them is contained in the Hayden annual report for that year.

The La Sal mountains comprise some thirty peaks, which are arranged quite irregularly in three groups within an area 15 miles long from north to south, and 5 miles wide. The summits range between 11,800 and 13,000 feet in altitude.

The mountains are quite precipitous for 3,000 feet or more, while their lower slopes are more gentle and gradually merge into various levels of the plateau, at between 7,000 and 8,000 feet. The western face is steeper than the eastern one shown in the sketch, and the bed of Grand River canyon, some 15 miles away, is nearly down to the 4,000-foot level, 9,000 feet below the summit of Mount Peale. Nearly 7,000 feet of this elevation properly belongs to the mountain uplift.

On the east and north of the group the Dolores river and its tributaries, and on the west the Grand river and its branches, cut deep gorges into the sedimentary beds, some of them displaying the underlying Archean. The most important formation is the red sandstone referred to the Trias, above which come Jurassic sandstones and shales, and then the Dakota Cretaceous.

The structure of the mountains under consideration is known in but the most general way. Peale states that sedimentary rocks, mainly of the Dakota, rise on *all* sides of the mountains, with dip corresponding to the slopes, even to the summits of some of the highest peaks. The great number of peaks are, however, formed in their upper parts by an igneous rock which Peale says is practically identical with that of the other groups under discussion. These two facts are all that is definitely known concerning the structure and constitution of the La Sal mountains.

Peale's description.[1]—Peale visited the group in the next season after his work in the West Elk mountains, and naturally compares the two areas. He says: "The following remarks are given simply as a sketch as the western side of the mountains was not visited, and the limited time we had to examine this interesting locality precludes our giving as detailed a description as I could wish. Enough, however, was seen to leave no doubt as to the structure of the mountains, which is the same as that of Mount Marcellina and its surrounding groups, and the Elk mountains, viz, eruptive. By this I mean that the sedimentary strata have been lifted up by eruptive rock which has broken through them in some places, and in others is seen only as the result of subsequent erosion.

"There are three high areas of volcanic rock separated by saddles of sedimentary rock, beneath which the volcanic rocks may be connected." He here refers to the three groups of peaks distinguishable in the sketch of Pl. XV. Of the largest group, reaching from Mount Waas to Mount Tomasaki, he says: "At the north end, on the east side, the red beds (Trias?) are seen rising up and forming outlying peaks, dipping steeply to the eastward. At the south end, near station 67, is a gray sandstone (probably Dakota group) reaching nearly to the summit." "The central peaks of the northern group are all trachytic."

In the eastern group (see sketch) there are strata on the summit of Mount Peale. "These consist of sandstones and shales very much metamorphosed, forming a capping to the peak." "This remnant is horizontal in position, and appears to have been carried up by the eruptive material. It may be a remnant of beds that once extended uninterruptedly across the mountains, or it may be that in the upheaval it was torn abruptly from the beds whose upturned edges rest against the mountains. On the sides of the peaks just north of station 68 [Mount Peale] fragments of black shales are seen included in the volcanic rock.
* * * These beds appear to be remnants of the Cretaceous."

In the southern group Peale thinks that Mount Tukuhnikavats is the only one showing igneous rock. These peaks were apparently not visited. "The other peaks probably have sedimentary rocks extending over them. On the main peak they extend to about timber line (11,000 feet), and on the east, south and west sides of the group a sandstone (probably Dakota) is seen dipping away from the mass 50° to 60°, and flattening out as we recede from the group."

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[1] Hayden Ann. Rep. 1875, pp. 59-62 and 95-98.

"Whether any of the sedimentaries extended across the mountains uninterruptedly at all points to the north we can not say. They did so at the south, but there were in all probability places where the eruptive material broke entirely through, reaching the surface."

As to the character of the igneous rock, Peale says: "The rock of the Salt mountains resembles that of Mount Marcellina. It is light gray rock—a feldspathic matrix, with crystals of feldspar and hornblende, giving it a porphyritic appearance. In Mr. Holmes's district there are several eruptive areas in which the rocks are of the same general character." The specimens collected by Peale were lost, but there is every reason to suppose that he was entirely correct in comparing them with the porphyrites of the groups already described and of the West Elk mountains.

Review.—The La Sal is an isolated mountain group in the plateau country, strikingly similar in position and physiography to the Henry, the Abajo, El Late, and other mountain groups, and like them has an igneous rock in the heart of the mountains, while on the lower slopes the strata are upturned. As the igneous rocks are of the same character as in the other groups they probably had a similar origin. But the known facts do not contribute at all to our knowledge of the occurrence of such rocks.

No single contact plane has been described, and the map does not express correctly the little that is known concerning the relationships of sedimentaries and eruptive. If the disturbance of the strata is due to the eruptive there must be huge laccolites beneath the present surface, of which the bodies now seen may or may not be portions.

In conclusion, it must be pointed out that while the porphyrites of the La Sal mountains are probably intrusions very similar to those of the Henry mountains, it is possible that orographic movements of another origin may have contributed to the formation of this mountain group. This is suggested by the presence of anticlines, and even of quaquaversal uplifts in the immediate vicinity, with which igneous rocks are not known to be connected. About 6 miles east of the mountains is the remarkable elevation called Sindbad's valley, shown in the sketch of Pl. XV *b*, which occupies the crown of a quaquaversal fold. It is possible that the uplift of the mountains was primarily and to unknown extent of this character.

Peale has suggested, on the other hand, that the quaquaversal of Sinbad's valley may be due to an igneous mass below.

THE MOSQUITO RANGE.

Having finished the consideration of the isolated mountain groups, which owe their existence as mountains to the intrusion of igneous magmas into nearly horizontal strata, it is desired to show that the same class of magmas were injected at, probably, the same period into the older and more or less disturbed strata of the mountain area, and are also found as dikes in the fundamental Archean complex. Two areas of such occurrences have been studied by the writer, and will be briefly described.

General sketch.—The Mosquito range is in central Colorado, between South Park and the upper portion of the Arkansas valley. Its trend is north and south and its length about 30 miles.

The geology of this region has been fully described by S. F. Emmons, first, in the Second Annual Report,[1] and later in greater detail in Monograph XII[2] of the U. S. Geological Survey. While reference is made to these publications for details, it is desirable for present purposes to repeat that the Mosquito range is a chain of high peaks, with an Archean core and sedimentary rocks on either flank. On the eastern slope the strata rise on the lateral ridges by reason of an easterly dip, nearly or quite to the crest of the range, while the high, deep amphitheaters and the gulches leading from them commonly cut through into the gneiss and granite below. On the western slope great faults have let down the sedimentary rocks, and they are still seen, with a general easterly dip, in successive steps or blocks, to the base of the range at Leadville.

The sedimentary section is summarized as follows: Cambrian quartzite, 200 feet; Silurian limestone and quartzite, 200 feet; Lower Carboniferous limestone, 200 feet; Middle Carboniferous shales and grits, 2,500 feet; Upper Carboniferous grits and conglomerates, 1,500 feet; a total of 4,600 feet.[3] In the Archean below the strata, and in all parts of the sedimentary section, are found eruptive rocks of nearly related varieties, in dikes, sheets, or more or less irregularly shaped masses and of various sizes.

Intrusive origin of the eruptives.—The eruptive rocks are of two classes, the one consisting of quartz-porphyries and diorite-porphyrites, the other of rhyolite and andesite. The former are most numerous and are clearly intrusive, while the latter are as plainly surface rocks. Mr. Emmons has presented the evidence as to the origin of the intrusive rocks of the Mosquito range as follows: "The greater mass of the older rocks occurs as sheets between the strata of sedimentary rocks, generally following a given horizon over great distances. That they were not poured out upon the surface and the overlying sedimentary beds deposited upon them—that is, that they are not interbedded sheets—is abundantly proved by the facts that they frequently cross the strata from one bedding plane to another, and that they also occur as dikes *cutting across the strata transversely, whose actual connection with* the intrusive sheet it was sometimes possible to observe; large fragments of the overlying beds are, moreover, often found entirely included in them."[4] To these proofs may be added the strong negative ones of

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[1] Second Ann. Rept. U. S. Geol. Survey, pp. 201-290.

[2] The Geology and Mining Industry of Leadville, Colorado.

[3] Monograph XII, U. S. Geol. Survey, p. 57.

[4] Op. cit., p. 295.

the absence of tuffs, or of eruptive débris in grits and conglomerates, and the positive evidence of the structure and texture of the eruptive masses.

The intrusions of this region are most commonly thin sheets, some of them being known to extend for miles, with a thickness of 20 feet or less, while others are huge lenses 1,500 feet thick in the middle, which Mr. Emmons has compared to the laccolites of the Henry mountains.

The rock of the intrusive sheets —The intrusive rocks of the Mosquito range are more numerous and vary more in composition than those of any other group thus far described. There are quartz-porphyries and corresponding plagioclastic rocks or porphyrites. The greater number of them belong, however, to the same great group which has been found recurring in every district described.

The main type is a very plainly porphyritic rock characterized by phenocrysts of plagioclase, with hornblende and biotite in a fine and evenly grained groundmass. This is commonly made up principally of quartz and orthoclase, and is usually an even grained mixture. With a large amount of free silica the rock almost invariably has quartz phenocrysts, which have been more or less rounded by resorbent action. Where orthoclase is abundant in the rock it usually appears in very marked phenocrysts, up to an inch in length, and such rocks are almost identical with the common type of the West Elk mountains. Rocks containing abundant quartz and orthoclase phenocrysts were called quartz-porphyries in the Leadville report, on the present writer's determination. As it now appears to him, these rocks are in fact still to be classed with the plagioclastic series, for reasons to be given in describing the Ten Mile district. The "Lincoln-Porphyry" of the Leadville report is the type especially referred to.

The series of porphyrites grades toward the basic extreme into types more and more characterized by the darker silicates, quartz and orthoclase being hid in the groundmass and being gradually replaced by plagioclastic feldspar and finally hornblende. Such groundmasses are less even grained and are often not easily distinguishable from the small phenocrysts.

The phenocrysts of these rocks do not show the characters commonly observed in andesites of similar chemical composition. They are almost free from inclusions of gas or glass, have grown slowly, and are embedded in a granular groundmass free from all suspicions of glassy residue, never showing fluidal structure, except in some dikes.

Magnetite, apatite and zircon are universally present in the well-known development, and to them is added allanite in small monoclinic prisms, and commonly in very fresh condition. It is probably to be found in every mass of porphyrite in the Mosquito range, though in varying abundance.

THE TEN MILE DISTRICT.

General sketch.—The Ten Mile district adjoins the Leadville district on the north. It lies on the west flank of the Mosquito range, and just to the north of the continental divide as it crosses from the Mosquito to the Sawatch range. The mapping of this district was carried out by Ernest Jacob, under the direction of S. F. Emmons. The present writer examined and collected specimens from the greater number of the eruptive masses after they had been traced out by Jacob. For permission to make a statement of the general geology the writer is indebted to Mr. Emmons. The area studied in detail is only about 8½ by 7¼ miles in extent. Along its eastern border is the great Mosquito fault, separating the rugged Archean range from the area of Carboniferous and Triassic beds on the west.

While the Archean area is higher and more rugged than the sedimentary, there are still important mountain masses made up of the latter rocks and the eruptives which have penetrated them. The stratified rocks have, in general, a slight easterly dip, with a shallow syncline near and parallel with the Mosquito fault.

The main sedimentary formations of the Ten Mile district are the Trias, and the Upper and Middle Carboniferous, the lower formations being shown to the westward in Eagle River valley. The Middle Carboniferous, or Weber grits, consists of shales, sandstones, grits, and thin limestones, in a thickness of about 3,000 feet. The Upper Coal-measures are mainly sandstones and fine conglomerates, with some shales and limestones, reaching a thickness of 1,300 feet. The Trias is here a series of sandstones and conglomerates, much like the Upper Coal-measures, and with a thickness of 1,700 feet now remaining.

Throughout the 6,000 feet of this sedimentary section are many masses of porphyrite, occurring principally in sheets nearly or quite conformable with the bedding of the strata and in a few small dikes. More than 60 different bodies are represented upon the map, and they are about equally distributed in the 3 great divisions of the strata.

Occurrence of the eruptive rocks.—The porphyrite sheets of the Ten Mile district are very regularly intruded on certain stratification planes, which they follow for several miles in many cases. They are of varying thickness, from 20 to 200 or more feet, and in some sections a dozen or more sheets are seen separated by sedimentary layers of nearly the same average thickness. In tracing out a given sheet it is usually found to have a more or less irregular contact with the strata, and in some cases cuts across from one horizon to another, slightly higher or lower. The forking of a sheet may occasionally be observed, and several of the larger ones include considerable slabs or lenses of sediments. Dikes appear at various horizons, the rock resembling the contact zones of the sheets in some cases, and in others being like the main sheet rock. Contact phenomena are usually confined to the eruptive, and consist merely in the development of a narrow band of finer texture for a few inches from the contact. The effect is the same on the upper as on the lower contact.

One mass at the head of Eagle river is a great lens, to be compared with a laccolite. Its maximum thickness is about 2,000 feet, and certain arms of it cut more or less sharply across the stratification. Sheets of just the same rock type occur above this large mass.

Several of these porphyrite sheets extend southward into the area of the Leadville map, and it is claimed by Mr. Jacob that one of the lower sheets of the Ten Mile district is continuous with the main sheet of "gray porphyry" found at Leadville, some 15 miles distant. The rock is of the same type, certainly.

The intrusive rock.—The different intrusions of this district are all porphyrites, and there is much less diversity in their composition than in the main Mosquito range. The "Lincoln Porphyrite," characterized by phenocrysts of plagioclase, biotite quartz, and a variable number of large orthoclases, with a granular groundmass of quartz and orthoclase, is the rock of the Eagle river laccolite and of several important sheets near it, as well as of dikes in various parts of the field. The same type occurs in dike form in the Archean, and in small sheets in a remnant of Cambrian quartzite left on one point just east of the Mosquito fault. Two sheets and several dikes of this type are found in the Trias.

The greater number of the sheets of the Ten Mile district belong to a type distinguishable from the preceding only by the absence of orthoclase phenocrysts. Chemical analysis shows that the two types are identical in composition and that the development of the large orthoclase is a question of conditions of consolidation. The significance of this point in connection with some theories of porphyritic structure are pointed out in a later section of this article.

These quartz-mica-porphyrites shade almost insensibly into forms carrying some hornblende and a little less quartz, and pass into a hornblende-mica-porphyrite with quartz in very small amount and restricted to the groundmass. Some of these are almost identical with the prevalent type of the plateau laccolite groups.

Allanite is more abundantly present in the Ten Mile rocks than in the Mosquito range, and it serves as a peculiar link, and a strong one in the writer's estimation, to prove that this great series of eruptives are all most intimately connected in origin.

Age of the intrusions.—The porphyrite sheets occur in the Trias at the highest point in that formation known in this region. The Mosquito fault is supposed by Mr. Emmons to be contemporaneous with the inter-Jurassic movement shown by the unconformity between the upper or fresh water Jura and the lower beds. In Middle park, at the eastern base of the Mosquito range, opposite the Ten Mile district, the Dakota, probably with a thin layer of upper Jura below it, rests on the Archean. The north end of the Mosquito fault, in the Gore mountains, is represented as faulting Trias and Jura, while the Dakota is unaffected. This representation rests upon unpublished data of the late A. R. Marvine, and has not been confirmed. If the Mosquito fault is of Jurassic age, then the porphyrites of the Ten Mile region are somewhat older, for they are distinctly faulted with the sediments. But this determination has two strong arguments opposed to it, namely, that almost identical rocks are intruded in the Cretaceous strata of Middle park, at Blue River Butte, and that, if of late Triassic or early Jurassic age, these intrusions can hardly have had as great a thickness of sediments above them as considerations of structure and analogy of occurrence would seem to demand.

OTHER OCCURRENCES.

Intrusive sheets and laccolites.—The type of rock forming the masses which have been described has a wide range in the Rocky mountains, but ignorance of the mode of occurrence in many cases forbids direct comparison with true laccolites and intrusive sheets. The Spanish peaks and several adjacent mountains in southern Colorado, on the eastern mountain border, have been stated by Endlich[1] and Peale[2] to be due to great intrusive masses, and compared by them with the laccolitic mountains of the western area. They have been reexamined in detail by R. C. Hills,[3] who has found the general horizon of intrusion to be Upper Cretaceous and not Carboniferous, as stated by Endlich. The rocks have not been fully described by Mr. Hills but they evidently possess the general characteristics of the type described in these pages. A remarkable complex of dikes appears in the beds above the Spanish peaks laccolities, according to Mr. Hills.

In Montana intrusive porphyrites very similar to those of Colorado occur in the Yellowstone park, according to J. P. Iddings,[4] and in the Highwood, Moccasin and Little Belt mountains, according to Waldemar Lindgren.[5] In how far these intrusions may be formally compared with those described in the preceding pages is not clearly shown in the publications cited. In the Yellowstone park there would appear to be great similarity in many respects.

GENERAL DISCUSSION.

THE LACCOLITIC ROCK.

Examination of the rocks forming the intrusive masses referred to in this article shows a very considerable range in composition, but it is a prominent fact that the great majority of them belong to one well

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[1] Hayden Ann. Rep., 1875, p. 128.

[2] Bull. U. S. G. and G. S., vol. III, p. 551.

[3] Preliminary notes on the eruptions of the Spanish Peaks region. Proc. Colo. Sci. Soc., vol. III, p. 24, 1888.

[4] The eruptive rocks of Electric peak and Sepulchre mountain. Twelfth Ann. Rep. U. S. Geol. Survey, pp. 569-664.

[5] A sodalite-syenite and other rocks from Montana. Amer. Jour. Sci., 3d ser., vol. XLV, p. 286, 1893.

marked structural type, with but slight variation in mineralogical constitution. This is plainly the result of the similarity of conditions of consolidation upon magmas which are much alike in their controlling elements.

There is every reason to suppose that other eruptive provinces may be characterized by intrusive masses of other rock types. If the magma of another region were very different from that here so common, another structural type might result from the same conditions of cooling, owing to the various formal characteristics of different minerals. A review of the characteristics of the rocks under discussion will now be presented.

Chemical composition.—In the table below are given quantitative analyses of nineteen rocks, representing laccolitic bodies of the Henry mountains (2), Carriso mountains (1), El Late mountains (2), San Miguel mountains (1), West Elk mountains (5), Ten Mile district (3), Mosquito range (2), and the Yellowstone National park (3). The analyses were all made in the laboratory of the U. S. Geological Survey by W. F. Hillebrand, L. G. Eakins, T. M. Chatard, and J. E. Whitfield. In all cases the freshest rocks available were taken. All of them excepting the three from the Yellowstone park have been studied by the writer; the exceptions have been described by Joseph P. Iddings.[1] The rocks from the mountains described by Holmes and Peale belong to masses whose occurrence is not accurately known, but their structure, and mineral and chemical composition, indicate that they may be taken, as they were intended to be by their collectors, as fair representatives of the igneous masses in their respective mountain groups.

The full range of rocks from the intrusive bodies described is not illustrated, for a few types were too much decomposed to warrant analysis. Thus the syenitic rocks of the La Plata mountains are not included. Concise descriptions of the rocks analyzed are appended:

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[1] The eruptive rocks of Electric peak and Sepulchre mountain, Yellowstone National park. Twelfth Ann Rep., U S. Geological Survey, pp 569-664

Descriptions of rocks analyzed.

I. Augite-porphyrite. Has few large hornblende phenocrysts and many more small ones of clear green pleochroic augite (p. 176). The hornblende much resorbed, the resulting augite grains having same color as the phenocrysts. Plagioclase phenocrysts tabular. Groundmass mainly feldspathic and particles are rude tablets, producing unusual structure. There is no distinguishable quartz.

II. Hornblende-porphyrite. Phenocrysts : plagioclase and hornblende, in nearly perfect crystals, fresh. Groundmass very even grained ; average size of particles 0·03 to 0·04 millimeter. Quartz often developed in minute dihexahedrons. Magnetite in two generations.

III. Hornblende-porphyrite. Phenocrysts : plagioclase and hornblende, in good crystals, fresh. Groundmass very even grained, 0·02 to 0·03 millimeter. Very much like II and IV.

IV. Hornblende-porphyrite. Phenocrysts: plagioclase, hornblende, and a little biotite. Hornblende somewhat resorbed. Groundmass even grained, 0·02 to 0·04 millimeter. Has a little plagioclase. Like II and III.

V. Hornblende-porphyrite. Phenocrysts : plagioclase, hornblende, and a very little augite. Plagioclase in very small crystals, hornblende being the most prominent constituent, in slender prisms up to about 2 centimeters in length. Augite very subordinate. Groundmass irregularly granular; consists of quartz, orthoclase, and plagioclase, the latter in small crystals. Some hornblende and augite may belong to groundmass. This rock is richer in dark silicates than any other from the plateau mountain groups.

VI. Porphyritic augite-diorite. Phenocrysts : plagioclase, augite> hornblende> biotite. All crystals small ; plagioclase strongly predominant ; scanty, very coarse grained groundmass of quartz, orthoclase, and plagioclase.

VII. Hornblende-mica-porphyrite. Phenocrysts : plagioclase, hornblende> biotite. Plagioclase and hornblende in distinct crystals ; biotite much intergrown with hornblende. Groundmass granular ; quartz grains 0·05 to 0·07 millimeter, filled with feldspar particles. Flakes of green mica scattered all through groundmass.

VIII. Porphyrite. Phenocrysts: plagioclase, biotite> hypersthene> hornblende> augite. Reddish gray, fine grained rock. Biotite most noticeable mineral, in glistening crystals (1 to 3 millimeters). Plagioclase occurs in few crystals 5 millimeters or more in length, and a lens shows many smaller ones. Hornblende, dull from resorption, and two pyroxenes visible with lens, and a scanty light reddish-brown groundmass. A few rounded quartz phenocrysts seen in thin section, with broad aureoles of groundmass quartz. Hypersthene in short crystals, strongly pleochroic ; augite similar to hypersthene but much less regular in form. Groundmass very subordinate ; consists quite clearly of quartz and orthoclase in interlocking grains.

IX. Porphyritic diorite. Phenocrysts : plagioclase, hornblende, and a little biotite ; groundmass of quartz and orthoclase grains nearly equaling phenocrysts in size (*see* p. 184).

X. Quartz-porphyrite. Phenocrysts : plagioclase> orthoclase, biotite> hornblende> augite, quartz. Orthoclase in large glassy crystals. Groundmass even grained ; 0·03 to 0·07 millimeter (*see* p. 192).

XI. Quartz-porphyrite. Phenocrysts : plagioclase> orthoclase; hornblende = biotite, quartz. Orthoclase locally very abundant. A little augite intergrown with hornblende. Groundmass subordinate, even grained; 0·015 to 0·030 millimeter, mostly of quartz and orthoclase (*see* p. 194).

XII. Quartz-hornblende-mica-porphyrite. Phenocrysts: plagioclase, hornblende, biotite, quartz. Hornblendes of variable size ; not much quartz. Groundmass coarse and irregularly grained, consisting mainly of quartz and orthoclase and a little plagioclase.

XIII Quartz-porphyrite. Phenocrysts: plagioclase, biotite, quartz. Groundmass up evenly granular, quartz and orthoclase principally

XIV Quartz-porphyrite. Phenocrysts: plagioclase > orthoclase, biotite, quartz. Orthoclase in crystals nearly an inch long in some cases; irregularly distributed, no hornblende; quartz abundant, groundmass evenly granular; quartz and orthoclase chiefly

XV. Hornblende-mica-porphyrite Phenocrysts: plagioclase, hornblende > biotite. Rich in dark green hornblende prisms, well terminated, of variable size Groundmass granular except for small hornblende needles and biotite flakes. Colorless part largely orthoclase with some plagioclase.

XVI Quartz-porphyry Phenocrysts plagioclase and biotite. The plagioclase crystals are usually less than 5 millimeters in diameter Biotite in irregular flakes. Groundmass a coarse grained mixture of quartz, orthoclase, and plagioclase, the latter in microlites embedded in the other constituents (*See* Geology and Mining Industry of Leadville, Mon xii, p 323)

One analysis of the above table belongs to a rock not distinctly of this series of eruptions. That is No. XVI, quartz-porphyry from the Mosquito range, and it is inserted with the opposite extreme, from the same district, to show the range of magmas intruded into the Paleozoic section of that region. The predominant intrusives of the Mosquito range agree closely in composition with those of the Ten Mile district. A somewhat exceptional rock is that of the first analysis, richer in alumina and alkalis than any other, but it is doubtless closely connected with the main series by types not analyzed.

The variable elements in the series are silica, iron, lime and magnesia, while alumina and the alkalis remain nearly constant. And the constancy of the alkali total is the most noteworthy feature of the series. It is to be remarked, moreover, that the magmas of the plateau groups and of the mountain area of Colorado differ in the relative abundance of the alkalis. It is, however, a characteristic of many Colorado magmas of widely different composition in other respects, that the potash contents should be unusually high. This seems to be evidence of what Iddings has called the consanguinity of magmas in certain provinces of eruption.[1] The rocks from the Yellowstone Park fall into place with those from the plateau groups.

Mineralogical composition.—It is interesting to note the mineralogical development from the magmas represented by the analyses of the table. Phenocrysts of plagioclase and the dark silicates were formed in all these magmas before eruption, but seem to have continued their growth after it to some extent. Plagioclase is the predominant mineral of all the rocks—excepting the quartz-porphyry—and the uniform appearance of its stout white crystals gives character to the whole series. It assumes tabular form only in the first rock of the table, the augite-porphyrite of Mount Pennell, the most feldspathic member of the series.

The variation of the magmas in iron, lime and magnesia is expressed in the amounts more than in the kinds of dark silicates developed. Hornblende and biotite are the most common. Hypersthene and

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[1] The Origin of Igneous Rocks Bull Phil Soc of Wash, 1892, Vol xiii, p 128

augite appear locally, but do not change the general appearance of the rocks, for all were developed under similar conditions. The finer grain of two or three rocks containing the pyroxenes is a result of other causes rather than the composition of the magma.

The rock with lowest silica contents still contains some quartz, but the range in silica agrees on the whole with the importance of quartz, especially as a macroscopic constituent.

The formation of plagioclase, hornblende, etc, left for the groundmass of each rock little beside silica, alumina, and the alkalis. The rather high and constant percentage of potash present in these magmas, with some residual soda and a considerable excess of silica, then came to expression in producing uniform granular groundmasses, mainly of quartz and orthoclase, for rocks differing considerably in their phenocrysts. The very characteristic macroscopic contrast between phenocrysts and a gray uniform appearing groundmass is now easily understood.

While the total of alkalis remains so nearly the same in the series, orthoclase appears as a phenocryst only in the Colorado rocks, and here generally in the more siliceous ones. With constant alkaline contents, an increase in silica means decrease in the heavier bases, and alkali feldspar becomes naturally prominent. But the most interesting fact is that the development of the huge orthoclase crystals depends principally on some delicate balance of conditions in the final period of consolidation. Orthoclase phenocrysts are characteristic of the rock of Analysis XIV, and are absent from that of Analysis XIII, from the same district, in similar masses of nearly the same horizon. They are present again in the rock of Mount Carbon (Analysis X), though this is richer in iron, lime and magnesia and poorer in silica and alkalis than XIII. They are developed in quite variable amounts in several of the larger laccolitic masses, being entirely suppressed in certain portions and abundant in others.

Orthoclase phenocrysts of the same character have also been observed by the writer as a local development in granular diorite masses. One such example may be seen in the main eruptive conduit of the Ruby range, mentioned above; another in the large diorite mass of Italian mountain on the eastern border of the Crested Butte district. The large pink orthoclase crystals of many porphyritic granites have also clearly been formed after other constituents which do not appear as phenocrysts.

Condition of magma at eruption.—It would be extremely interesting if we could ascertain the temperature, degree of fluidity, water contents, number of crystals in suspension, etc, in these magmas at eruption. It is a kind of dogma accepted by some petrographers that the groundmass of such rocks represents the portion of the magma fluid at time of eruption, and that the phenocrysts were all formed at a lower level in an earlier period. As will be brought out in discussing structure, the writer does not accept this idea in toto, but it is probable that hornblende, biotite, the larger part of the plagioclase, and sometimes quartz, existed in crystals at the time of eruption. Deducting their materials in most of the analyses, and there would be left a composition much like that of rhyolite for the fluid residue.

The amount of water can not be inferred. The temperature was low enough to prevent caustic action upon wall rocks or inclusions. The statements of Peale and Holmes that the magmas "absorbed" sedimentary masses are not supported by definite evidence of fusion, and this is probably not their meaning.

One interesting difference between these magmas and the closely allied ones of the Elk mountain diorites has already been alluded to. Not only are the sediments adjoining the laccolitic masses unattacked by heat, but they seldom exhibit any development of secondary minerals as contact phenomena. About the diorite masses, on the contrary, there is a marked development of vesuvianite, garnet, scapolite, epidote, pyroxene, orthoclase, quartz, hematite, magnetite, and, in one case, topaz. Fluorine, and, rarely, chlorine have been found in these minerals about the diorite mass of Italian mountain, and the evidence is very strong that these mineralizing agents were present in the diorite magma at eruption. Their influence, if present, upon the physical condition of the magma and the course of its consolidation is as yet a matter for speculation. But many investigators are coming to the belief that such agents may have a very decided influence upon the structure developed.

Conditions of cooling.—The facts of great range in geological distribution and in size and form of masses of practically identical rocks present perfect evidence that the conditions of cooling or consolidation were almost the same throughout this wide zone. This must mean that pressure as a function of depth has had very little influence within the limits represented. The rate of cooling must have been essentially the same for all masses. This shows that the highest laccolite was far enough below the surface to be sensibly free from the influence of conditions dependent on proximity to the surface.

The conclusion which seems clearly indicated is that below a certain depth there is a zone in the earth's crust within which conditions of cooling are practically uniform. It is certainly true that the increments of pressure and of temperature from top to bottom of this zone are without visible influence upon the structure or composition of the rock resulting from the consolidation of such magmas as these were. This last qualification is to express the possibility that in magmas of quite different composition and physical condition the ranges of pressure and temperature here represented might well cause differing structures in extreme parts of the zone.

Neither upper nor lower limit of this zone is known. It would seem, however, as if a depth of several thousand feet must be necessary to secure a temperature so high and a rate of cooling so slow that the chilling effect upon an intruded magma should be no greater than that at a depth of 20,000 feet.

Structure.—Nearly all of the intrusive rocks under discussion possess the typical porphyritic structure, i. e., they contain many very distinct crystals—phenocrysts—embedded in a fine-grained groundmass. The character of the minerals constituting the two parts of the rocks has been given, and it is desired here to dwell upon the interesting variations in development presented by some of the phenocrysts and upon the character of the transition stages toward the granular structure exhibited in certain masses.

Plagioclase, hornblende and biotite are very uniform in their development, especially in the class of quartz-bearing rocks with quite subordinate dark silicates, which includes the vast majority of all occurrences. These crystals were brought up from some earlier reservoir of the magma, though some of them had not reached their full growth at the time of eruption.

The variable development of quartz and orthoclase has been mentioned. The former seems to have existed in crystals in many of the magmas at eruption, but to have been resorbed more or less in nearly all cases. The unequal extent of resorption on different crystals in the same rock is a puzzling fact, but the writer is unable to accept the theory of Küch that the apparently corroded forms are in fact irregularities of growth and not due to resorption.[1]

The development of orthoclase in great crystals many times the size of any other constituent has been described as seen in the rocks of the West Elk mountains, the Ten Mile district, and the Mosquito range. These large orthoclases are in many cases clearly the product of crystallization after intrusion, and evidence showing that they were ever brought up with other phenocrysts seems to be lacking. This point is of considerable interest in connection with the definition of the granular and porphyritic structures, and as other facts concerning these rocks bear upon the same subject, it is specially treated in a following section.

The groundmasses of the various laccolitic rocks exhibit very admirably several different types of structure possible under the circumstances. In general they may be characterized as granular, and are usually quite uniform in character for any given mass. They illustrate the influence of the relative abundance of the minerals concerned, and also the effect of slightly differing conditions.

Beginning with the rocks richest in silica and alkalis, it is usually found that the formation of the earlier phenocrysts left a residue which, on crystallizing, could yield practically only quartz and orthoclase. Under the usual conditions of the zone within which these magmas solidified the most common structure for the resulting groundmass is

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[1] W. Reiss und A. Stübel · Reisen in Süd-Amerika. Geologische Studien in der Republik Colombia. I, Petrographie, 1, Die vulkanischen Gesteine, bearbeitet von Richard Küch. Berlin, 1892.

the even, typically granular. This may be fine or coarse. In the coarser grained rocks orthoclase generally forms larger grains than the quartz, and often includes smaller quartzes. A variety of this structure seen in many normal laccolites is caused by a decided effort of the quartz grains to assume crystal form. This ordinarily produces rude dihexahedrons which are clearly recognizable by the great number of imperfect square sections with extinction parallel to the diagonals. Sometimes a part of the groundmass quartz appears in sharp, distinct dihexahedral crystals, which usually exceed in size the remaining irregular groundmass grains.

Another type of groundmass structure is produced when the grains of quartz and orthoclase interlock by very jagged edges, and this grades over into a kind of micropoikilitic structure, where quartz develops in large roundish grains but is crowded with the feldspar in small particles. This often causes a mottled look to the groundmass, and its structure becomes very obscure with the beginning of decomposition in the orthoclase. Such a groundmass has macroscopically a denser appearance than the common granular one.

No pegmatophyre or micropegmatite structure has been seen in any of these rocks, there being no observable regularity of orientation in the intergrowth above mentioned. Aureoles of oriented groundmass quartz about phenocrysts are, however, not rare.

With decrease of quartz and abundance of orthoclase the latter assumes a microlitic form and the groundmass structure then approaches that common in trachyte. A microlitic element of subordinate importance is sometimes seen where plagioclase enters into the groundmass. This is an important feature only in the rocks practically free from quartz, such as some from the San Miguel mountains.

The laccolitic rocks whose structure is not typically porphyritic illustrate in most significant degree the transition between granular and porphyritic structures arising from a scanty and also coarse grained groundmass. The most marked instances are in the San Miguel or La Plata mountains, in rocks with very little quartz and a smaller amount of orthoclase than is common. But the most interesting rock is that of Mount Marcellina (p. 184), which occurs at the top of the Cretaceous, yet possesses a groundmass whose grains approach the phenocrysts in size, the quartz especially striving for crystal form. Coarseness of grain in groundmass crystallization is here clearly not a function related to depth, for nearly all the allied markedly porphyritic intrusions of the adjacent region are at lower geological horizons.

Definition of the granular and porphyritic structures.—The granular and porphyritic structures of igneous rocks were recognized long before the progress of petrographical science had led to an understanding of the history of such rocks and of their various characteristics. The facts made known by the microscope have especially tended to show that a granular structure results when the effective conditions of crystallization of a magma have been practically the same from beginning to end, and that a porphyritic structure results when there have been two periods of consolidation differing materially in attendant conditions. Without attempting any exhaustive historical review of the subject, it seems especially appropriate to discuss in this place the conception and definition of the structures in question put forth by Prof. H. Rosenbusch more than ten years ago,[1] which have been incorporated in his well known work,[2] long the standard handbook of students the world over, and which have recently been reaffirmed.[3]

In the works cited Rosenbusch defines the *granular* structure as that resulting from the uninterrupted and complete crystallization of a magma, so that there has been but one period of formation for each mineral constituent. The *porphyritic* structure, on the other hand, is that due to an interruption of crystallization, with a consequent and essential recurrence in the formation of one or more mineral constituents in the second period of consolidation. These definitions clearly attempt to express a formal relationship of parts—structure—in terms of its supposed origin. The writer has already presented objection to the form of these definitions, and also pointed out that the rock groups resulting from their application are not the same as the structural groups under discussion.[4] But the reason for the form of the definitions is not far to seek, and the error contained in them is illustrated by the rocks described in the preceding pages.

At the time that Rosenbusch put forth the above definitions he was also developing and formulating a scheme for the classification of igneous rocks, a fundamental principle of which was to be the geological distribution of structural types. Most deep seated rocks are granular and most effusive rocks are porphyritic in structure, and the definitions of the structures were made to express the conception that their essential differences arose necessarily from the different conditions prevailing in the two extreme loci of consolidation But in the definitions set up and in the classification alike the characteristics of the great and important class of intrusive rocks, solidifying at horizons between the deep seated centers and the surface, were practically ignored.

The laccolitic rocks described often contain hornblende, biotite and plagioclase only in phenocrysts, while the groundmass consists of quartz and orthoclase, and cases are not rare where neither of the latter minerals occurs in phenocrysts. Such rocks are neither granular nor porphyritic according to the definition of Rosenbusch, unless orthoclase be considered as a recurrent form of plagioclase. But the phenocrysts of laccolites, or some of them, have continued to grow after intrusion.

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[1] Ueber das Wesen der kornigen und porphyrischen Structur bei Massengesteinen Neues Jahrbuch fur Min , etc , 1882, II, pp 1-17

[2] Mikroskopische Physiographie der massigen Gesteine, 2d ed , 1887, Stuttgart, pp 11 40, 285

[3] Ueber Structur und Classification der Eruptivgesteine Tschermak s mineral und petrograph Mittheilungen, XII, pp 351-396, 1891

[4] Mon XII, U S Geol Survey Petrography of the Leadville region, p 320

This is shown by the small size of the phenocrysts of contact zones and small dikes. Again, the large orthoclase crystals are in these rocks, apparently in all cases, to be regarded as wholly developed after intrusion. Thus the most conspicuous porphyritical constituent was not formed in the first period, but in the second or groundmass period of consolidation.

As for the granular rocks of this region they demonstrate the converse proposition that granular structure may result from crystallization after intrusion. The dikes of the Ruby range, cutting late Cretaceous strata, are predominantly porphyritic, but in the larger conduits there is a transition to the purely granular, and in certain masses the only porphyritical constituent is orthoclase, a local development in the final stages of consolidation. Many instances are known to the writer of granular intrusive rocks in which it is clear that conditions of cooling allowed a resumption of crystallization after eruption with so nearly the same character of products that the contrast characteristic of the porphryritic structure was not developed. Every granular rock that can not be called deep seated must be assumed to have possessed no crystals at time of eruption, or else it stands as proof of the inapplicability of Rosenbusch's definition; and likewise all porphyritic masses which contain phenocrysts not formed in depth are evidence to the same end. Instances of one or both of these cases are surely known to every petrographer. The observations of Iddings upon various igneous rocks of the Yellowstone park[1] have an especial bearing upon this point.

The recurrence in mineral development, made by Rosenbusch an essential feature of the porphyritic structure, would seem to be primarily independent of conditions of consolidation and depend rather upon the original composition of the magma and the extent of crystallization prior to eruption. In extremely acid or basic magmas it is, of course, natural that the fluid residue at time of eruption should continue to furnish the same or corresponding minerals on its consolidation. But with such intermediate magmas as those of the laccolite rocks the crystallization of phenocrysts left a residue from which different minerals must result, at least in strongly predominant degree.

Viewing structure in its only legitimate sense, as a formal relationship of parts of a complex, it appears immaterial where it is developed or in how many periods. The granular structure is commonly a product of uninterrupted crystallization in depth. It may result in large intrusive masses, when conditions favor a resumption of the interrupted crystallization, rather than a new form. Or if a magma contained no phenocrysts at eruption the product might be granular. The interior parts of large extrusions of basic magmas are sometimes granular in structure.

The porphyritic structure arises when different periods of consolida-

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[1] The Eruptive Rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park, by Joseph Paxson Iddings. U. S. Geol. Survey, Twelfth Ann. Rept., 1892, pp. 569-664.

tion are attended by materially different conditions, affecting the products as seen in porphyries. Between the general conditions of great depth and those of the surface there is naturally the most marked contrast in external conditions. But while conditions determining rate of cooling are extremely important, the changes in chemical composition of a crystallizing magma and in its physical condition as consolidation progresses are also of decisive weight in determining structure in many cases. Phenocrysts begun in depth may continue to grow after eruption. A part of the new crystallization may be in phenocrysts and a part form the groundmass. The presence of large orthoclase phenocrysts in many laccolitic rocks and their absence in adjacent masses of the same chemical composition show that in acid alkaline magmas a delicate balance between internal and external conditions may exist, so that with a swing in one direction a most marked porphyritic structure will develop, while in the other a purely granular form results.

These crystals must be compared with those so often found in granitic rocks formed at great depths. The uncrystallized part of the laccolitic magmas in which the large orthoclases were formed was practically identical in chemical composition with that of many granites. Their origin seems to explain that of the phenocrysts in porphyritic granites, and shows that porphyritic structure does arise in depth during continuous crystallization of certain magmas, the requisite change in conditions being internal and not external. The latter alone have been considered in many discussions of the origin of structure.

Since the above discussion was written the first volume of the new edition of Prof. F. Zirkel's invaluable Lehrbuch der Petrographie[1] has appeared. The views of the granular and porphyritic structures advocated in this work are practically identical with those here presented as to conditions of origin. Zirkel believes, and cites numerous instances to prove, that the phenocrysts of porphyries are not always nor entirely the products of crystallization in depth, and also that the granular structure may be the result of repeated epochs of crystallization. Both structures are, however, viewed by Zirkel as purely *macroscopical* conceptions. The groundmass must appear homogeneous to the unaided eye, and a granular rock may not be aphanitic or dense.

This limitation seems to the present writer both unnatural and undesirable. Aphanitic should not be opposed as a structure to granular or porphyritic, but should simply indicate that the grain of the mass has become so fine that the eye can no longer determine the character of the microstructure. It may be microgranular, microporphyritic, or of some other formal relationship. A rock may, on the other hand, possess a very coarse grained groundmass and yet the contrast with large phenocrysts may be very pronounced, as in many granite-porphyries.

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[1] Lehrbuch der Petrographie, von Dr. Ferdinand Zirkel. Zweite, gänzlich neu verfasste Auflage, Leipzig, 1893, pp. 465–469

THE LACCOLITE.

Forms of laccolites.—The regular dome shape of the theoretical laccolite can seldom be realized in nature, and the necessity for the extension of the use of the name to include more or less irregular bodies was recognized by Gilbert. He remarks: "If the strata had experienced anterior displacements so as to be inclined, folded and faulted a symmetrical growth of laccolites would have been impossible. * * * But the type form being known, it is to be anticipated that in disturbed regions aberrant forms will be recognized and referred to the type."[1] His own usage of the term is broadened to practically include all thick lenticular masses of intrusive igneous rock occurring at a certain geological horizon in a sedimentary complex.

In the Henry mountains the force propelling the magma seems to have performed the entire work of lifting the load to form the chamber of the laccolite. But in regions where the beds are under orographic stress, almost or quite to the point of folding, a magma would find intrusion on certain planes a comparatively easy matter. Such conditions are illustrated by the sheets in the spring of the arch of strata over the laccolite, Fig. 26, and it seems probable that such occurrences as those of the Mosquito range and Ten Mile district, where many thin sheets are intruded very regularly, represent localities where lateral pressure has already overcome the gravity of the strata to a great extent, and the intrusion planes were planes of easy parting. Such conditions would not cause irregularities of form.

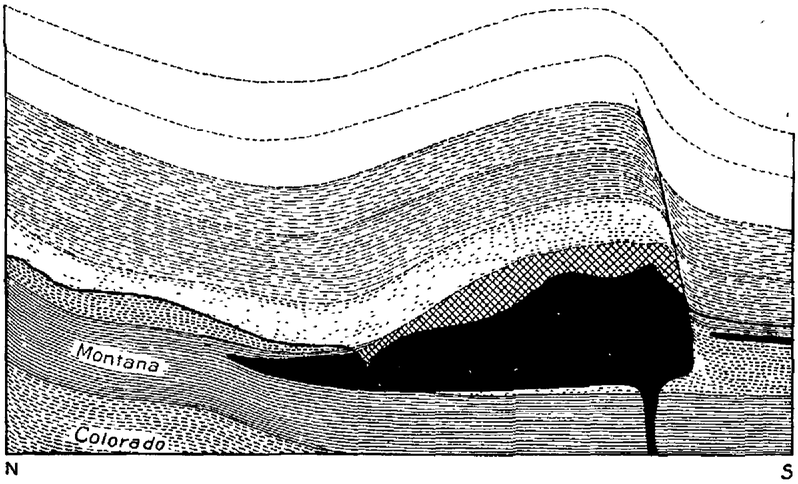

FIG 43.—Profile section through Mount Marcellina, with ideal restoration of laccolite and strata above it

If regular position with regard to stratification planes be regarded as essential to the laccolite many masses which have been described as laccolitic must be thrown out of the class. But it seems much more

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[1] Report on the geology of the Henry mountains, p 98.

reasonable to include all masses as laccolites where the expansion of the body has taken place from a plane even approximately parallel to the bedding. In horizontal strata the lifting of the load by the intrusive force may be taken as the prime essential. The deviations from the type form from accidental causes are many.

In the West Elk mountains four principal causes of irregularity in the form of the laccolite seem to be illustrated. These are: (1) Oblique position of the plane of expansion to bedding planes of the sediments; (2) lines of structural weakness in the strata; (3) presence of earlier intrusions; (4) lack of coherence and pronounced bedding in strata invaded. These are no doubt often closely connected, but each is in itself sufficient to produce distortion in the resulting laccolite. A good example of the combination of the first two causes is presented in Mount Marcellina.

In describing this mountain (p. 184) a profile section was given, illustrating the cross-cutting lower contact and the asymmetric form of the eruptive mass. This section is repeated in the adjacent Fig. 43, with a hypothetical restoration of the strata assumed to have existed above the laccolite at its intrusion.

At Mount Marcellina, as in the Anthracite range, strata approach on the south in practically undisturbed position very near to a high, abrupt face of porphyrite, while on the north strata of a lower horizon than those found at the base of the southern cliff are seen resting on the eruptive. Suppose that the beds were nearly horizontal at the time of the intrusion, but that a line of weakness existed in an east and west direction, from whatever cause—from axial tension, preexisting fracture, or resistance offered by an earlier intrusion to the southward—the intruding magma might develop this into a dislocation, as illustrated. The effect would be a faulting of some thickness of strata above the local horizon of intrusion, but it is conceived that if a great thickness of strata existed above the forming laccolite, and especially if the beds were not firmly indurated, this fault would gradually pass into a fold upward and the disturbance at the surface would be an unsymmetrical doming up of the beds, as indicated.

The known facts of the Mount Marcellina mass seem to agree perfectly with the hypothesis, but even if the cause of the irregularity is not fully expressed above, the type is one which seems natural for any region where a distinct line of weakness does exist in beds above a developing laccolite.

The irregularities in form and relationships of a laccolite due to earlier intrusions are in a measure shown in the Henry mountains. It is probable that if the relationships of the Anthracite range, Mount Axtell, and Mount Carbon, masses of the West Elk mountains, were fully known one of them might be taken as a type of the aberrant form due to such causes. The Axtell body seems to be a very regular intrusion at a certain horizon, the Anthracite range mass to represent chiefly the Marcellina type, and the Mount Carbon body to be most irregular, as if the last to form. Its contacts are, however, so little known that one can say that if the other two great laccolites were present when the Mount Carbon magma was injected they must have prevented its assuming a symmetrical form. Further, if the fissure through which the magma ascended lay under the Axtell mass its deflection by that mass would very likely cause it to ascend at the side, obliquely to the stratification, and thus introduce another cause of irregularity.

It is difficult to conceive that if the upward leading fracture caused or followed by the injected magma terminated in the midst of a great series of clays or arenaceous shales, the latter could adjust themselves symmetrically with regard to the forming laccolite. In Gothic mountain the lower contact of the laccolite is nearly parallel to the bedding of the shales for some distance under the center of the mass, and then cuts up diagonally for 1,000 feet. It is probable that in such cases the shales are often crushed and distorted in the vicinity of the laccolite, but as distance from the latter increases the regularity increases, and the heavy sandstone bank at the base of the Laramie may have been very symmetrically upheaved by the Gothic mass. This type of laccolite grades into the hypothetical forms assumed by Holmes for the masses of some of the plateau groups.

The questions of age and load.—In all the laccolitic groups of the plateau and mountain border the highest Mesozoic strata now remaining have been disturbed by the intrusion, and in the West Elk mountains some of the laccolites appear in the Ruby formation, which is above the Laramie and probably represents the highest Cretaceous formation. These latter intrusions are therefore certainly Tertiary, and everything suggests that the other groups are of the same age.

No stratigraphical evidence bearing upon the nearer determination of age is as yet known, but considerations of the load necessary to fulfill the requirements of his laccolitic hypothesis led Gilbert to the conclusion that some thousands of feet of Tertiary strata existed above the Cretaceous at the time of intrusion in the Henry mountains. The study of the laccolitic rocks makes it plain that the load of Tertiary strata above the highest laccolite was sufficient to procure for that mass conditions of cooling identical with those experienced by the lowest, as far as is expressed by the structure of the rocks. We do not know what depth of strata would produce this result, but several thousand feet would seem necessary.

Origin of laccolites.—It has been the writer's object to assemble the facts concerning the occurrence of the numerous intrusive masses of the laccolitic type, as a contribution toward a final understanding of their origin. Much detailed work is plainly necessary in some of the promising fields before the data for a generalization of great value can be obtained. But some facts seem to have an obvious bearing upon certain features of the working hypothesis set up by Gilbert to explain the Henry mountain intrusions.

The facts of intrusion, as set forth in the preceding pages, can scarcely be doubted. Magmas did intrude themselves between strata at great depths, and for such areas as the Henry mountains, at least, no known evidence indicates that the work of lifting the load of sediments was performed by any other force than that propelling the magma. The question at once arises, Why did the magma stop at these various horizons and perform this work rather than ascend higher in the sedimentary complex?

In discussing "the question of cause" Gilbert concludes that "the coincidence of the laccolitic structure with a certain type of igneous rock is so persistent that we can not doubt that the rock contained in itself a condition which determined its behavior;" and further, on the basis of several considerations, he says: "We are led to conclude that the conditions which determined the results of igneous activity were the relative densities of the intruding lavas and of the invaded strata; and that the fulfillment of the general law of hydrostatics was not materially modified by the rigidity and cohesion of the strata."[1]

As to the laccolitic rock type of the areas in question, Gilbert did not know its chemical composition, and must have had reference to its structure, as constituting it a type. But the structure is a result of the conditions of consolidation, *after* intrusion. In chemical and mineralogical composition the laccolitic rocks are identical with certain surface andesites, as shown above in discussing the rock.

In regard to the second conclusion above cited, the logical consequence is also stated by Gilbert: "But, in order that the laccolitic structure should have been determined by density, the acidic rock of the laccolites must have been heavier in its *molten* condition than the more basic rocks of the neighboring volcanoes; and since in the *crystalline* condition the acidic is the lighter, it follows that it has gained less density in cooling than the basic."[2] It is admitted by Gilbert that this has not been demonstrated. The following facts of observation have a decided bearing upon Gilbert's theory:

It has been shown that the geological horizons occupied by these instrusions in Colorado range from the Cambrian to the post-Laramie.

In the Ruby range of the anthracite district, West Elk mountains (see map, Pl. VI), a great system of dikes occurs, cutting the Upper Cretaceous strata to the highest known stratum of the post-Laramie Ruby beds, and the rocks are often indistinguishable mineralogically and structurally from some of the neighboring laccolitic rocks. No connection is indicated between these dikes and any of the laccolitic intrusions. In this district, then, a certain magma rose during one eruption to unknown distances above the levels at which it formed laccolites in other and probably older eruption.

At Electric peak, in the Yellowstone National park, there occurs,

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[1] Report on the Henry mountains, p 75.

[2] Loc cit

according to J. P. Iddings,[1] a great series of intrusive sheets and dikes of rocks, some of which are practically identical with the most common laccolitic type of the plateaus, while in the adjacent Sepulchre mountain the identical magmas are shown as surface rocks—andesites. The intrusions are the oldest of the series. The whole belong to one volcano, as conclusively shown by Iddings.

In the Mosquito range, Colorado, it has been shown by S. F. Emmons[2] and the writer that rocks having a very considerable range of chemical composition occur in intrusive sheets and laccolitic masses through the entire Paleozoic section. They are not distributed in any order corresponding to specific gravities. Two extremes of these unmistakable intrusions are included in the table of analyses, p. 227.

The facts above cited seem to demonstrate that the horizons occupied by intrusive magmas are not determined by "relative densities of the intruding lavas and of the invaded strata," and the question recurs as to what was the determining cause.

In introducing the discussion of cause Gilbert[3] says: "It is not necessary to broach the more difficult problem of the source of volcanic energy. We may assume that molten rock is being forced upward through the upper portion of the earth's crust, and disregarding its source and its propelling force may restrict our inquiry to the circumstances which determine its stopping place." But his hypothesis takes account only of that propelling force which arises from the tendency of gravity to maintain hydrostatic equilibrium in the earth's crust as far as possible If the laccolitic magmas were impelled by other volcanic forces, other explanations of the horizons chosen are necessary. Of this question Prof. J. D. Dana has recently spoken as follows: "*The origin of volcanic heat*, the *source of lava columns* beneath the volcano, the *cause of the ascensive force* in the lava column, are subjects on which science has various opinions and no positive knowledge."[4]

The marked contrast between the dike system of the Ruby range and the laccolite masses shows that the forces producing the fissures followed by the magmas must have been of very different intensity if not of different kind in the two cases. The channels followed by the laccolitic magmas must have terminated at the horizons occupied. The difference between the fissures of the two kinds of eruption corresponds to that which might be expected between the effects of sudden, violent shock—earthquake shock—and of a gradually-exerted force. The latter would be more easily deflected by various causes, and once traversing the strata in oblique course would naturally pass to coincidence with some marked stratification plane. Injection of magma causing and following such a fissure would develop it only on such lines.

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[1] The eruptive rocks of Electric peak and Sepulchre mountain, Yellowstone Nat Park, Twelfth Ann Rept. Director U. S. Geological Survey, 1892, pp 569-664

[2] Geology and Mining Industry of Leadville, Colorado, Mon XII, U S. Geological Survey

[3] Report on the Henry mountains, p 72

[4] Characteristics of volcanoes, etc, 1890, p. 24.

An illustration of the manner in which volcanic fissures of a certain type are developed with a singular indifference to stratification planes is exhibited in the Uinkaret plateau, adjoining the Colorado canyon, as described by C. E. Dutton.[1] Here are basaltic volcanoes situated near the brink of the canyon, and in some places their lavas form cascades descending into it for a depth of 2,000 feet or more. These fissures were evidently not made by a force like that of the laccolitic eruptions to the north.

The conclusion the writer draws from the facts and other considerations, above noted, agrees very closely with that expressed by J. D. Dana in 1880, in reviewing Gilbert's monograph. He remarks that Gilbert's explanation of the laccolite "appears to be complete without reference to this difference of density. With so powerful a forced movement in the lavas as the facts, if they are rightly interpreted, show to have existed, no other cause could be needed for a flow to the surface in case of an open channel, or for a flow to any level in the strata at which a fissure might terminate; and this is true whether the lava be light or heavy."[2]

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[1] The Tertiary history of the Grand Canyon district, Monograph II, U S Geological Survey, Chapter VI

[2] Amer. Jour of Science, 3d series, Vol XIX, 1880, p 24

THE GOLD-SILVER VEINS OF OPHIR, CALIFORNIA.

BY

WALDEMAR LINDGREN.

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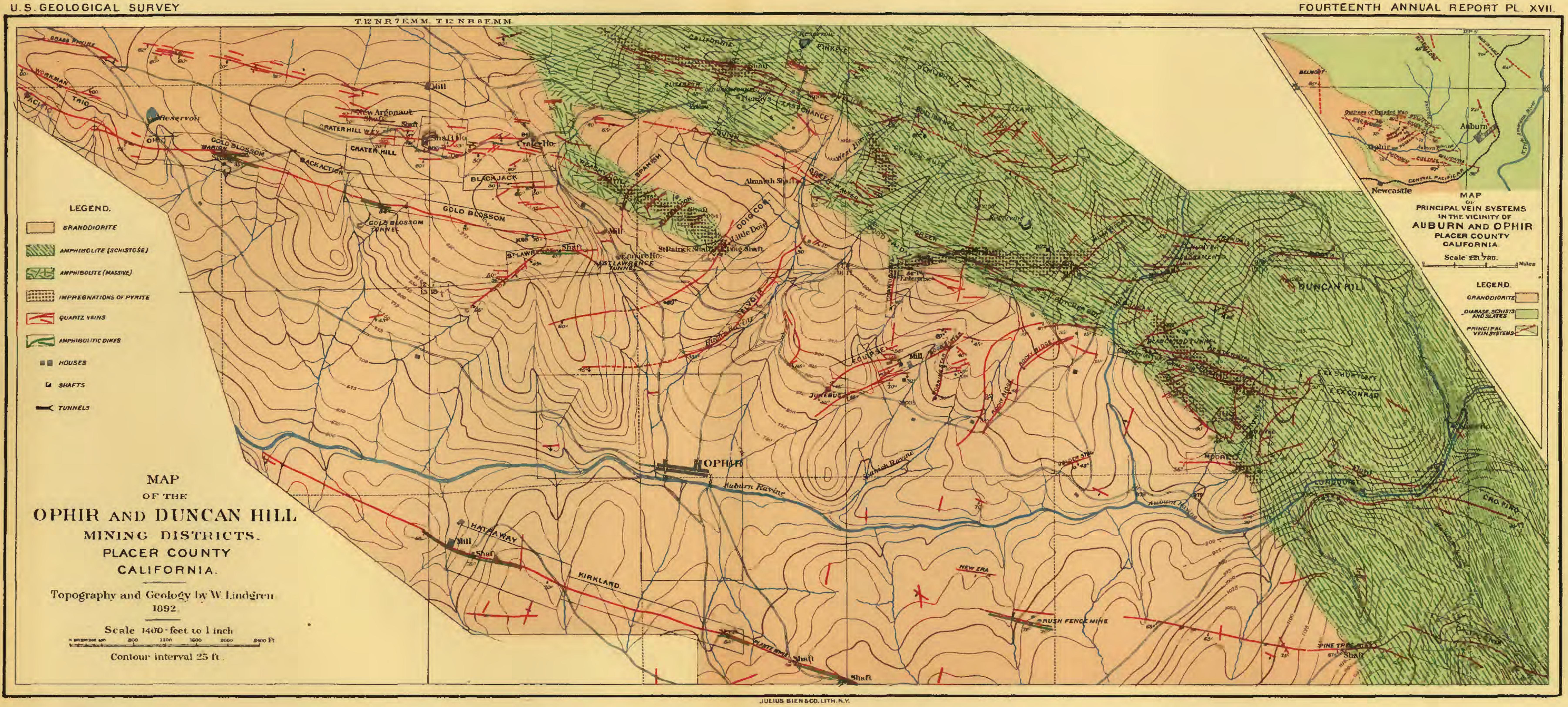

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THE GOLD-SILVER VEINS OF OPHIR, CALIFORNIA.

By Waldemar Lindgren

INTRODUCTION.

The examination of the Ophir mining district was made during the summer of 1892. The map accompanying this report is based on the section lines and corners established by the Land Office. In some of these lines and corners there are notable errors of azimuth and distance, but most of these have been ascertained by the numerous subsequent surveys for mining claims.[1]

HISTORIC NOTES.

When, in 1848, the gold seekers invaded the Sierra Nevada their first explorations were confined to the river courses and the adjacent gulches; but emboldened by success, it was not long before they began to explore the high divides between the canyons. In this manner the Neocene auriferous gravels and the richer quartz vein districts were early discovered. The surface gravels at Auburn and Ophir were first found in 1849, and for several years yielded large returns. Even before these were exhausted attention began to be directed to the numerous croppings of quartz from which a great deal of gold in the shallow gravels was clearly derived. The mining districts of Ophir and Duncan hill were organized, and thus early in the history of California quartz mining was inaugurated in this vicinity, although it was long before it came to be carried on in an extensive and scientific way.

During the twenty years following the discovery of gold in California a great many of the quartz veins in the districts were located and worked in a desultory way. It was not until the end of the sixties that quartz mining began to be carried on in a more energetic manner.

One of the earliest mines was the Green Emigrant, or Green mine, which was discovered in 1864. In 1867 it is said that $100,000 was extracted in hand mortar from this vein near the surface. In 1868 the New York and Empire, now called the Centennial, Conrad, and Hope

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[1] In plotting claims and also in field work, I have had the valuable assistance for a few days of Mr. R. L. Dunn, of Auburn.

veins, were worked to some extent. During the same year the Empire company had numerous locations and worked a shaft 35 feet deep. Their ore was treated in a small 10-stamp mill. The Golden Rule, Walter, and Saint Lawrence were also located then, but little work was done on them. In 1871 the Green mine is said to have yielded $150,000.

In 1872 quartz mining was very active, and numerous rich pockets were discovered. On the Saint Patrick $75,000 was extracted near the surface, and a shaft was sunk 220 feet deep, which yielded excellent milling ore, some at the rate of $67.50 per ton. The Big Doig and the Peachy were worked to some extent. On the Green mine a shaft was sunk, yielding extraordinarily rich ore, running, it is said, from $50 to $1,000 per ton. Later a two-weeks run of four stamps gave $50,000.

The group of veins referred to as the Bellevue, Elizabeth, and California yielded 200 tons, which milled $40 per ton. In 1872 55 stamps were running in the district.

The rich developments continued during 1873. The Green shaft had been sunk to 240 feet and in all 500 tons of very rich ore extracted. The Saint Lawrence and Bellevue were also producing. In the Crater hill, which contains a network of ledges noted for their rich ore, only one vein was then worked through a shaft 130 feet deep, the ore averaging $50. The Shipley mine, on the most westerly of the vein systems noted on the sketch, in the upper right-hand corner of the map, had a shaft 150 feet deep and the ore averaged $25.

During 1873 the Saint Patrick company worked the vein of the same name through a 300-foot vertical shaft, and also had a 15-stamp mill, in which 4,140 tons were milled, averaging $16.81. During the same year the Saint Patrick company explored the Spanish Ledge and sunk the Crater hill shaft to a depth of 212 feet. The total bullion product of the Saint Patrick company in 1872–'73 was $60,000 and the average yield of all the ore was $20 per ton. In the same year a $15,000 pocket was taken out from the Mina Rica. The Gold Blossom vein was also worked to some extent during this time.

In the year 1875 large bodies of ore were found in the Crater hill mine between the 200 and the 300 feet levels, from which $74,000 of bullion was extracted.

The many rich ore bodies found from 1871 to 1874 had stimulated prospecting and developing of all the mines in the district. Unfortunately success did not always follow these ventures. In many cases costly mills were erected before the ore bodies exposed warranted such action. The pay-shoots were often found to be rich but of very limited extent. In other mines the character of the ore rendered it difficult to obtain anything near the assay value in the mills. Thus from 1875 to 1883 but little work was done. In 1881 the Gold Blossom vein began to be exploited. In 1882 the Mina Rica shaft was sunk to a depth of 275 feet, three levels run, and considerable ore extracted. The Saint Lawrence was also worked to some extent. During the following year considerable improvements were made at the Gold Blossom, a 10-stamp mill and a roasting furnace being built, and the shaft was sunk to a depth of 200 feet. In the same year the Crater hill shaft was sunk from 700 feet to 800 feet, making it the deepest shaft it the district. The yield of Crater hill mine in 1883 is stated to have been $225,000.

In 1884 the Gold Blossom was idle, difficulties having been encountered in treating the ore. The Crater Hill closed down, it is stated, on account of the heavy expense and because the pay-shoot pitched into the adjoining ground.

In 1889 the Gold Blossom was worked and a 20-stamp mill had been erected on the Hathaway mine, developed by a shaft 200 feet deep. Work had also been resumed on the Eclipse, and a mill of 10 stamps erected, which, however, was only run for a short time.

At the same time rich pockets were taken out of the Mina Rica, the Conrad and the Moore mines. Two hundred thousand dollars is said to have been extracted from the Rock Creek mine to the northeast of Auburn, and the mines on the Belmont vein were also successfully exploited. In 1892 but very few mines were worked, and those only on a small scale.

From the few data given above it may be seen that the Ophir and Duncan hill mining districts have in a marked degree been subject to the vicissitudes and changing fortunes incidental to many mining camps. Stimulated by rich finds, large sums of money have been unsuccessfully invested, and periods of activity have been followed by times of depression.

YIELD OF THE DISTRICT.

It does not seem possible to arrive at any reliable estimate of the production of the mines since their discovery. Statistics are very deficient and only in the Mint reports of 1890 and 1891 are there any detailed returns given from individual mines. The production has been so variable from year to year that no general average can be given. It is probable, however, that during the last eight years the production has never exceeded $100,000 from all the mines in the Ophir and Duncan hill mining districts, and some years probably not more than $10,000 or $20,000 was produced. The highest production was probably obtained in 1883, when it is said to have reached $300,000. A rough estimate for the forty-three years since the discovery would be about $3,000,000, only a fractional amount, it will be noted, of what the surface and deep placers have produced in the county.

THE REGION IN GENERAL.

TOPOGRAPHY.

The mining districts to be described are situated in Placer county, a mile or two to the north of the Central Pacific railroad. The general topography and geology is represented on the Sacramento sheet, recently issued by the Survey. Most of the veins are found at short distances from the contact of the isolated massif of granodiorite situated in the center of that sheet, and surrounded toward the north, east, and south by higher ridges of amphibolite and diabase, while adjoined to the west by the Pleistocene deposits of the Great valley. In the upper right-hand corner of the map (Pl. XVII) a portion of the northeastern corner of the Sacramento sheet is inserted on a larger scale in order to show the general direction of the principal vein systems.

The area is drained by the North fork of the American river and by Auburn ravine, both of which empty into the Sacramento river far down on the plains. Corresponding to the geology, the topography shows two different types: First, that of the granitic area, with gentle slopes and curves and broad flat valleys; second, that of the schist and slate area, characterized by steep ridges and deep, narrow canyons with rocky slopes. North of Auburn, however, where the modern erosion has only begun to modify the Tertiary topography, there is a part of the more gently undulating Neocene surface preserved. The elevations range from 500 to 2,000 feet above the level of the sea.

GEOLOGY.

The area shown on the western part of the small map is occupied by a rock standing between a granite and a diorite in composition, and to which the name of granodiorite has been given on the sheet mapped by the California division of the U. S. Geological Survey. This species of rock, which is extremely common on the western slope of the Sierra, and to which nearly all of what has formerly been called granite really belongs, is of coarse grain, easily decomposing and crumbling. It consists in its normal development of quartz, plagioclase (soda-lime feldspars), orthoclase, biotite, and hornblende; near the contacts, however, the biotite is usually less prominent and the rock approaches more closely to the normal diorites. Detailed descriptions of this rock are given below. The granodiorite is always massive, and observations along the contacts show that it is later than and intrusive into the surrounding schistose rocks. At Folsom this same granitic rock cuts off and metamorphoses the black Mariposa slates, which are either Jurassic or early Cretaceous. This granodiorite is consequently of more recent age than the Mariposa beds.

The eastern area, colored green on the smaller map, consists largely of schistose amphibolites with a northwesterly strike and usually dipping east at steep angles. It is, as a rule, a dark green, fine-grained rock in which many minute hornblende crystals are visible. It consists of hornblende, feldspar, and sometimes quartz, together with smaller quantities of chlorite, epidote, and titanic iron ore. The schistose structure, often less noticeable in the fresh rock, becomes much more apparent in the weathered outcrops. More detailed descriptions are given below.

North of Auburn areas of massive diabasic rocks occur with the amphibolite in such a way as to prove that the latter has been derived from the former by dynamo-metamorphic processes. In the extreme northeastern corner of the small map an area of sedimentary rocks with a northerly strike and steep easterly dip begins, which, from the few fossils found in them, have been referred to the Carboniferous. The amphibolite and the diabase sometimes contain smaller isolated areas of these sediments, principally clay slates and limestone masses. The diabase from which the amphibolite is derived is later than the Carboniferous sediments, and during its eruption shattered and penetrated them.

Smaller areas of serpentine of uncertain derivation occur near Auburn.

THE VEIN SYSTEMS.

The region described is traversed by many quartz veins, which usually are auriferous. Their thickness varies from a few inches up to 10 or 20 feet; the average thickness being about 1 foot. Several veins may be traced continuously for 1½ miles, or even more. Among the veins four systems may be distinguished. The first occurs principally in the areas of amphibolite and diabase about Auburn. Its direction is northwest to north-northwest and roughly parallel to that of the strike of the schists; the dip is mostly to the west at angles ranging from 45° to 70°, while the schists have an easterly dip. The veins of this system are mostly "pocket veins" in which the pay-shoots are narrow and rich, while the mass of the vein quartz is too poor for profitable mining. Pockets of great richness have been found in the Rock creek vein and in the Black Ledge. The gold is usually free and coarse and does not contain much silver. Rich sulphurets, however, occur in the vein 1 mile to the north of Auburn.

The second is represented by the heavy Belmont vein in the granodiorite area. Its direction is nearly north and south and the dip steep. Good bodies of milling ore have been found on the Belmont and the Three Star locations.

The third and fourth vein systems are those which are represented in the region to be specially described in this paper. One of these is represented by a system of strong, continuous, parallel veins, with a direction varying from W. 10° N. to W. 25° N., and dipping uniformly south at angles ranging from 40° to 80°. The other is represented by a somewhat less strong system of parallel veins ranging from E. 20° N. to E. 40° N., dipping uniformly to the southeast at angles from 20° to 60°. The two vein systems thus meet at an angle of about °45.

Perhaps the first fact attracting attention in regard to the vein systems enumerated is their apparent independence of the geological formations and of the structural lines of the range. In general they follow the schists neither in strike nor in dip, and often cross the contact line, while they seldom follow it for any distance. Both in the granodiorite and in the amphibolite rich ore bodies are found, though the character of the ores is somewhat different in the two formations.

THE OPHIR VEINS.

The vein systems to be described in detail in this paper are comprised in the two mining districts of Ophir and Duncan hill. They are collectively referred to as the *Ophir veins*, the exact outlines and boundaries of the districts being of no importance for the present purpose.

TOPOGRAPHY.

The town of Ophir is situated in the broad valley of Auburn ravine, about 1½ miles north-northeast of Newcastle, on the Central Pacific railroad, and 2½ miles west of Auburn, the county seat. Its elevation is only 700 feet above the sea, and it consequently has a mild climate; no snow falls during the winter, and in the summer the temperature sometimes reaches 110° F.

The area investigated is comprised in a rectangular figure 3 miles from east to west, and 1½ miles from north to south. The elevations range from 600 to 1,300 feet above the sea level. It is drained by Auburn ravine and its principal branch, North ravine, both heading a few miles to the northeast. In the schist areas occupying the eastern part of the map these creeks have cut steep miniature canyons to a depth of a few hundred feet; the bottom is narrow and rocky and the sides deeply scored by lateral ravines. As soon as the granitic areas of the western part of the district are reached the topographic character changes. The canyon widens to an extensive valley with gentle slopes; the elevations of hills and ridges suddenly diminish and their outlines become gentle and flowing. A section across the valley of Auburn ravine in the granitic area shows at most places broad, gently sloping shelves or benches at the foot of the higher ridges; the water-course itself flows through this bench in a somewhat narrow and steeper canyon cut down to a depth of from 75 to 150 feet. The grade of the creek in the vicinity of Ophir is about 125 or 150 feet to the mile, and it is a fact worth noticing that in many places gravels of moderate coarseness are accumulating along its course.

The tops of the higher hills and ridges are generally flat and more or less level, and some of the ravines when reaching a certain elevation have but slight fall, and form marshy flats. This is notably the case with the creek heading a quarter of a mile to the east of Crater House. The highest of these flat topped hills and ridges represent what remains of the old Neocene surface, such as it was before the lava flows covered the slope of the Sierra. To the south of Ophir there is a lava-covered ridge, just outside the southern limit of the map, at which the bed rock has an elevation of about 975 feet above the level of the sea. It is altogether probable that Crater hill, the hill southeast of Crater House, the 1,300-foot high ridge to the north, and the high ridges in the southeast corner of the map represent parts of that same surface. If these points are connected it is apparent that the Neocene surface, though not so accentuated as the modern, still corresponded to it in its principal features. The amphibolitic hills then, as now, projected above the more level surface of the granodiorite.

GEOLOGY.

GRANODIORITE.

It has been stated above that the rock of granitic texture occupying the area west of the contact stands between a diorite and a granite, and belongs to the type to which the name of *granodiorite* has been given. There is considerable variation in its composition, but in its normal development it consists of feldspar, quartz, biotite, and hornblende with medium to coarse grained hypidiomorphic structure. The soda-lime feldspars are usually considerably and to a variable extent in excess of the alkali feldspars. The silica varies between 55 and 73 per cent; the amount of lime sometimes falls short, but rarely exceeds the sum of the alkalis. While in some varieties which can not be distinguished from the others in the field there is more potassa than soda, the usual relation is 2 per cent K_2O and 4 per cent Na_2O. The rock at the quarries of Lincoln, about 8 miles west of Ophir, may be considered a typical granodiorite, and its composition is as follows:

SiO_2	65·54	MgO	2·52
TiO_2	·39	K_2O	1·95
Al_2O_3	16·52	Na_2O	4·09
Fe_2O_3	1·40	H_2O	·59
FeO	2·49	P_2O_5	·18
MnO	·06		
CaO	4·88		100·73

(Analyzed by W. F. Hillebrand.)

Within the area embraced in the special map the granodiorite does not quite correspond to the normal type, as, indeed, is often the case near the contacts. Over the northern and largest part of the area it contains much hornblende and little or no biotite, and might appropriately be called a quartz-diorite. In the southern part of the area it approaches the normal type more closely. At the contact very basic forms sometimes appear; so, for instance, in the deep embayment in the slates at the Bullion mine the rock is a coarse grained, very dark and basic diorite, locally even going over into a facies consisting only of large hornblende crystals, 1 centimeter or more in diameter. The rock is of a greenish gray color, quite coarse grained, and crumbles easily under the influence of atmospheric agents. It forms a deep and mellow soil on all slopes of moderate inclination, and appears to decompose more rapidly than the erosion can carry off the products. In contrast to the red ferruginous soil of the schist areas, the granodiorite is light colored, grayish or brownish.

The rock from near the place where Pine Tree ledge crosses the New Castle road is a medium grained, normal granodiorite, in which, besides white feldspar and quartz, dark green hornblende and a little brown biotite may be discovered. Under the microscope it is seen to consist of irregular grains of the above minerals; only the hornblende and the plagioclase sometimes show roughly crystallographic outlines. In addition there is abundant apatite in short prisms. The rock is somewhat decomposed, and secondary calcite and white mica have formed to some extent in the feldspar, while chlorite and epidote occur in connection with the ferro-magnesian silicates. A partial analysis of this specimen by Mr. George Steiger gave 60·89 per cent SiO_2, 5·77 per cent CaO, 1·05 per cent K_2O, and 3·75 per cent Na_2O.

The rock from the vicinity of the Hathaway and the Gold Blossom veins is coarse grained, and consists principally of grains of dark green hornblende, sometimes 4 or 5 millimeters in diameter, white feldspar, and a little quartz. Under the microscope the rock is usually found to be more decomposed than would be expected from its appearance. The feldspars, which are predominatingly plagioclastic, are filled with muscovite and a little calcite. The green hornblende is to great extent converted to aggregates of chlorite and epidote, and secondary quartz occurs abundantly through the sections.

AMPHIBOLITE.

The area to the east of the contact line is composed almost exclusively of amphibolitic schists. Only in a few places chloritic schists are found. Within this area the strike of the schists varies from N. 30° W. to N. 70° W., and may be said, in general, to follow the contact line as if the intrusion of massive granodiorite had curved the already formed schists and pushed them over toward the east. The dip of the schists is universally and uniformly to the east, at angles ranging from 75° to 85°. The degree of schistosity varies considerably. Crossing the Auburn ravine at the Stone House there is a belt of very schistose, almost slaty, amphibolites, which is excellently exposed in the bed of the ravine. This belt, several hundred feet wide, is bordered on both sides by a more massive rock, continuing up to Auburn on the east and down to the contact on the west. Along the bottom of Auburn ravine, which is about the only place where perfectly fresh rock is exposed, the amphibolite most frequently appears massive and is traversed by joint planes in several directions. Weathering, however, rapidly brings out the inherent schistosity, and the same rock on the summits of the hills has a decidedly schistose appearance. Some ledges of more massive rock occur, however, which, even on the slopes and hills, only give an evidence of schistosity by the elongated appearance of the outcrops.

The amphibolite is entirely of secondary origin; it is derived by dynamo-metamorphic processes from igneous rocks, such as diabases, perhaps also from diorites and gabbros. It is not intended to give in this place a complete demonstration of this derivation. Within the limited area described there are but few places where such a transition could be shown.

The amphibolite is a dark green, usually very fine grained, rock, in which may be noted, with a magnifying glass, small needles and grains of hornblende and minute grains of a whitish or greenish feldspathic mineral. Somewhat coarser varieties also occur, which very much resemble a fine grained diorite. In the more distinctly schistose varieties the planes of schistosity are covered with a smooth greenish chloritic mineral. Small aggregates and streaks of yellowish green epidote are often seen. Scattered grains of metallic sulphides, predominantly iron pyrites but also pyrrhotite and copper pyrites, are universally present.

A specimen from the Auburn railroad station gives a good idea of the process by which a massive igneous rock may be converted to an amphibolite. The rock (specimen 193, Placer) is dark grayish green, fine grained and massive, and, although considerably altered, gives more evidence than usual of having been a diabase. Small square and elongated cleavage faces of feldspar may be frequently seen. It may be mentioned in this place that it is not necessary that dynamo-metamorphosed rock should exhibit a schistose structure. Some radically amphibolitized diabases have preserved their massive structure, and on the other hand there are some in which, though distinctly schistose, the original augite and feldspar have been largely preserved. Under the microscope larger lath-like feldspars, often with ragged outlines, are interbedded in a fine grained mass, consisting of hornblende, chlorite, and feldspar. Some lath-shaped crystals of the latter also occur in the groundmass. The rock is seen to be subject to a "recrystallization," which has furnished the larger part of the apparent groundmass. The larger feldspars, which mostly show extremely marked undulous extinction, have, as indicated by their ragged and cataclastic outlines, been attacked vigorously by the recrystallizing process. The tendency is to form a micro-crystalline, interlocking aggregate of authigenetic quartz and feldspar, probably largely albite, in which are embedded acicular light green hornblende, together with chlorite and epidote. There is no trace of augite in this slide. The probability is, however, that the rock originally contained this mineral, but the first change involved was the transformation of this augite to an uralitic hornblende; then, followed by a blending of mechanical and chemical forces, the crushing and recrystallization of the primary soda-lime feldspars and the uralitic hornblende into the hornblende-quartz-albite-epidote aggregate of which the amphibolite consists. Grains of pyrrhotite and magnetite, in part intergrown, are common in the rock.

The amphibolite a few hundred feet east of the Stone House (specimen 192 Placer) in Auburn ravine, is a massive dark green and fine grained dioritic rock, containing numerous grains of pyrites. Under the microscope no structure characteristic of an igneous rock is visible, although from the appearance of the rock it might have been expected. Abundant light green fibrous hornblende, together with streaks of fine granular epidote, are embedded in a clear allotriomorphic mass of principally unstriated feldspar and a little quartz. The section shows a marked "stretched" appearance by the parallel arrangement of hornblende needles and epidote streaks.

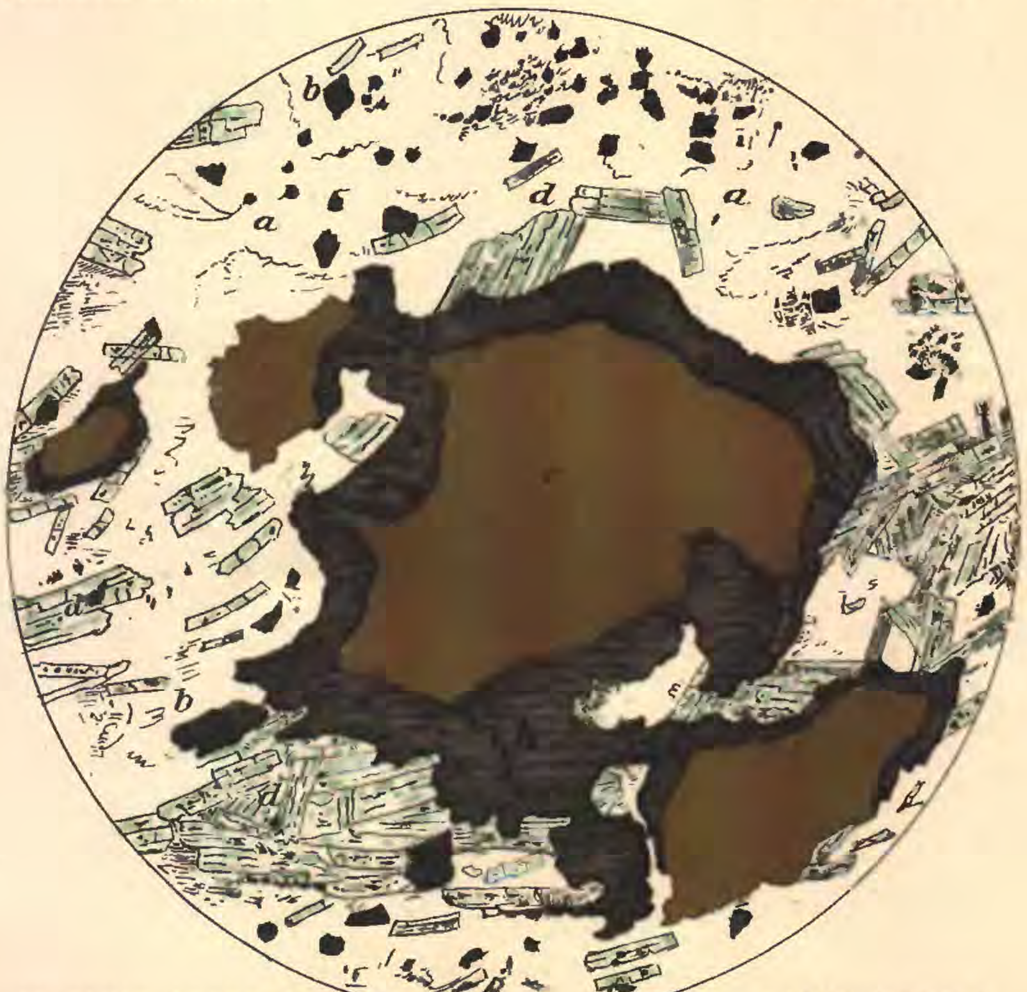
The amphibolite at the contact in Auburn ravine is a very fine grained, almost aphanitic, rock. Under the microscope abundant needles and prisms of a light green hornblende, all parallel to the plane of schistosity, but not arranged in any one direction, together with grains and crystals of magnetite, and probably also ilmenite, are embedded in a clear allotriomorphic groundmass mostly consisting of unstriated feldspar grains, and some quartz. A few of the feldspar grains, however, show a fine twin striation, such as is characteristic of albite.

The amphibolite from the Conrad tunnel is a fresh, dark greyish green, fine grained and very schistose rock. The planes of schistosity are undulating, but smooth and covered by glistening dark green chlorite. Much iron pyrite is present, which in cross section is seen to form aggregates and streaks usually parallel to the schistosity. On the planes of the latter movement has taken place and the pyrites have been squeezed out to bright reflecting and striated faces, veritable "slickensides." On fractures across the grain small streaks of quartzose character are noticed. This quartz is greyish or brownish and very different from the ordinary white vein quartz.

The microscopic section consists of two belts of hornblendic character separated by a streak of epidote. The former, or the amphibolite proper, consists as usual of grains, prisms, and needles of green hornblende, imbedded in a clear "groundmass." The green hornblende is of the usual character; pleochroism: 𝔠, bluish green; 𝔟, olive green; 𝔞, light yellowish brown. The prisms of hornblende are principally parallel to the plane of schistosity, but lie in all directions in that plane.

The ores are very abundant and consist principally of magnetic iron ore and iron pyrites. In the residue washed out in a pan all except a few grains of the black iron ore were attracted by the magnet; consequently but little ilmenite is present. From the considerable amount of $Ti\,O_2$ shown in the analysis it is probable that the magnetite is strongly titaniferous. All occur as imperfect crystals or irregular grains and are intergrown with the hornblende, epidote, feldspar and quartz in such a manner that they must have been formed simultaneously with these minerals. The magnetite often occurs in intimate intergrowth with the iron pyrites in such a way that the former surrounds the latter, as shown by Pl. XVIII, *a*, *b*. This certainly proves that the ores were formed simultaneously. The clear mass in which

a FELDSPAR AGGREGATE
b MAGNETIC IRON ORE
1
c IRON PYRITES
d HORNBLENDE



a FELDSPAR AGGREGATE
b MAGNETIC IRON ORE
2
c IRON PYRITES
d HORNBLENDE

AMPHIBOLITE CONRAD TUNNEL OPHIR.

the hornblende and the ores are embedded consists of a very interlocking aggregate of quartz grains. Together with the quartz there are also feldspar grains, usually with very fine twin striation, which most likely consist of albite. All the minerals in the slide show more or less strongly an undulous extinction, indicating the strong pressure to which the rock has been subjected. The central streak in the section consists of coarser aggregates of bright yellowish green epidote, together with coarser grained quartz. Of secondary products but little is seen; some chlorite occurs together with a few scales of white mica and small grains of carbonates. When the amphibolite is exposed to atmospheric agencies the pyrite and most of the feldspar and hornblende weathers out, leaving streaks of greenish grey quartzose rock traversed by rusty cellular streaks. A thin section of one of these showed a mosaic of quartz grains with undulous extinction, in which needles of hornblende and a great number of rutile crystals are intergrown.

Specimen 34 Ophir, collected near the veins in the Pinkeye claim, shows a more rarely occurring type, that of a chloritic schist. In appearance it is similar to the rock just described, but is a little darker and finer grained. The planes of schistosity are curved and wavy and coated with bright and smooth green chlorite. Under the microscope it is seen to consist of abundant chlorite in foils and irregular aggregates, together with magnetite, ilmenite, and some pyrites, all embedded in a mass of clear interlocking grains of quartz and non-striated feldspar.

The pyritiferous amphibolite from the Conrad tunnel (Specimen 48 Ophir) was analyzed by Dr. W. F. Hillebrand, with the following result:

SiO_2	45.56	MgO	6.76
TiO_2	1.11	K_2O	1.18
Al_2O_3	14.15	Na_2O	1.57
Fe_2O_3	1.20	Li_2O	trace.
FeO	9.83	H_2O (below 110° C.)	.23
FeS_2	7.86	H_2O (above 110° C.)	4.84
Cu_2S	.10	P_2O_5	.14
Ni, Zn	traces.	SO_3	.03
MnO	.25	CO_2	3.04
CaO	2.30		
SrO	trace?		100.15
BaO	trace.		

The FeO and Fe_2O_3 percentages as given are probably only approximate, owing to the impossibility of an exact determination of FeO in the presence of sulphides. The CaO, FeO, and MgO are to some extent present as carbonates, the MnO probably entirely as such. In addition, the rock contains minute quantities of gold and silver (see p. 262).

THE CONTACT.

The intrusive character of the granodiorite is well shown in the bed of Auburn ravine where it crosses the contact. Dikes of that rock are there seen penetrating the amphibolite, fragments of which are torn away and included in the granodiorite. At many other places near the contact fragments of amphibolite are seen inclosed in the granodiorite and fractured by it. In the vicinity of the Hathaway mine and also on Crater hill the patches of dark amphibolite in the granodiorite are very numerous and sometimes many feet in diameter. It can hardly be proved, however, that all of these are fragments torn away from the amphibolite; on the contrary, it is very probable that most of them are earlier and more basic segregations in the fluid or semi-fluid magma such as are known to have taken place often near the contacts. It has already been mentioned that such basic rocks occur on the Quinn claim and in the dike of diorite projecting into the amphibolite on the Bullion claim.

In further evidence of the intrusive character of the granodiorite may be cited the granitic dike cutting the Carboniferous slates along the railroad about a thousand feet south of the Auburn station. The long amphibolite wedge shown in the sketch in the northeast corner of the map is also shattered and injected by granitic magma to a remarkable extent. This is well exposed in the bed of Auburn ravine.

The long slab or wedge of amphibolite projecting on the ridge to the north of the Doig shaft shows some features of interest. Where the narrow neck crosses the road from Crater House to Pellows the amphibolite is dark, fine grained, and distinctly schistose, but about the Humbug and Spanish claims no continuous schistose structure can be made out. The rock is in part massive, in part schistose, and of rapidly varying grain. A specimen from the Humbug dump appears as a medium-grained hornblende schist containing a small patch of coarse hornblende crystals; epidote and pyrites are present in abundance. At the extreme southern end, at the Saint Patrick and Doig shafts, the rock is a diorite of rapidly changing grain and in places running over into fine grained amphibolites. Fissures along which chlorite and pyritic slickensides have been formed traverse the specimens.

THE DIKE ROCKS.

The most recent part of the bed-rock series is formed by a series of basic dikes cutting both the granodiorite and the amphibolite. In the granodiorite these dikes, which seldom are over 1 or 2 feet thick, usually form the hanging wall of the quartz veins, as at the Hathaway, New Era, Brushfence, Saint Lawrence, and Gold Blossom. The pressure has sometimes, as for instance at the Hathaway and the Gold Blossom, rendered them schistose, and the possibility was considered that they might be slabs of amphibolite torn away from the adjoining mass, or dynamometamorphic forms of granodiorite. The rock was soon, however, found in a fresher form, and this proved to be such a characteristic dike rock that all doubts were set at rest. As will be shown later, the pressure at some parts of the vein systems was intense and resulted in the converting of the dike rocks into amphibolitic schists not to be distinguished from those of the main area. Similar dike rocks were soon afterwards found in the amphibolite area cutting in comparatively fresh condition the thoroughly altered amphibolitic schists. Such rocks were found at the tunnel on the Flat ledge on Duncan hill, and on the dump of the California and Bellvue veins.

There are two types of this dike rock. One from the Saint Lawrence and the California mines is dark-green granular and coarse grained, being largely composed of green hornblende, between the grains of which lie striated and unstriated feldspar grains. It contains also much rutile, and it appears as if the hornblende had originally been of the brown variety, but had been altered to green uralitic amphibolite. The amphibole is not uralitized pyroxene, and the rock might be regarded as a basic diorite.

The other and more common type is markedly porphyritic by slender phenocrysts of a dark green hornblende, sometimes 4 or 5 millimeters long, imbedded in a grayish green groundmass of fine grain. Sometimes smaller porphyritic crystals of feldspar may be distinguished. Pyrites is frequently sprinkled through the rock. Under the microscope the large, often twinned, hornblende crystals have greenish colors, which in the interior of the crystals sometimes change to pale brown, conveying the impression that an originally brown hornblende has been altered to a greenish more or less uralitic modification. Some of the crystals are filled with sagenitic needle webs, probably representing the TiO_2 set free in the decomposition of the titaniferous brown mineral. The groundmass is composed principally of idiomorphic and allotriomorphic feldspar crystals forming a holocrystalline aggregate. A great many of the feldspar grains are not striated. On those that are the twin lamellæ are mostly very fine and close, indicating oligoclase or albite. Some of the feldspars show distinctly zonal structure. Some apatite is always present. The pressure to which most of the dikes along the vein have been exposed has resulted in similar alterations by means of which the normal amphibolites were formed. New hornblende needles have been formed, as well as epidote and pyrites, and the feldspar of the original rock has acquired undulous extinction and breaks up in quartz-albite-epidote aggregates. An extreme effect of the pressure is to produce an almost schistose structure parallel to the plane of the vein.

These rocks forming dikes or smaller masses have been met with in many parts of the Sierra Nevada, and usually when fresh carry dark-brown hornblende phenocrysts. They are allied to Rosenbusch's "lamprophyric dike rocks," and more especially to the camptonites, An analysis made by Dr. W. F. Hillebrand of one of these dike rocks (specimen 15, Casey's tunnel, on the Flat ledge), gave:

SiO_2	60·09	MgO	4·37
TiO_2	·63	K_2O	·70
Al_2O_3	16·43	Na_2O	4·52
Fe_2O_3	2·28	H_2O*a*	·20
FeO	3·01	H_2O*b*	1·16
FeS_2	·34	P_2O_5	·12
MnO	·12	SO_3	trace
CaO	5·76	CO_2	·07
SrO	trace.		
BaO	trace.		99·80

a Below 110° C. *b* Above 110° C.

THE IRON BELTS.

While it is difficult to pick up a specimen of amphibolite in which no specks of iron pyrites can be found, still there are certain lines along which a more extensive impregnation has taken place. This impregnation of the schists with sulphides must be regarded as antedating the quartz veins and as about contemporaneous with the forming of the schist itself from primary basic intrusive rocks. These lines or belts of heavy impregnation have an important bearing on the ore bodies, and the miners, early recognizing this, called them "iron belts," which term has been adopted here as a convenient expression.

Though iron pyrites is the most common mineral in these impregnations, copper pyrites also occur, and sometimes, indeed, so abundantly as to be of some economic importance. Thus the iron belts on the Good Friday location were at one time worked for copper, and a few miles northwest of Ophir a similar belt occurs at Whisky Diggings, which at various times has been worked as a copper mine. On the surface the iron belts are traceable by the rusty brown color of the outcrops, due to the decomposing pyrites. They frequently follow one and the same plane of schistosity, but this is by no means universal, many crossing that plane at considerable angles. The iron and copper pyrites in the iron belts appear to contain both gold and silver. The amounts are of course small, but the metals have frequently been concentrated in the decomposed rusty surface rock, which in such cases may be, and has been, worked for gold, as for instance at Whisky Diggings and in the Good Friday iron belts. The silver seems always present in considerably larger quantities than the gold. From all the data at hand and from a careful inspection of the specimens assayed there is no doubt in my mind that the earlier impregnations of pyrite are auriferous. A complete proof of this is not easy to furnish, as it may be claimed that, however fresh looking the specimen, gold solutions might have infiltrated on some minute crack during the period of vein formation.

Three specimens of amphibolite with pyritous impregnation were kindly assayed for me by Mr. Catell Whitehead, assayer of the Mint bureau in Washington. The first a somewhat decomposed amphibolite from the Good Friday mine, with about 30 per cent sulphides, gave 0·3 ounces Au. and 3·3 ounces Ag. to the ton, an unusually high amount. The second and third were a fresh amphibolite with slickensides of pyrites from the Conrad mine. The assays gave respectively 0·050 ounces Au. and 0·182 ounces Ag., 0·010 ounces Au. and 0·240 ounces Ag. The microscopic examination of these specimens shows that the pyrites were formed contemporaneously with the epidote, hornblende, feldspar, and quartz of the amphibolite, and also that the forming of magnetic and titanic iron ores and sulphides went on at the same time, the former often enveloping the latter. This is illustrated in Pl. XVII, *a*, *b*. The source from which these ores were derived is of course not positively known, but it is most probable that they simply represent concentrations during the progress of dynamo-metamorphic action from the primary diabase. Why the ores were concentrated just along these lines is a question which it is not easy to answer; they may represent old lines of disturbance, but, if so, there is nothing to prove it at present.

It need scarcely be stated that the iron belts are very difficult to map and plat; they can only be indicated in a general way. The impregnation is not uniform, and heavily impregnated sheets alternate with others containing but little pyrite. The surface rock is often so decomposed that it is difficult to tell whether it was originally pyritous or not. The most important zones of impregnation have been indicated in a rough way on the map only to give an idea of their location and extent.

It is in their connection with the quartz veins that the iron belts are of most importance. It seems to be a fact that all the richest ore bodies in the quartz veins of the amphibolite area have been found where the latter cross the iron belts. Thus along the iron belts on Duncan hill the rich pockets of the Moore, the Conrad, and the Centennial were discovered. The iron belt of the Mina Rica contained the rich pockets of the last-mentioned mine, the extraordinary treasures extracted from the Green mine, alluded to in the introduction, and finally the rich shoots of the Good Friday mine. Similarly abundant pyritous impregnation is found along the amphibolite wedge from the Doig to the Spanish mine, a line along which the quartz mines contained many rich ore bodies. The schists impregnated with pyrite usually dip at 70° to 80° eastward; the ledges usually dip southward at angles from 45° up; consequently the line of intersection between these planes dips eastward at varying angles. According to the concurrent testimony of those who have been connected with the mines it is an almost invariable rule that the pay-shoots, which are narrow and rich, follow this line of intersection between the iron belts and the quartz veins. In other words, the quartz veins, more or less auriferous along their whole extent, are usually exceptionally rich where the vein traverses the iron belts. That in this case the gold in the rich chimneys is principally derived from the auriferous, earlier, impregnations in the amphibolite, seems certain.

The impregnations appear to have antedated the intrusion of granite. In one case at least the iron belt runs up towards the granite contact and stops there. Near the contact pyrite is sometimes sprinkled in the granodiorite, but as a rule it contains no noteworthy amount of this mineral. While thus the iron belts may explain the rich pockets in the amphibolite area, they do not explain the occurrence of the large ore bodies in the granodiorite.

It is perfectly evident that the iron belts described above are identical with the "fahlband" first noticed at Kongsberg, Norway, and subsequently described from many parts of Europe,[1] and consisting of sulphides in fine distribution through gneiss and other schists. Like those described here they universally have the characteristic of enriching the mineral veins passing through them. V. Groddeck seems to regard all the rocks in which they occur as Archean, and favors a genesis by separation and deposition in superheated oceans. It has already been explained that no such theory can be held in this case, but that they must be regarded as the products of dynamic and hydrochemical metamorphism, and that the age of these impregnations must be post-Carboniferous, and probably Mesozoic.

THE VEIN SYSTEMS.

GENERAL DESCRIPTION.

The directions of the two predominant vein systems have already been given. It should be added that there are also a few veins with a general north-south direction and steep dip; the latter appear to correspond to the Belmont system mentioned above. The veins striking west-northwest are the most important from an economic standpoint; those striking east-northeast are less so, and the north-south veins have yielded but very little.

THE SOUTHERN VEIN SYSTEMS.

Beginning at the eastern end of the district and referring to the map, the first important vein met with is the California, cutting obliquely across the schists with a dip of about 40° south. Some of the amphibolite is considerably impregnated with iron pyrites. The developments are not extensive, although the surface has been worked all along the eastern end of the claim. The vein is not rich in sulphurets. This vein is continuous as far east as the railroad and a few hundred feet at least beyond that. Its width varies from 1 to 2 feet.

About 400 feet to the south of the California lies the Pine Tree ledge; it is claimed that this is the continuation of a branch of the former, but such does not appear to be the case. The ledge is continu-

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[1] V. Groddeck, Die Lagerstätten der Erze, p. 107.

ous at least as far as the Newcastle road. Its width is from 1½ feet down to a few inches. Two small shafts have been sunk at its western end and one near the granite contact; in the latter a rich ore body pitching eastward was struck in 1892 with abundant tetrahedrite and gold (carrying more or less silver). The Brushfence vein, 4 to 6 miles wide, lies somewhat to the south of the continuation of the Pine Tree; its hanging wall consists of dark-green amphibolite dipping southward at the same angle as the vein; this rock, which should apparently be regarded as a dike, has been specially described.

The Erie vein, on which a small shaft has been sunk, has a similar dike in the hanging wall. Between this vein and the Kirkland several barren and strong north-south veins are found which appear to cut off the other veins.

The vein on which the Hathaway and Kirkland mines are located is of unusual strength and continuity. It has a uniform dip of 60° to 75°, and a rather uniform thickness of 1½ to 2 feet. The developments at the eastern end are not extensive nor have any important ore bodies been found. The Kirkland shaft is sunk to a depth of 200 feet, but has been idle for a long time. The most important place is the Hathaway mine, which has been opened up by means of tunnel and shaft to a considerable extent. The ore shoot is very long, stated to be 1,200 feet, and is said to dip eastward at an angle of 60°. The quartz contains about 2 per cent of galena and pyrites, which, concentrated, are said to assay $230 per ton.[1]

There are no rich pockets or narrow shoots—in contrast to many of the mines in the amphibolite—but the ore bodies are extensive, though of low grade. The ore contains an unusually large amount of silver, much of which is undoubtedly lost in milling, and the bullion is sometimes only 500 fine. West of the Hathaway the vein is continuous, but has not been worked to any extent. I did not succeed in tracing it any farther than down to Auburn ravine.

Persistently, though not uninterruptedly, following the Hathaway ledge there is usually in the hanging wall a sheet of amphibolite, similar to those already mentioned from the New Era and Brushfence mines, which probably should be regarded as a dike. At the Hathaway mine it becomes schistose, parallel to the vein, and is properly designated as an amphibolite-schist. In the tunnel to the west of the Hathaway mill it incloses the 16-inch vein on both sides as a casing 5 or 6 inches wide, but was not noted farther west than this.

Unfortunately, the Hathaway mine being shut down in 1892, I could not gain access to the underground works. It is stated that some relation appears to exist between the pay-shoot and this accompanying dike converted into massive or schistose amphibolite. The peculiar ribboned character of the Hathaway quartz and the evidences of motion along the vein will be mentioned farther on.

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[1] Tenth Annual Report of California State Mineralogist, p. 431.

DUNCAN HILL.

Along the eastern edge of the map near Auburn ravine the less important veins of Oro Fino and Floyd are noted; many of the apparent curves in the former one are due to the flat dips and rapid changes in elevation, but if projected on a horizontal plane a notable curve in the vein will still be found. The Moore vein is approximately in continuation of the latter and continues to the granodiorite contact; a very rich pocket of $20,000 or $30,000 was found on this vein in 1889–'90.

Duncan hill, between Auburn and North ravine, is intersected by a perfect network of veins, in a great number of which some superficial work has been done. Most prominent are the three parallel veins, the Centennial, Conrad, and Hope; in the first of these a 900-foot tunnel has been driven and the vein explored between this level and the top of the hill; in the second there is a 500-foot tunnel, above which considerable work has been done. From the Centennial and the Conrad many rich pockets have been extracted along the line of the iron belt crossing them. The quartz between the pay-shoots is auriferous, but hardly enough so for profitable working. The pay-shoots are very rich in free gold, but usually of no great extent either laterally or in depth. Projected on a horizontal plane the veins are somewhat less curved than the irregular surface makes them appear on the map; the width ranges from a few inches to 2 feet, and the dip in the central and eastern parts is about 45°, but grows steeper westward. Cutting across this vein system are two flat ledges, their dip ranging from 20° to 30° southeasterly; although some rich bunches have been found on them they do not compare in richness with those above described. While the thickness usually ranges from 1 to 2 feet the easterly one of the two flat ledges swells up to a heavy outcrop of several feet at its northern end.

On the northern side of Duncan hill the long Bullion vein system begins at the Booth mine; this vein, about 16 inches thick, has been prospected considerably along the outcrop and several rich pockets found. The quartz frequently contains galena, rich in silver. In the continuation of the Booth lies the Crandall from 6 inches to 2 feet wide, and adjoined to the south by several other less important veins apparently radiating from a center near the Booth mine: all dip south at about 45°.

The developments on these veins are not extensive and they have distinctly the character of pocket veins. The Crandall can be traced to the top of the hill to the west of North ravine; from there a break occurs until the eastern end of the Bullion No. 2 claim is reached, but there seems to be but little doubt that the Bullion veins represent the continuation of the same system.

SOUTHWEST VEINS.

Cutting across the veins of Duncan hill there appears, on the western side of North ravine, an extensive system of northeast-southwest veins, beginning on the north with Mina Rica. This vein is continuous for about 1,000 feet, from 1 to 2 feet wide, and has contained several rich but narrow chimneys. At the contact just west of North ravine, and cutting across it at a small angle, there is a very flat ledge several feet thick. It is said to contain scattered bunches of gold. The direction of this vein is nearly east and west, and at the western end is replaced by other veins bending about in more southwesterly direction. The Rocky Ridge claim, in granodiorite, contains a system of parallel narrow veins dipping southeast at about 45°. Near the surface these veins contained several rich spots, but the developments along them are confined to a few smaller shafts. West of the Rocky ridge lies a flat vein of very white crystalline quartz, sometimes several feet wide. No work has been done on it, and it is said that it is nearly barren. The apparent curves in this vein would be somewhat lessened by a projection on a horizontal plane.

Adjoining this there is the complicated Eclipse vein system, consisting near the mill of seven or eight fissures, dipping southeast at about 45°, containing quartz bodies up to 3 feet wide. The Eclipse has produced some good milling ore, and is developed by a 300-foot shaft, but in the last few years no work has been done on the claim. To the same system belongs the Good Easter, near the southeastern line of the Eclipse claim. At the shaft indicated, which is 300 feet deep, a rich ore body was found at the junction of the Good Easter with the Morning Star. The latter, which is a flat ledge, similar to the one described above, contains some good milling ore. The hill just to the east of the Morning Star is completely shattered by fissures, containing little or no quartz and dipping 40° or 50° southward.

West of the Eclipse, and about 800 feet apart, there are two very heavy and persistent ledges with a west-southwest direction and southerly dip ranging from 30° to 60°. The first of these is the Belvoir or Bowlder vein, which has been worked to some extent in its northerly part, where it is well exposed on the northwesterly side of Hugh's ravine.[1] It can be traced only to about 600 feet from the contact line, where it apparently splits up into several minor veins. Where the dotted line appears it can not be traced with certainty, but the occurrence of a vein in exact continuation of the Belvoir ledge on the long ridge running down from Crater hill makes it probable that the fissure is continuous, though containing no quartz, for some distance.

The Doig has an almost parallel course with the Belvoir, the curve in both being largely due to the flat dip and uneven surface. It has proved remunerative for working at its northeasterly end only, where, at the junction of the main vein dipping about southeast with a small nearly vertical seam, the Little Doig, a big pocket was found. Close to the Doig shaft lies the Saint Patrick vein, which crops out for about

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[1] In 1893 a mill was erected on this property and a large body of low-grade ore was developed. Rich bunches with much tetrahedrite occasionally occur.

500 feet, with a width of from 2 to 10 feet, and a southwesterly dip of 45°. Both the Doig and the Saint Patrick here cross the extreme end of a wedge of massive amphibolite. The rock exposed on the dump shows an intimate mixture of amphibolite and diorite, the latter rock penetrating and brecciating the former in all directions. This amphibolite and diorite is heavily impregnated with pyrites. On the Saint Patrick a shaft 300 feet deep has been sunk, but the property has been idle since 1874. The superintendent, Mr. J. H. Crossman, states that the pay-shoot is 60 feet long and pitches 13° easterly in the plane of the vein. Work was discontinued because to find the pay-shoot, which the shaft passed through on the 200-foot level, would necessitate either a new shaft 350 feet deep 800 feet northeast of the present one, or an 800-foot-long tunnel from the 300-foot level of the old shaft, both of which alternatives seemed too expensive. The ore is stated to have averaged $41.50 per ton, with 2½ per cent of sulphurets.[1]

In the same wedge of amphibolite with pyritous impregnation lies, to the northwest, the Humbug and Spanish veins, together with several others. Some pockets have been taken out of the Humbug Consolidated, while the Spanish vein in 1874 yielded about 900 tons of milling ore averaging $8.37 per ton.[2]

THE GREEN AND BULLION SYSTEMS.

To the north of the veins between the Rocky ridge and the Spanish, which are principally of the second or west-southwest system, there is a broad belt along the contact and in the amphibolite in which the veins of the first or west-northwest system predominate. There are two principal veins, nearly parallel and almost if not quite continuous. The northerly one, or the Bullion, is probably the continuation of the Crandall mentioned above. The developments are slight until the western end of the vein is reached. North of the Bullion No. 2 lies the complicated vein system of the Lizard, on which but little work has been done. The Bullion shaft is sunk on the contact of amphibolite and a diorite dike, 100 feet deep, and is said to expose some amount of good milling ore. To the westward of the Bullion lie the eight parallel veins of the California, Bellevue and Elizabeth claims. Like the Bullion, they are rather narrow veins, ranging from 6 to 30 inches, dipping at high angles to the south, and thus cutting both dip and strike of the amphibolite at acute angles.

The California veins have been developed to a depth of 150 feet by shafts and tunnels. Considerable milling ore, averaging $30 per ton, has been extracted and the sulphuret contained is said to be very rich.

The ridge between the two veins on the Golden Rule claim is extensively fissured by a series of short veins from 6 to 12 inches wide and dipping south at steep angles. The developments consist only in a few small shafts and surface cuts.

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[1] Raymond's Report, 1874, p. 94.

[2] Loc. cit.

The southerly of the two veins mentioned above is the Green vein. Beginning at the southerly end of Mina Rica it continues with one interruption through the Green, the Green-Walters, and the Quinn claims. Toward the west it bends to a direction almost parallel with that of the Crater hill veins. The thickness ranges from 6 inches to 3 feet, and the dip is uniformly to the south at angles from 45° to 70°. The principal developments are found where the vein crosses the Mina Rica iron belt. The Green shaft, 240 feet deep, exposed some extraordinarily rich ore bodies in 1870–1873, much of which is said to have milled $100 per ton. The Good Friday shaft is probably sunk on a branch vein of the Green and has also yielded some rich milling ore. Two narrow north-south veins, on which but little work has been done, cross the Green and Good Friday claims. On the intersection of the Cornucopia and the Good Friday a rich ore body was found.

The Almatah shaft was sunk 115 feet deep in 1863 on a cropping of copper-bearing amphibolite; in sinking a rich but narrow stringer of quartz was encountered.

THE CRATER HILL VEINS.

Crater hill west of the road leading by Crater House is to a remarkable degree shattered by fissures, among which those belonging to the first system predominate. This fissuring is so extensive that every fragment of granodiorite picked up is likely to be bordered by one or more faces polished and covered with chlorite. The Peachy vein appears to mark the beginning of the Crater hill east-west system, but it can not be actually traced across the road. The Crater ledge, on which the shaft house is located, is the only one which has been extensively worked and which contains one of the largest and richest pay-shoots in the district. There are so many veins on the surface that the Crater ledge can not be traced with certainty to the eastward, but it is probably the same which runs in under the Crater House. In the Crater ledge proper, or the "hanging wall ledge," which is about 1 foot wide and dips south at about 45°, the pay-shoot is said to have been △-shaped; near the surface it was 40 feet long, on the 50-foot level 80 feet, on the 150-foot level 117 feet, on the 212-foot level 203 feet long, and pitching eastward; the shaft is 800 feet deep, and on that level a new pay-shoot was found to the west of the shaft. When the mine shut down, in 1884, the pay-shoots above the 800-foot level had been worked out; there is little doubt that they continue down deeper.

In the "foot wall ledge," which is 32 feet northward of the principal ledge, a smaller and less rich pay-shoot has been found. According to Mr. J. H. Crossman[1] the Crater hill vein averaged $42 per ton and contained 3 per cent sulphurets. A system of parallel veins extends

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[1] Raymond's Reports, 1874, p. 98.

about 1 mile to the westward of Crater hill. The thickness of the veins ranges from 1 inch or less up to 1 foot; the veins are exposed in many places by means of small shafts or prospect holes, but on the whole the developments are very slight. There are no dikes of dark amphibolitic rocks connected with the Crater hill vein system, although dark hornblendic patches are sometimes met with in the granodiorite which probably should be regarded as early secretions in the granitic magma.

THE GOLD BLOSSOM.

This is a very strong vein, continuous for about 1½ miles and dipping south at angles varying from 70° to 85°; it is first seen on the hill to the northwest of Empire House, where it at once appears as a heavy 2 to 3 foot vein of white quartz. From here to a few hundred feet west of the limits of the map it is practically traceable all the way, but toward the west becomes somewhat less heavy. It has been opened up extensively at two or three places, but prospect holes and small shafts are found all along the outcrops. Probably the whole extent of the vein is auriferous to a considerable degree, but there are some difficulties, to be referred to later, in the working of the ore. At the western end of the Gold Blossom claim it is opened by a tunnel, from which considerable ore has been extracted. The principal developments are found on the westerly Gold Blossom claim, where an adjacent branch, the Marion, has also been worked. The Gold Blossom shaft is here sunk to a depth of 218 feet, and a considerable amount of ore is stoped out on both veins. At this place the Gold Blossom has in the hanging wall a dike of dark diorite, and the Marion, in a corresponding position, a dike of amphibolitic, somewhat schistose, rock. The veins are about 2 feet thick and the width of the pay-shoots is not determined; probably they are very extensive. At the Gold Blossom tunnel there is also some altered amphibolite exposed among the material on the dump. The sulphurets are abundant and consist of pyrite, galena, copper pyrites, tetrahedride and zincblende. The percentage of sulphurets is said to vary between 1½ and 3 per cent. The ore is low grade and contains much silver; an assay of good ore gave 0·5 ounces Au. and 2·15 ounces Ag., or about $12 to the ton. Mr. J. H. Crossman states[1] that the Gold Blossom ore averages $7.50 per ton. A specimen taken from the main ledge at a prospect hole 200 feet west of the road on the Ohio claim, consisting of white quartz with comb structure and containing a few specks of pyrites, gave 0·225 ounce Au. and 2·125 ounces Ag., or about $6 to the ton. Large parts on the eastern end of the vein are also said, on reliable authority, to assay $7 to $8 per ton. The concentrated sulphurets assay from $70 up.

Towards the western end some shafts have been sunk on the Pacific claim, where the quartz is said to contain an unusually large amount of silver.

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[1] Loc. cit.

THE SAINT LAWRENCE.

This vein is first noticed across the ravine from the Empire House and continues, with an easterly direction, to the summit of the hill, where it turns and runs southwest for about 1,200 feet. These two parts are really veins belonging to different systems; still the quartz filling is said to be continuous and the junction in the nature of a bend. In the hanging wall lies a narrow dike of dark granular diorite, largely composed of hornblende crystals. The vein is from 1 to 1½ feet thick and dips to the south at 45°, and in the tunnel sometimes only at 20° to 30°. The tunnel is run on a stringer in the hanging wall for some distance from the mouth. The ore is rather low grade, but the shoot extensive; it contains sulphurets in quantity similar to that of the Gold Blossom; Mr. J. H. Crossman states that the average assay value of the ore is $7.50. The mine is worked by a tunnel 250 feet long, connecting the surface by means of an inclined shaft.

MINERALOGY.

Quartz.—The minerals occurring in the Ophir veins are not many, nor are the ores often found in a crystallized form. The gangue consists, as stated, nearly entirely of quartz. Vugs and cavities are common in the vein, and their inside is often coated with brilliant and transparent crystals of the usual form. The mass of the quartz is of a milky white color. A comb structure caused by quartz crystals growing simultaneously from both walls is not uncommon. In some veins chalcedony occurs. Beautiful specimens were found at the Spanish mine, in which the mineral has been deposited on the previously formed quartz crystals.

Calcite occurs sometimes in massive form. It was especially noted from the Conrad mine, but occurs in smaller quantities in most of the veins.

Native gold, always alloyed with silver, is the principal valuable mineral in the Ophir ores. It should be remarked at this place that there is an unusually large proportion of silver in the Ophir gold. While the average fineness of the gold from California quartz mines is about 850, the Ophir bullion seldom exceeds 700 in fineness and sometimes goes as low as 500 or 600. Even bullion worth as little as $9 per ounce is reported to have been obtained by simple amalgamation from some mines in the western part of the district, such as the Hathaway and the Pacific. This would correspond to a fineness of about 425. In many of the veins in the amphibolite, however, specimens of gold 800 or 900 fine may be met with, and some of them have produced even larger quantities of such bullion.

Electrum.—Most of the native gold occurring in these mines should more correctly be referred to as electrum. It has a pale yellow color and frequently is noted in coarser form, visible to the naked eye; usually, however, its distribution is so fine that no particle of it can be discovered in the quartz. It often occurs intergrown with the sulphides mentioned in such a manner that although present in considerable quantities it is difficult to detect its presence even with the magnifying glass—a fact probably due to its forming thin coatings on the surface of the sulphides. A specimen of electrum from the Moore mine gave Dr. W. F. Hillebrand 27·91 per cent Ag. and 72·09 per cent Au.

Native silver has been found at the Gold Blossom and the California (east of Crater House).

Horn silver, and perhaps also other rich silver minerals, probably derived from highly argentiferous galena, have been met with at the places mentioned, and many others, as for instance at the Duncan ledge on Duncan hill, where, Mr. Tharp informs me, he obtained 2 tons of ore assaying $900 in silver. This mass was found as a separate shoot 60 feet down from the surface. Immediately below this streak was found a small chimney of unusually yellow gold. A similar mass of rich silver ore was found at the surface in the Mina Rica veins.

Native copper is said to have occurred in the Gold Blossom shaft.

SULPHURETS.

Metallic sulphides and arsenides occur scattered through the veins but are usually more concentrated along the pay-shoots. Their abundant presence is considered as an indication of the richness of the ore., In the ore extracted for milling purposes the percentage of these minerals, collectively called *sulphurets*, varies from 1½ to 3 per cent. They always contain gold and silver in varying proportions, the latter usually considerably preponderating by weight if not in value.

Three tons of concentrates consisting of different sulphurets mixed from the Gold Blossom are quoted in the Tenth Annual Report of the State Mineralogist, page 443, as containing 64 ounces of silver, and 12·76 ounces of gold. Another lot of 8 tons contained 57 ounces of silver and 0·9 of an ounce of gold, thus showing considerable variation. The concentrates sometimes reach a value of $1,000 per ton. In general the silver is connected with the tetrahedrite, galena and zincblende, while the gold is contained in the pyrites.

Iron pyrites is most abundant and may be said to occur with all the veins, both in the gangue and in the adjoining country rock. Very frequently it is more abundant in the latter than in the vein proper. It is often found in crystals of cubes or combined cube and pentagonal dodecahedron forms.

Copper pyrites occurs in most of the veins, being most frequently found where the veins traverse the *iron belts*. It has already been mentioned that these streaks of ore-impregnated amphibolite also contain this mineral together with iron pyrites.

Galena, always argentiferous, is equally common. It occurs abundantly at the Booth mine, the Gold Blossom, and many others. At the Gold Blossom it sometimes is found in small vugs in the quartz, as small crystals of usual form.

Zincblende, of brownish or yellowish green color, is universally present in the pay-shoot. A yellowish transparent variety was noted from the Moore mines.

Arsenical pyrites is equally common.

Tetrahedrite, or antimonial fahlerz, rich in silver, has been noted from several places, and appears to occur only in rich pay-shoots. It is a dark steel-gray massive mineral, intimately intergrown with other sulphurets, and often also with electrum; the streak is dark brown. I have noticed it from the Boulder, the Gold Blossom, the Pine Tree, and the Golden Stag (Monahan) veins. All these are in granodiorite.

Molybdenite was found rather abundantly in the Golden Stag or Monahan veins, in a pay-shoot about 50 feet below the surface.

Stibnite, tellurides and selenides are mentioned in the mint reports for 1883 as occurring in the district. I have not been able to find any specimens or reliable statements indicating their occurrence.

All of the sulphurets mentioned occur in intimate intergrowth and were formed nearly contemporaneously.

THE GANGUE.

The quartz forms practically the only gangue material. When in normal, fresh condition, and not having suffered any changes from chemical or dynamical forces, it is milky white or transparent when occurring as small crystals. It has a glassy, often somewhat greasy, luster, and is composed of relatively large individuals, not intergrown to any extent, but forming a coarse mosaic. Some grains show crystallographic outlines. Gas and fluid inclusions of mostly irregular outlines fill the grains, and, while sometimes wholly irregularly arranged, usually show a banded or parallel appearance, the bands often continuing across different grains. Calcite sometimes occurs in smaller grains, but is entirely accessory in character. On the Conrad vein and a few others it appears in larger quantities, though still very subordinate to the main quartzose gangue. On the surface, of course, the quartz is often reddish or brownish from decomposed pyrites. The structure of the veins is in most cases distinctly ribboned. It should be observed, however, that the ribbon structure may be primary, due to the deposition; or secondary, due to movements along the vein, by which it has been divided into sheets. The first-named structure is very common and exhibited beautifully, for instance, along the heavy Gold Blossom vein on which the growth of the layers beginning from the walls and extending inward is apparent from the comb structure of the quartz crystals. The clean, white quartz frequently also contains cavities beautifully lined with quartz crystals. The structure of the majority of the Ophir veins is such that one can not doubt but that they simply represent once open fissures filled with gradually depositing material.

In thin sections of the quartz which has not been subjected to strong pressure subsequent to its deposition the individuals between crossed nicols extinguish uniformly and normally; very frequently, though, the strong pressure which had formed the fissures continued or recurred after the deposition of the quartz, and the gangue subject to such pressure became optically deformed, broken, crushed, and comminuted. The ore from the Gold Blossom shaft shows in a marked way these phenomena in their milder form. The large quartz grains can still be discerned, but each one either shows strong undulous extinction or is broken up in many grains with somewhat different optical orientation. In some parts of the slide the quartz is even crushed and comminuted, and a ragged and crushed fringe usually marks the lines between the grains. The galena, pyrites, and zincblende have also been pressed and squeezed in between the quartz grains. Particularly in such pressed quartz the irregularly shaped fluid inclusions become extremely abundant. Moving bubbles are sometimes seen, which did not disappear by heating to about 50° C.

THE ALTERED WALL ROCK.

The rock contiguous to the quartz veins, whether amphibolite or granodiorite, has usually been subject to a more or less intense alteration. This altered wall rock, to which the miners incorrectly give the term "gouge," is from a few inches to a few feet wide. Only rarely does the unaltered wall rock lie up against the vein.

The process and the final products of this alteration are similar in both rocks, and it may in general be characterized as a conversion into an aggregate composed of white mica, carbonates, and pyrites, effervescing with cold hydrochloric acid. The amphibolite is changed into a grayish or white, fine grained rock with somewhat greasy luster and feeling on the cleavage planes. It is usually filled with small cubes of pyrite. This mineral occurs much more abundantly in the altered wall rock than in the veins. The microscopical appearance is that of a sometimes coarse but on the whole extremely fine and felted aggregate of wavy or straight fibers of sericitic muscovite and grains of a carbonate, predominatingly pure calcite. Large, sharp crystals of pyrite are imbedded in this aggregate. Of other minerals there is a small amount of a colorless substance of undulous extinction and low interference colors, probably a variety of chlorite; further, white opaque grains which almost certainly are titanite altered from the titanic iron ore in the amphibolite. All traces of the original minerals have disappeared. This mass is sometimes traversed by small veins of quartz which contain rhombohedrons of calcite.

The granodiorite altered in the same manner becomes a grayish green rock of slightly greasy luster and feeling. In the less profoundly changed rock the hornblende crystals are still visible as dark patches; but with increasing alteration a more uniform medium grained product is the result. Pyrite is as usual very abundant, and foils of a green chlorite may sometimes be seen. This chlorite is distinctly biaxial with an optical angle of about 20°. In thin section the granitic structure is usually still apparent. The former hornblende is indicated by foils of chlorite and an opaque grayish brown mineral, most probably titanite. Some quartz grains showing undulous structure still remain, and the outlines of some feldspar grains are still visible, but practically the whole mass is altered to an aggregate of calcite and white mica, in which the calcite often forms triangular or polygonal masses bordered by the straight mica foils. The remaining quartz grains show a corrosion by the secondary mica calcite aggregate, long foils of muscovite reaching into the quartz grains at some places. Crystals of apatite remain fresh. Some distinct leucoxene, inclosing unaltered grains of titanic iron ore, are also noticed. In some specimens secondary aggregates of quartz also occur.

The altered wall rock, in places at least, contains gold and silver. A sample from the Mina Rica gave 0·125 ounces Au. and 0·250 ounces Ag., or about $2.75 to the ton. The decomposed diorite from near the Gold Blossom vein northwest of the tunnel gave trace of Au. and 0·050 ounces Ag. to the ton. The altered amphibolite from the Gold Blossom tunnel gave 0·012 Au. and 0·098 ounces Ag. to the ton. Wall rock from the Gold Blossom shaft adjoining quartz, which assayed 0·5 ounces Au. and 2·15 ounces Ag., or $12 to the ton, gave trace of Au. and 0·20 ounces Ag. In all cases the altered rock was free from vein quartz.

In order to obtain a better insight into the changes which have taken place in the wall rock typical samples were selected and analyzed.

I. Typical altered wall rock from the Mina Rica vein; from the amphibolite area.

II. Typical altered wall rock from the Plantz vein; from the granodiorite area. For comparison the compositions of fresher rocks are given.

III. Fresh granodiorite from Lincoln (cited above, p. 255).

IV. Amphibolite from the Conrad claim; partly altered.

	I.	II.	III.	IV.
SiO_2	37·01	46·13	65·54	45·56
TiO_2	·85	67	·39	1·11
Al_2O_3	12 99	15·82	16·52	14·15
Fe_2O_3	·43	·89	1·40	1·20
FeO	3·57	2·27	2·49	9 83
FeS_2	7·99	1·61	....	7·86
Cu_2S	(?)	(?)	....	·10
NiZn	traces.	traces.	....	traces.
MnO	·24	·09	·06	·25
CaO	9·78	10·68	4·88	2·30
SrO	traces.	traces.	....	traces!
BaO	traces.	traces.	....	traces?
MgO	5·49	2·13	2 52	6 76
K_2O	4·02	5·30	1 95	1 18
Na_2O	·13	·17	4·09	1·57
Li_2O	traces.	traces.	....	traces.
H_2O (below 110° C.)	·13	·12	....	·23
H_2O (above 110° C.)	1 92	2·42	59	4·84
P_2O_5	·06	·10	·18	·14
SO_3	04	·04	....	·03
CO_2	15·04	11·24	....	3·04
	99·69	99·68	100 73	100·15

Note to analyses I, II, and IV: The FeO and Fe_2O_3 percentages, as given, are probably only approximate, owing to the impossibility of an exact determination of FeO in the presence of sulphides. The FeO in I and II is largely present as carbonate; to some extent also in IV. The manganese appears to be nearly, if not quite all, as carbonate; also the magnesium in I and II.

A comparison of I and II shows that the products of alteration of the granodiorite and the amphibolite are essentially similar, as, indeed, would be expected from the microscopic examination; II, derived from granodiorite, is only somewhat more acid, and contains less Mg than I. A comparison of I and II with the original rocks at once shows the radical character of the alterations. The silica is diminished; the titanic acid remains about constant; the alumina slightly diminished; the oxides of iron considerably lessened in the amphibolite, while not so much in the granodiorite. The lime is greatly increased, while the magnesia is somewhat lessened. Most notable are the changes in the alkalies, the altered rocks being very high in potassa and low in soda, while the reverse is true of the fresh rocks. In I the CO_2 is almost sufficient to form carbonates with all of the CaO, MgO, FeO, and MnO, the surplus of bases being considered as MgO and amounting to 0·49 per cent. In II the quantity of CO_2 necessary to form carbonates with all of the CaO, MgO, FeO and MnO amounts to 10·80 per cent, while the analysis indicates 11·24 per cent. This apparent excess of CO_2 is probably due to the uncertain determination of FeO.

In rearranging the analyses I and II, the very small quantity of apatite, remaining unaltered, has been neglected. The TiO_2 has been calculated as titanite, the microscopic examination showing this mineral present. The following results are then obtained:

	I.	II.
Iron pyrites	7·99	1·61
Titanite	2·08	1·63
Calcium carbonate	16·57	18·23
Magnesium carbonate	10·50	3·47
Ferrous carbonate	5·76	3·67
Manganese carbonate	·42	·14
SiO_2	36·38	45·63
Al_2O_3	12·99	15·82
Fe_2O_3	·43	·89
MgO	·49	....
K_2O	4·02	5·30
Na_2O	·13	·17
H_2O	1·92	2·42
	99·68	98·98

The lower part of these analyses evidently, according to the microscopic evidence, represents a mixture of muscovite and quartz. If we assume that I contains 15 per cent and II 24 per cent of quartz, the latter being more acid by reason of its derivation from granodiorite, the following compositions are obtained for the muscovite:

	I.	II.
SiO_2	51·70	46·79
Al_2O_3	31·41	34·22
Fe_2O_3	1·04	1·93
MgO	1·18	....
K_2O	9·72	11·47
Na_2O	·31	·36
H_2O	4·64	5·23
	100	100

Both of these agree fairly well with the composition of normal muscovite. The composition of the muscovite minerals or the white micas appears to be so variable that it did not seem worth while to calculate the percentages of quartz and muscovite in the mixture by means of a given formula for the latter mineral. Besides these constituents the altered wall rock contains a small amount of a chloritic mineral. The data are not sufficient for a calculation of this; its presence is indicated by the MgO contained in at least the first of the compositions obtained for the muscovite.

The altered wall rock then appears to be composed approximately as follows:

	I.	II.
Iron pyrites	7·99	1·61
Titanite	2·08	1·63
Calcium carbonate	16·57	18·23
Magnesium carbonate	10·50	3·47
Ferrous carbonate	5·76	3·67
Manganese carbonate	·42	·14
Quartz	15·00	24·00
Muscovite (with a little chlorite)	41·35	46·23
	99·67	98·98

The usually wavy or felted character of the white mica and also its greasy feeling indicate that it belongs to that somewhat indefinite class of the muscovites designated as *sericite* and frequently occurring in altered rocks. Sericite or minerals of somewhat analogous composition have often been described as being formed in the decomposed wall rock of mineral deposits. V. Groddeck has treated the subject in a careful and exhaustive manner in his Studien ueber Thonschiefer, Gangthonschiefer, und Sericitschiefer,[1] and Sandberger[2] has described the formation of hygrophilite and similar minerals from granitic and gneissoid rocks near the veins; in the case of the Ophir rocks this change to sericite is even more striking than in the instances cited, because in the original rock the soda is so decidedly predominant.

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[1] Jahrbach d. Koenigl. Preuss. Geologischen Landesanstalt, 1885, Berlin.

[2] Studien ueber Erzgänge.

The extensive carbonatization of the Ophir wall rocks is very remarkable indeed, especially as the main fissures are almost completely filled with quartz and contain very little or no carbonates. In the researches of Sandberger and v. Groddeck, referred to above, the process is usually rather a silicification instead of a carbonatization, even in veins containing large quantities of carbonates. A gneiss, largely converted into carbonates, is mentioned by Sandberger (Erzgänge, p. 69) as an exceptional occurrence.

I think future investigation will show that this carbonatization of the wall rocks is a process which has occurred very frequently during the forming of the California quartz veins. The fact that each vein and veinlet is surrounded by a distinct, bleached, and altered zone of greater or less extent—in the small stringers sometimes only a fraction of an inch wide—appears to me to indicate, beyond doubt, that the veins were filled with solutions acting with a certain intensity on the walls; in other words, that there can be no question of surface waters gradually percolating through the wall rock and depositing there dissolved substances, but rather of strong mineral solutions circulating in the fissures.

Some specimens of vein quartz show, on the faces adjoining the walls, small but distinct pseudomorphs of quartz after calcite. Taken into consideration with the carbonatization of the wall rock this may mean that the character of the solutions changed during the process of formation of the veins from predominatingly carbonated to siliceous.

Two facts referred to above should be accentuated: first, that the iron pyrites are more abundant in the altered wall rock than in the veins, and this not only in the iron belts of the amphibolite, but also in rocks originally not containing any pyrites; second, that although the wall rocks have been so radically altered by the solutions in the fissure, very little gold is contained in them. They are, however, as shown above, not wholly impervious to the gold and silver solutions.

DISTRIBUTION OF GOLD AND SILVER IN THE VEINS.

It may be said with considerable confidence, though, of course, a more extended series of assays would be desirable, that all the quartz veins in the Ophir district carry gold and silver in notable though often minute quantities. The proportion of gold to silver varies from 1: 1 to 1:10 or more by weight; the silver always predominates by weight, though not by value. A large portion of the silver is contained in the sulphurets, which usually contain much more silver in proportion than the ore, but the bullion obtained by ordinary plate amalgamation is only from 500 to 700 fine, as noted above.

The richer ore in the pay shoots is nearly always characterized by more sulphurets than usual in the poor quartz. Galena is especially considered a good indication. The very crystalline and bright quartz in which no sulphurets occur is usually considered poor; in general this, perhaps, holds good, but it may be said to be a most difficult feat to tell the approximate value of the quartz by its appearance. A specimen of very clean and crystalline quartz free from any sulphurets from the Rocky ridge gave, in spite of its very unpromising appearance, 0·187 ounces Au. and 0·263 ounces Ag., or about $4 per ton.

In the granodiorite the richer ore bodies are of considerable extent and their width and dip are not always known; still there are some, as the Crater hill ore shoot, for instance, which distinctly dip eastward in the plane of the vein. It is worthy of note that at many of them there is an amphibolitic dike rock adjoining the vein. The veins in which this is notable were shut down during 1892 and offered no opportunity of investigating this relation; it would seem, however, as if the dikes were of such small extent that the metals in the ore shoots could hardly have been derived from them alone. Moreover, one of the largest ore bodies, that of Crater hill, occurred without any such adjoining dikes, and several other smaller rich shoots have also been found at various places in the granodiorite without them.

In the veins of the amphibolite area the richer ore shoots are, on the whole, of small extent, though more extensive bodies of milling ore may occur. The usual width of these chimneys is from a few feet up to 50 or 60. As already stated, they dip eastward at varying angles on the plane of the vein, and the richest shoots are usually found in the crossing of the vein with the iron belts. In this case the ore bodies have certainly been enriched by leaching from the auriferous sulphides of the amphibolite. Pockets or rich ore shoots are also sometimes found at the crossing of the two veins, such as at the junction of the Little and Big Doig and at the junction of Good Easter with Morning Star. The rich ore shoots are usually of small depth, seldom exceeding 100 feet, but others may come in at any place when the vein is explored.

There is an accepted dogma of many miners that "the gold in the veins is a surface formation," or that "gold veins invariably become poorer as the distance from the surface increases." These are views which are based on a misconception of the data involved. It is correct to say that *one and the same ore shoot seldom continues beyond a depth of a thousand feet or thereabouts*, but thorough prospecting of the same vein would, in all probability, develop new ore bodies in other places on the level in which the old one was found to thin out. Of course it is not in every case certain that such thorough exploration of the vein would be a paying investment. When the ore shoot found at the surface gives out the mine is often abandoned through lack of funds.[1] It seems to be a characteristic of all gold quartz to form rich chimneys of limited extent, irregularly distributed in the plane of the ledge. There is a curious misconception abroad that the present surface is

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[1] Nothing original is claimed for these remarks Similar views have been expressed by mining engineers conversant with the occurrence of gold, for instance, by J. A. Phillips, as long ago as 1868, in his book The Mining and Metallurgy of Gold and Silver, p. 9

also the surface of the period when the veins were formed. Not only is the present surface cut down and eroded to a considerable extent, since the late Tertiary time when the auriferous gravels were deposited, but there is every probability that the surface at the time of the formation of the veins was far above the Tertiary surface.

The ore bodies of to-day are thus probably far below the croppings at the time the fissures were filled, provided that they reached the surface. Rich ore bodies now occur, as in the Washington, Nevada county, mines, about 3,000 feet below the Neocene surface; they occur at the present surface, and they certainly also did occur above the Neocene surface, as evidenced by the rich Tertiary gravel. The veins may, on the whole, have been richer near the original surface, or perhaps only more numerous, but the occurrence of rich ore bodies at a depth of several thousand feet below it certainly appears to indicate that the limit where gold was no longer deposited from its solutions has not by any means been reached in our present mines.

MOVEMENTS ALONG THE VEIN—RELATIVE AGE AND GENESIS OF VEIN SYSTEMS.

The opportunities for examining the junctions of the veins were not so good as would have been desirable. It seems, however, very probable that the veins of the first and second systems were formed at the same time. They do not appear to fault each other to any noticeable extent, and the Saint Lawrence vein, for instance, continues unbroken from the direction of the first vein system to that of the other. According to reliable information, it is frequent to find two veins at their crossing pinch out without faulting; it is also said to be usual to find two veins when approaching each other simply join without faulting or cutting out. The north-south veins, which are few in number, are said to frequently cut off the east-west veins; so, for instance, it is stated that the Brushfence mine is cut off a few hundred feet beyond the shaft by a heavy north-south vein, though I could not convince myself beyond doubt that such was actually the case. The flat Morning Star vein is certainly cut and faulted a few feet by a nearly perpendicular stringer running north-northeast. In the Plantz mine I am informed that several smaller cross veins are cut and faulted, sometimes also bent, by the main ledge. The shaft is not now accessible.

Striations and slickensides are very common on the veins, and generally indicate more or less horizontal motion. At the same time, it may be said with considerable confidence that no faults of large throw have taken place, for many of the veins cross the granodiorite contact without displacing it to any notable extent. Near the principal vein systems it is not uncommon to find the adjoining rock divided in sheets 1 foot or more in width. Such sheeting of the amphibolite may be noticed in Auburn ravine in the vicinity of the Floyd and the Oro Fino veins, and at several places along the vein system west of Crater hill.

The amphibolite often shows evidence of a movement parallel to the planes of schistosity, which probably in most cases took place before the veins were formed. Along these planes chlorite and mirrors of polished pyrites are usually found. The striations on the veins sometimes run down parallel with the pitch of the deposit, but it is, as stated above, much more common to find them running more or less horizontally, and they are usually most marked on the hanging wall. On the Gold Blossom vein the striations, which are often coarse, almost appearing as a corrugation of the sides of the vein, dip west from 10° to 20°. In the Conrad tunnel the inclination of the striations were measured on the hanging wall to 58° east, 50° east, and in one place 30° west. On the Hathaway the striations are very marked and dip west constantly at angles of 40° or 50°. They are not only found in the hanging wall, but in many places the whole vein, which is about 2 feet thick, is divided into sheets, producing the effect of a ribbon structure. The faces of the dividing planes are covered by scales of chlorite and minute crystals of iron pyrites. They have a slightly wavy or curved surface and are rifled by narrow and straight striations. The thickness of the sheets varies from a few millimeters up to several centimeters. It was suggested that this structure might be due not to a sheeting of the quartz vein, but to the replacement of sheeted and striated wall rock by quartz, so that the present striations would be simply the reproduction in quartz of the original slickensides of the country rock. The faces covered with chlorite and separating the sheets might be considered as the only remains of the replaced striated country rock. Such an explanation is, however, wholly untenable. Vugs and cavities lined with crystals are often found in the thicker sheets as well as other indications of deposition in open fissures. Moreover, many thin sections cut across the sheeted veins indicated beyond doubt that the quartz was not deposited as a mold reproducing striations; on the contrary, indications of extreme pressure were most evident. The dividing planes were found to correspond to lines in the sections along which comminution and crushing had occurred to an extraordinary extent, converting the original coarse grained quartz aggregate, which still remains in many places between the dividing planes, into a fine grained aggregate.

Replacement of country rock by quartz and ores doubtless frequently occurs, but that the Ophir vein systems principally consist of quartz-filled fissures once open appears to me beyond doubt. It does not follow that they were open throughout, for it is common enough to find even the heaviest veins occasionally "shutting down" and the fissure narrowing to a seam, thus affording support to the walls. Moreover, it does not seem possible that the country rock could be converted into a pure coarse granular quartz aggregate without some remaining indications of its original structure. In the case of the altered wall rocks it is certain that, however profound the chemical changes, the original structure and grain have to some extent been preserved.

Mr. S. F. Emmons has recently, and with excellent reasons, called attention to the fact that "many so-called fissure veins are formed by percolating water circulating along joints, shrinkage cracks, fault planes, or zones of crushed rock, which have filled the interstitial spaces and replaced the materials of the adjoining country rocks to a greater or less extent by the materials they held in solution, but are not the filling of any considerable open cavities."[1]

In very many cases this view is undoubtedly correct,[2] but I do not think it can be applied to the veins described in this paper. Fissure veins with comb structure and other evidences of filling of preexisting cavities do not seem to me to be quite so rare as Mr. Emmons states, and among the gold quartz veins of California one does not have to search far to find them.

On the cropping of a quartz vein near the gravel hill 2 miles north of Auburn, on the Clipper Gap road, an interesting structure is observed. The vein projects for about 16 inches above ground through the decomposed schists; its hanging appears as a smooth and polished wall. A closer inspection reveals the fact that a part of the apparently uniform surface consists of breccia of quartz fragments several inches or more in diameter, each of which is striated in a different direction; in another part of the cropping the original striation does not seem to have been disturbed and is nearly horizontal. The explanation of this seems to be that subsequently to the movement to which the original striation was due another disturbance took place, which brecciated the vein, and that this breccia was soon afterwards pressed together and cemented. A thin section of the quartz from this place shows that it has a fine grained quartzitic structure, and that the individual grains are usually extremely pressed, broken, and crushed.

This quartz vein is at the same level as an adjacent hill of Neocene gravel and volcanic deposits, and consequently cropped out on the surface of the range in Neocene times. Nearly the same is true of the Gold Blossom and Hathaway veins, the striated surface croppings of which can only be a short distance below the Neocene surface.

It seems evident that phenomena such as those described above—sheeting, striating, brecciating, and recementing—could not have taken place except at considerable depth below the surface, and that we are, therefore, justified in believing that a considerable extent of the vein had been eroded already in Neocene times. Just how deep the croppings on the Neocene surface were below the croppings at the time the veins were formed is not easy to tell; but the amount of the erosion is most probably not less than 1,000 or 2,000 feet—it may have been very much more.

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[1] The genesis of certain ore deposits, Trans. Am. Inst. Min. Eng., May, 1886.

[2] The veins of Meadow Lake, California, appear to have been formed in this manner. W. Lindgren, Am. Jour. Sci., Sept., 1893.

Concerning the age of the veins, nothing more definite can be said at present than that they are later than the granodiorite, which again is later than the Jurassic or early Cretaceous Mariposa beds. On the other hand, they are older than the Neocene deposits overlying them.

Mr. G. F. Becker has shown[1] that direct pressure applied to a mass presenting great resistance to deformation will induce fractures along the lines of greatest tangential strains, and four systems of fissures may be formed; in the common case, however, that there exists any inequality of resistance in the plane perpendicular to the line of pressure, the rupture will take place only along planes perpendicular to that of the greatest and least of the axes of the strain ellipsoid, and two systems of fissures will be formed separating the mass into columns. The direction of the compressive stress is perpendicular to these columns, and in usual cases bisects the obtuse angle between the fissure systems. An experiment by Daubrée, an illustration of which is copied in Mr. Becker's paper, confirms these deductions.

These conclusions appear to offer a solution of the problem of the direction of the force which produced the principal fissure systems of Ophir.

Leaving out of consideration for the present the few and unimportant veins which run north and south, there are in the Ophir district two systems of fissures, according to best evidence, formed and filled at the same time; roughly speaking, they cut each other at an angle of 45° and all dip southeast or southwest at angles ranging from 30° to 70°. The compressive stress that formed the fractures evidently bisected the obtuse angle between the fissure systems, that is, had a north-northwesterly direction about parallel to the trend of the Sierra, and was inclined downward at angles ranging from 30° to 70°. Most prevalent is a dip of 50° or 60°, which would correspond to an inclination of the force of 30° or 40°. The compressive stress not only produced these fissures, but, continuing to act for some time, or being repeated even after the fissures had been filled, the columns ground against each other, producing slickensides and striations.

As fissure systems with this direction are uncommon in the Sierra Nevada, it is likely that exceptional conditions produced a local compressive stress or intensified it in an uncommon degree.

As soon as the fissures had been formed they offered special facilities for heated subterranean waters to circulate, and were soon filled with mineral solutions containing silica and carbonates as well as small quantities of heavy metals probably dissolved in alkaline sulphides. It is probable that the solutions already contained gold, silver, etc., derived from unknown sources when ascending, but that encountering exceptionally auriferous wall rock in the iron belts a local enriching process took place. Concerning the principal source of the metals nothing definite can be said; more extensive observation, and especially

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[1] Finite homogeneous strain, flow, and rupture of rocks. Bull. Geol. Soc. Am., vol. 4, p. 49 et seq.

more chemical examinations than have been made for this paper, are needed. A certain part of the gold and silver in all probability came from the amphibolites, but this is only referring the question one step back, for the accumulations in the amphibolites are themselves of secondary nature.

CONCLUSIONS.

The quartz mines of Ophir are located near the contact of a massif of granodiorite of late Mesozoic age with older, post-Carboniferous, probably also Mesozoic, amphibolite schists. The latter contain belts or zones impregnated with iron pyrites in part at least auriferous and which correspond to the "Fahlband" of German and Swedish authors. The quartz veins principally belong to two systems, one west-northwest and the other northeast in direction; all the fissures dip southeast or southwest at angles ranging from 30° to 80°.

The principal valuable mineral is native gold, usually containing so much silver as to be classed as *electrum;* besides a small amount of sulphurets, such as iron, copper and arsenical pyrites, galena, zincblende, tetrahedrite, and molybdenite. The gangue is principally quartz, filling the fissures, which are from a few inches to 3 feet wide. Calcite is subordinate in quantity. While practically all the quartz is auriferous, the richer ore is concentrated in pay shoots or chimneys; those in the granodiorite are low grade, rich in silver and very extensive; those in amphibolite are mostly rich, contain less silver and are of small extent in width and depth, sometimes only "pockets." When the quartz veins cross the iron belts the richest pay shoots have been found; all the pay shoots appear to have an easterly dip on the plane of the vein. The adjoining wall rock is both in amphibolite and granodiorite altered to a calcite-sericite aggregate, while there is but little calcite in the veins proper.

The fissure systems have in all probability been formed simultaneously by a compressive stress acting in a direction parallel to the trend of the Sierra, and the fissuring was attended with considerable horizontal motion. Hot siliceous and carbonated solutions containing heavy metals dissolved in alkaline sulphides ascended the veins, altering the wall rock and depositing the silica and ores in the largely open fissures. Action of percolating surface waters seems out of the question. The auriferous iron pyrites of the iron belt were probably a source of local enriching of the veins, but the derivation of the largest part of the precious metals must as yet be considered an open question.

GEOLOGY OF THE CATOCTIN BELT.

BY

ARTHUR KEITH.

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ILLUSTRATIONS

GEOLOGY OF THE CATOCTIN BELT.

BY ARTHUR KEITH.

GEOGRAPHY.

GENERAL DESCRIPTION.

Under the above title it is the author's object to discuss an area for which at present there is no convenient name in use. This area, roughly speaking, is the mountain belt of Virginia and Maryland. The Paleozoic valley of Virginia has been aptly named the Shenandoah valley. The lowlands of the coast have been termed the Coastal plain. The crystalline uplands have been named the Piedmont plain. Between the Piedmont plain and the Shenandoah valley lies the area under discussion.

It is composed in general of three members—the Blue Ridge on the west, the Catoctin mountain on the east, and an intermediate valley. The Blue Ridge is continuous through Virginia to its end in Maryland; there South mountain begins, lapping past the Blue Ridge and continuing the line of elevation far into Pennsylvania. Catoctin mountain runs through Maryland into Pennsylvania and is immediately terminated there by a fault, which also cuts off all except South mountain and ends the belt. Southward through Virginia, Catoctin mountain and its direct continuation, Bull Run mountain, extend for perhaps 50 miles, about to the latitude of Luray; thence southward the eastern member, representing Catoctin, is cut off at intervals by the same fault which removes it at the north, while the intermediate valley and the Blue Ridge go on. After passing the James river the Catoctin belt loses its unity by the disappearance of its eastern member and by the breaking down of the Blue Ridge. A geological change of considerable extent also occurs in the diminution of the volcanic rocks and the substitution of gneisses and mica schists.

The Catoctin belt as a unit thus traverses Maryland and most of Virginia. Field work, however, has been limited to the northern portion—that which lies west of Catoctin and Bull Run mountains. Within this region the chief problems are well developed, and it may be taken as a type of the whole. The name "Catoctin belt" is applied to this region because it is separated by Catoctin mountain from the Piedmont plain as a geographic unit more distinctly than in any other area, and because its geological unity is completed by Catoctin more fully and compactly than elsewhere. The location of the area mapped is shown on the accompanying general map, (Fig. 44). The greater part of this area is represented upon the Frederick, Harpers Ferry, Winchester, Warrenton, and Luray atlas sheets of the U. S. Geological Survey.

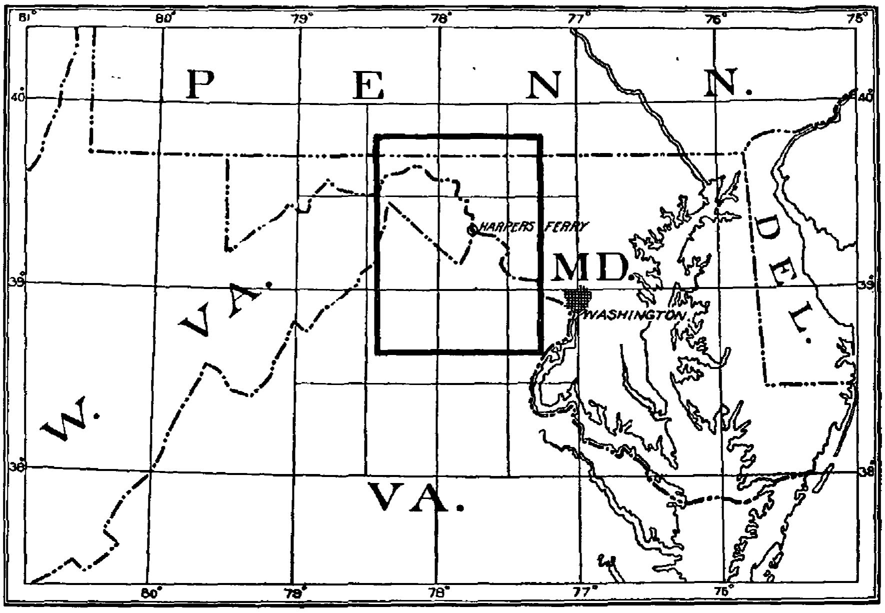

Fig. 44.—General map

BLUE RIDGE.

Of the features which demarcate the Catoctin belt the Blue Ridge is perhaps the most variable, both in continuity and in elevation. Through Virginia it is continuous far beyond the area under discussion; shortly after crossing the Potomac it disappears entirely, but its function of limit to the Catoctin belt is carried out toward the north by South mountain. The Blue Ridge owes its existence as a mountain to the hard rocks which it contains and their resistance to weathering. With their variations, therefore, the Blue Ridge itself varies both in altitude and in shape. Through Maryland and into Virginia as far south as Berryville its character is due to the Lower Cambrian sandstones. Over this portion its summits are rough and rocky and usually sharp crested. In Pl. XIX, from a photograph, is shown a lengthwise view of the south end of South mountain and its characteristic sharp sandstone crest. From Berryville south the main crest is formed of the epidotic Catoctin schist, and to some extent of granite in the vicinity of Luray. Throughout this portion of its length the sandstone forms a series of lesser spurs and knobs upon the northwest flanks of the ridge. The crest formed by the Catoctin schist is broad and arching, has little definite linear arrangement, and is quite unlike the sandstone ridges. At the left of the view (Pl. XX) appear the wooded, rocky sandstone knobs; at the right, the broad dome of Catoctin schist; in the foreground, the gentle slopes covered with fragments of epidote from the schist. East and south of Front Royal is an area of high ground, which may properly come under the name "Blue Ridge." This expansion of the mountain area causes the Blue Ridge to lose its definite simplicity, but the whole mass should none the less be classed as Blue Ridge. The irregularity of the ridges is due to the absence of the linear folds of sandstone and their control of the direction of drainage.

CATOCTIN MOUNTAIN.

Catoctin mountain, excepting two water gaps, is a continuous line from its inception in Pennsylvania for 20 miles into Virginia. The direct continuation of its elevation is interrupted there for a mile or two, but is taken up by Bull Run mountain, with a slight offset, and carried south to the limit of the area mapped. Catoctin mountain is formed in the main of the hard lower Cambrian sandstones with the exception of few miles toward its south end, where the Catoctin schist makes the summit of the range and the sandstone is relegated to the flanks, just as upon the Blue Ridge to the west. In Pl. XXI, from a photograph, is shown the easy rolling character of the mountain where the elevation is caused by the Catoctin schist. The direction of view is the main direction of the ridge and of the outcrop of the schist, and the small control of the schist upon the direction of the topography is obvious. In the foreground appears the debris of epidote lenses in the schist. The continuation of Catoctin in Bull Run mountain resembles the northern part of Catoctin, and its crests are straight and ragged lines of sandstone.

INTERMEDIATE VALLEY.

The intermediate valley, or third member of the belt, is a remarkable example of a baselevel plain. The northern part of its course in Maryland is a valley only in its relation to the two mountains on either side, and contains many high points of the Catoctin schist. Its southern part in Maryland, when viewed from one of its summits, appears as a true plain with a rolling surface and but slight differences of elevation. Into this old surface the streams have recently cut canyons of small length. Its northern portion in Virginia is an even more perfect plain than in Maryland, and the later erosion by the present drainage has made but slight impression upon it. Its broad level is well marked in Pl. XIX, from a photograph. In its southern portion the period of erosion which produced the great middle plain failed to reduce considerable sections of the uplands, and they remain as spurs and outliers of the Blue Ridge. These encroach upon the central valley quite extensively and emerge from the plain with a rapid change of slope. On the map (Pl. XXII) these different topographic features are shown by 200-foot contours.

GEOLOGY.

GENERAL.

The different topographic belts—the Piedmont plain, the Shenandoah valley and the Catoctin belt—are but an expression of the different phases of the geology of the region. The Catoctin belt is the chief object of study, but the other belts will be considered in their bearing upon the history and structure of that belt. The three zones differ radically in their component rocks. The Shenandoah valley is composed almost exclusively of Siluro-Cambrian limestone, with occasional troughs of Lower Silurian shale. The Piedmont plain, where it borders upon the Catoctin belt, is composed in the main of the Newark strata, red sandstone and limestone conglomerate. East of the Newark areas lies a broad belt of old crystalline rocks whose relations to the Catoctin belt are unknown. G. H. Williams[1] considers them as older than the sericitic schists east of Frederick, which are probably equivalent to the Cambrian schists of Catoctin mountain. The distinction is based upon the difference in stage of crystallization and upon the large proportion of eruptive material in the more crystalline rocks. The Catoctin belt itself may be described as a broad area of igneous rocks bordered by two lines of Lower Cambrian sandstones and slates. Over the surface of the igneous rocks are scattered occasional outliers of the Lower Cambrian slate; but far the greater part of the surface of the belt is covered by the igneous rocks. The belt as a whole may be regarded as an anticline, the igneous rocks constituting the core, the Lower Cambrian the flanks, and the Silurian and Newark the adjoining zones. The outcrops of the Lower Cambrian rocks are in synclines, as a rule, and are complicated by many faults. The igneous rocks have also been much folded and crumpled, but on account of their lack of distinctive beds the details of folds can not well be traced among them.

PREVIOUS VIEWS OF THE ORIGIN OF THE IGNEOUS ROCKS.

The igneous rocks of the Catoctin belt are the oldest in the belt and occupy most of its area. They are also prominent from their unusual character and rarity.

Mention of these formations has often been made in literature, although their real nature has only of late been made known. Frequent reference is made by Rogers to the rocks of the Catoctin belt, especially the epidotic schists. In his reports, published as the Geology of the Virginias, he says (page 83) that "a large portion of its area is occupied by beds of genuine sandstone and conglomerate rocks, and

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[1] Geol. Soc. Am., Vol. II, pp. 305, 307, 313.

RESIDUALS ABOVE TERTIARY BASELEVEL NEAR ROUND HILL, VIRGINIA.

the chief parts of those strata, which on first view might be regarded as crystalline and primary in character, are in reality modified forms of sandstones and conglomerates which, through intense igneous action, have been made to assume appearances more or less closely resembling those of rocks of the latter description." On page 84 he refers to the schist of Carters mountain as "greenish and dark blue argillaceous sandstone," and says: "This rock bears the strongest marks of intense igneous action in its flinty hardness and in the large quantity of green epidote which has been developed through its structure." Further on he says of the same rock: "The greenish blue rock is studded with black and greenish spots, indicating an incipient crystallization." In his section of the Blue Ridge at Turk's gap (page 89) he mentions "fine grained bluish green argillaceous sandstone full of incipient crystallization in small vitreous specks." "These specks are small amygdules," he says, and he makes other statements of similar nature. On page 91 he notes "the dark greenish blue sandstone, such as occurs so abundantly in the Southwest mountain," referring to the epidotic schists. On page 313 he speaks of "the greenstone and greenstone amygdaloid" of Tye River gap in the Blue Ridge. On page 205, in mentioning the "igneous rocks of Stony Man," in this case a granite, he refers to the "modifying agency of the subjacent igneous rocks." In short, Rogers plainly regarded the major part of the schists as sedimentary rocks altered by igneous intrusion of granite and trap. He also saw the igneous nature of some of the green rocks, and cites (page 313) "dikes of greenstone" in gray granitic rocks on Tye River gap section.

W. M. Fontaine discusses the rocks of the Catoctin belt in various places. In 1875,[1] he says of the interrupted chain of mountains forming the eastern outline of Catoctin belt: "For the sake of convenience, I shall call this entire range by its more northerly name, Catoctin." Fontaine recognized in most places the difference between the sedimentary series and the schists and granitoid rocks. The alterations in the schists he attributed to the action of intrusive granites and syenites. Appended are extracts from his articles, which show the relations of the rocks as they appeared to him.

"The rocks composing the Catoctin mountains here [Point of Rocks] are, in their least altered condition, well defined argillites. * * * It forms also most of the Blue Ridge at the latter place [Harpers Ferry]. * * * This central, highly altered portion has plainly been sufficiently softened to be capable of motion, like a fused mass." Page 17: "The entire distance from Point of Rocks to Harpers Ferry on the Maryland side is apparently occupied by the argillites." Page 20: "The material composing the mountain, however [Catoctin mountain, here called 'Southwest'], is no longer argillite, but a more massive, argillaceous quartzite, of greenish color, from the great amount of chlorite and epidote developed in it." Page 21: "The mountain

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[1] Am. Jour. Sci., 3d ser., Vol IX, p 15-21

proper [Blue Ridge] in the vicinity of Rockfish gap is composed of argillites highly altered by local metamorphism. * * * Along these bands [of metamorphism] the slates have lost their cleavage and have become impregnated with epidote, quartz, and chlorite."

In other instances he repeatedly states his belief that the schists are *metamorphosed sediments*.

Henry Rogers, alluding to similar rocks in South mountain, Pennsylvania, calls them "green slates" and "highly altered slates."[1]

Philip Tyson called the Catoctin rocks "gray and green slates," or "argillites," and mentions their disturbance by igneous rocks, such as "porphyries, amygdaloid, serpentine, and epidote."[2]

In a later report he also calls Catoctin mountain a "vast mass of epidotic trap."[3]

Persifor Frazer, in 1877,[4] distinguished in South mountain an older quartz conglomerate series and a younger series of orthofelsite interbedded with hydromica and chloritic schists.

With reference to the origin of the schists he says: "The porphyry which carries the copper of this region shows no character of igneous action."

T. Sterry Hunt, in 1876,[5] identified petrosilex in the South mountain rocks, and considered it sedimentary.

J. F. Blandy, in 1879,[6] described as "amygdaloid trap," the copper rock from South mountain.

J. P. Lesley[7] follows Frazer for the most part in classifying South mountain rocks. The feldspathic felsite series he speaks of throughout as sedimentary in origin.

G. H. Williams, in 1892,[8] treating of the rocks of South monntain, divided them into rhyolite and basalt, and substantiated the determination of their volcanic nature with considerable detail.

The author, in 1890,[9] recognized the volcanic nature of the schists of Catoctin mountain and Blue Ridge, in the vicinity of the Potomac, but made no publication of the fact. Attention was called by him to the irruption of granite into the schists. In 1892, two classes of volcanic rocks, quartz-porphyry and diabase, were recognized by him in Maryland and Virginia along the Catoctin belt.[10]

From the foregoing extracts it is apparent that the true nature of these rocks has only lately been recognized, with the exception of some

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[1] Geol. of Penn, Vol. I, pp. 203–250.

[2] First Report of State Agricultural Chemist to House of Delegates of Maryland, pp. 34, 35, 1860.

[3] Second Report, op. cit. 1862, p. 70.

[4] Report of Progress in York, Adams, Cumberland, Franklin Counties, 2d Geol. Surv. of Penn., CC, for 1875, p. 285.

[5] Proc. Am. Ass. Adv. Sci., 1876, pp. 211, 212

[6] Trans. Am Inst. Min. Eng., Vol. VII, p. 331.

[7] Geology of Pennsylvania, by J. P. Lesley, Vol. I, 1892, p. 148.

[8] Am. Jour. Sci., 3d ser., Vol. XLIV, 1892.

[9] Bull. Geol. Soc. Am., Vol. II, p. 156.

[10] Am. Geologist, Dec., 1892, p. 366.

of the more massive greenstones and porphyries. The main body of the quartz-porphyry and schist and the northern portion of the granite series were classed as "altered sedimentaries." Their true nature is now established beyond dispute. It remains to develop their mode of occurrence and relative histories.

Classification.—In description the rocks will be classed according to their genesis into igneous and volcanic, the former comprising granite and the latter quartz-porphyry, andesite, and diabase. In the section in Pl. XXIII the sequence of these rocks is shown and their age relative to the sedimentaries.

IGNEOUS ROCKS.

GRANITE.

Form of outcrop.—The granite is very important in point of extent, almost as much so as the diabase in the southern portion of the belt, and the outcrop gradually diminishes in size and frequency until its limit is reached in Maryland, about 10 miles north of the Potomac. The general form of its outcrop is triangular, the apex being in Maryland and the base, about 30 miles wide, southeast of Front Royal, in Virginia. The areas of granite are, as a rule, long narrow belts, and vary in width from a yard to 6 miles, with an average of perhaps 100 yards. This linear character prevails except in the southern portion of the belt.

Granite and schist areas.—At the south the granite spreads out in patches of considerable length and several miles in width; into these the long fingers of Catoctin schist come down from the north. Separate representation of these areas upon a map is impracticable, as they are too intimately intermingled, especially in the northeastern portion of the belt. A general division can be made, however, into areas in which there is no granite, areas in which granite and schist are interbedded, and areas containing little else but granite, and on that basis the accompanying map (Pl. XXII) is constructed. This method, of course, makes it necessary to draw rather arbitrary and generalized lines of separation, but the sacrifice of accuracy made thereby seems to be outweighed by the illustration which it permits of the distribution. It has the added advantage of coinciding with the only distinction possible in the schists, that between epidotic and nonepidotic.

Composition and varieties.—The mineralogical composition of the granite is quite constant over large areas. Six varieties can be distinguished, however, each with a considerable areal extent, which is set forth in the diagram (Pl. XXIV). The essential constituents are quartz, orthoclase and plagioclase, and by the addition to these of biotite, garnet, epidote, blue quartz, and hornblende, five types are formed. All these types are holocrystalline, and range in texture from coarse granite with augen an inch long down to a fine epidote granite with scarcely visible crystals. Under the microscope the different types have the following groups of minerals:

Epidote granite, 3 miles west of Aldie, Virginia, is composed of fine grained quartz, plagioclase, orthoclase, and biotite both unaltered and altered to chlorite. Accessory minerals are magnetite, a little epidote, and some doubtful allanite. Another specimen from the same locality shows a coarse holocrystalline mass of quartz, orthoclase, a little plagioclase, and epidote. The epidote is both granular and crystalline and is associated with quartz (rarely feldspar) in groups of crystals. A third specimen from the same locality shows epidote in bunches of crystals and as inclusions in the feldspar.

Garnetiferous granite from the Potomac river 1 mile east of Harpers Ferry shows quartz, orthoclase, plagioclase, garnet, epidote, and apatite; all except the last two are in large crystals. Dynamic action has caused considerable alteration of feldspar to quartz, muscovite, and chlorite, and cracks in the quartz which are cemented with chlorite. A specimen from the granite 4 miles southwest of Hillsboro, Virginia, contains quartz, plagioclase, orthoclase, pink garnet, magnetite, and a little chloritized biotite.

Granite from 1 mile northwest of Browntown, Virginia, shows quartz, orthoclase, plagioclase, hornblende, a little biotite, magnetite, and, along the feldspar cleavage, chlorite. Another specimen from the same locality shows the same minerals in larger crystals. A third specimen contains a large amount of garnet in rude crystals and fragments, a little apatite and pyrite, and but very little orthoclase.

The biotite variety is far the most common. The biotite is always small in amount and often absent, so that the rock has a prevailing light gray color. Its minerals are quartz, orthoclase, plagioclase, biotite, magnetite, and usually a little secondary muscovite and chlorite from feldspar decomposition.

The varieties of granite characterized by blue quartz do not differ under the microscope from other varieties containing biotite. As a macroscopic constituent, however, the blue quartz is very striking, and the brilliancy of its color renders it noticeable wherever seen. It occurs both as original crystals disseminated through the mass and as veins and patches.

Metamorphism.—Dynamic metamorphism has produced great rearrangement in these minerals in many places. This is notably the case along the eastern side of the Catoctin belt, and results at times in complete obliteration of the characters of the granite. The first step in the change was the cracking of the quartz and feldspar crystals and development of muscovite and chlorite in the cracks. This was accompanied by a growth of muscovite and quartz in the unbroken feldspar. The aspect of the rock at this stage is that of a gneiss with rather indefinite banding. Further action reduced the rock to a collection of angular and rounded fragments of granite, quartz, and feldspar in a matrix of

TOP OF BLUE RIDGE AT SNICKERS GAP, VIRGINIA.

quartz and mica, the mica lapping around the fragments and rudely parallel to their surfaces. The last stage was complete pulverization of the fragments and elongation into lenses, the feldspathic material entirely recomposing into muscovite, chlorite, and quartz, and the whole mass receiving a strong schistosity, due to the arrangement of the mica plates parallel to the elongation. This final stage is macroscopically nothing more than a siliceous slate or schist, and is barely distinguishable from the end products of similar metamorphism in the more feldspathic schists and the Loudoun sandy slates. The different steps can readily be traced, however, both in the hand specimen and under the microscope.

Textural variations.—The variations of the granite in texture are most manifest in the biotite granite, which makes up by far the largest portion of the mass. The augen are only found of noticeable size in the extreme southwestern portion of the Catoctin belt; the coarse grades are mainly on the south and west; the fine varieties are chiefly limited to the south and east. When grouped by the other criteria little correspondence is shown with the grouping by texture. The garnetiferous granite occurs in only three areas along the extreme western side of the belt; the epidote variety occurs in a few places near the border of the epidote schist; the blue quartz variety occupies four lenticular areas arranged en échelon along a line transverse to the belt; the remainder of the area is made up of the biotite granite. Thus the granitic types occur—biotite, blue quartz, biotite, and garnetiferous biotite—in areas ranging decidedly across the line of the Catoctin belt. The grouping by texture reveals a maximum near Washington, Virginia, and two axes of coarse crystallization running out from this to the northeast. The reason for this divergence of the zone of chemical identity and physical identity is obscure. The lines of physical identity in the case of the coarsest beds can be interpreted to mean lines of uplift, on the assumption that the coarsest beds were buried deepest. That being granted, the eastern line of coarseness parallels the line of blue quartz development; the western line of coarseness parallels the garnetiferous zone and the main axis of the Blue Ridge. Whether these coincidences are more than fortuitous it were hazardous to say. The fact of interest is that the conditions of chemical development and of textural development are totally distinct.

Relation of granite to other rocks.—The question of the relation of granite to the other igneous rocks is easily settled in some cases and quite uncertain in others. It never comes in contact with any body of the quartz-porphyry, so that its relation to that rock is a matter for inference. Various very small patches of andesite occur next to the granite, but their areas are so small and their mechanical condition so disturbed that they throw little direct light on the question.

With regard to the attitude of the granite to the schist the question is much simpler, inasmuch as the facts are everywhere to be observed.

The granite and schist are interbedded, and this fact is indicative of the real nature of the boundary between them; that is to say, it is an eruptive contact. As far as the fact of interbedding goes either might be eruptive into the other, but study of a few contacts proves that the granite breaks through the diabase schist. While there are many narrow tongues and wedges of schist in the granite it is usually the case that there the granite areas too are narrow and represent repeated fracture and injection. The reverse case frequently occurs of a narrow tongue of granite in broad expanses of schist. Several of these narrow tongues traverse the schist for a number of miles, and their form and extent are such that they could not be considered to be inclusions in the schist. A study of the immediate contacts where they are unweathered brings out the usual contact features, narrow tongues of granite penetrating the schist mass, fragments of the schist included in the granite mass, granite finer in texture toward the contacts, and schist to some extent indurated near the contacts. This, of course, proves the relation of the schist and granite for the areas where granite and schist are frequently interbedded. Whether or not it can be applied to the schist as a whole will be discussed with the other relations of the schist. In various places on the contact of schist and granite the schist appears to be intruded into the granite, but no sure case of this relation has been discovered. This relation would, however, be quite natural on the hypothesis to be developed later, that some of the schist was later than the granite.

VOLCANIC ROCKS.

The other igneous rocks, the quartz-porphyry, andesite, and diabase, are of volcanic nature, and thus closely associated with each other in mode of production, though not in constitution. The quartz-porphyry is an acid rock and more nearly allied to the granite in that respect; the andesite and diabase are basic. The quartz-porphyry and andesite are greatly subordinate to the diabase in extent and importance in the make up of the Catoctin belt.

QUARTZ-PORPHYRY.

Appearance.—The quartz-porphyry is a close grained, dark rock, highly siliceous and frequently showing porphyritic crystals. Its color when fresh is usually a dark bluish gray, which turns on weathering of the feldspar to a grayish white. Occasionally the rock assumes a full red color that is very striking, and often a reddish purple tinge is noticed. The red color is very common in the areas of Pennsylvania,[1] but only occurs in the Catoctin belt west of Myersville, Maryland.

Composition.—The quartz-porphyry contains about 74 per cent of

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[1] G. H. Williams, Am. Jour. Sci., 3d ser., Vol. XLIV, Dec., 1892.

silica, and almost its only components are quartz and feldspar. The following analysis is quoted by Williams from C. H. Henderson:[1]

SiO_2	73·62
Al_2O_3	12·22
Fe_2O_3	2·08
FeO	4·03
CaO	0·34
MgO	0·26
Na_2O	3·57
K_2O	2·57
Ign.	0·40
Total	99·09

Varieties.—In its present condition the rock is a holocrystalline mosaic of quartz and feldspar. Added to this, in the coarse varieties, are the porphyritic crystals, usually feldspar, but occasionally quartz. In areas of this rock farther to the north in Pennsylvania, described by Williams, occur spherulites, lithophysæ, and perlitic structures, which indicate an original glassy nature for the rocks. Northwest of the end of Catoctin mountain, near Fountain Head, spherulites occur in a much squeezed and flattened form. None of these structures, except spherulites, however, have been observed in the portion of the Catoctin belt under the knowledge of the author. The fine grained rhyolitic types of the quartz-porphyry are observed in perhaps equal amount with the porphyritic varieties, but as a whole the porphyritic type is more characteristic in the Catoctin belt. All varieties will, therefore, be classed as quartz-porphyry. At several localities, notably east of Myersville, Maryland, is a fine illustration of the wavy flow structure and banding peculiar to volcanic flows. This feature is especially brought out by the weathering of the feldspathic constituents. In the same locality there is a considerable development of a rhyolitic tufa composed of angular fragments of rhyolite and quartz-porphyry in a rhyolitic matrix. These, however, are exceptional phases of the quartz-porphyry within the Catoctin belt, where, as a rule, it is a dark fine grained rock with few macroscopic characters.

Distribution.—The quartz-porphyry has two types of occurrence which depend largely upon the structure of the region of outcrop. One is the massive flow at the north end of the Catoctin belt, the other is a series of small isolated outcrops scattered along the borders of the Catoctin belt. The northern zone, beginning a short distance north of the apex of the granite areas, is rather irregular in its outline and comprises several distinct patches; the principal one is in the form of a rude elongated cross, the others are long narrow ovals. The small areas are of interest chiefly from the stratigraphic point of view and are too small to represent upon the map. That there is a genetic difference in these forms of outcrop can not be shown, since the smaller masses might be either thin edges of a great flow or the crests of closely appressed anticlines in a great flow.

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[1] Trans. Am. Inst. Min. Engrs., Vol. XII, p. 80.

Microscopic characters.—The appearance of the quartz-porphyry in polarized light is characteristic but disappointing, in view of the variety shown in the hand specimens. The phenocrysts of quartz and feldspar are clear and fresh; the feldspars usually and the quartzes occasionally have sharp crystalline faces. Frequent inclusions of the groundmass occur in the phenocrysts, and their faces are corroded and indented with bays. The groundmass consists of minute individuals of quartz and feldspar that have the same orientation over distinct patches. In the groundmass occur also a very few small crystals of epidote, magnetite, and biotite. In ordinary light, however, appear the true and original structures that are masked by the development of the quartz-feldspar mosaic. Then the forms so conspicuous in the hand specimen and so characteristic of acid lavas are brought out in minutest detail. In the tufaceous lavas the fragments comprise the different forms which are seen in the flows themselves and have the same features under the microscope. The fragments are sometimes surrounded by borders of muscovite, and are sharply angular and conchoidal. In some specimens considerable magnetite is developed in minute crystals in the groundmass. By the darker lines which these grains produce the flow-structure is admirably shown.

Deformation products.—Mechanical deformation of these rocks has been but slight as a rule. Occasionally, however, along fault lines the rock has been tremendously altered by differential motion due to shearing. The resultant rock is a fine, silky, lustrous slate whose only point of resemblance to its parent is its bluish gray color. The first steps of destruction were cracks and breaks in the larger minerals recemented by muscovite and a little chlorite. Further action granulated the phenocrysts and drew them out into strings, decomposed the feldspars into muscovite and quartz, and gave the rock a decided schistose appearance. A section of slate, the final stage of the process, shows a series of light and dark bands parallel in a high degree. The dark bands are composed of a large amount of magnetite in fine grains, chlorite, plagioclase in fresh, small crystals, and small lenses of mosaic quartz. The light bands consist of sericite, minute quartz lenses, and a little magnetite and chlorite. Hand specimens of the slate show the amount of distortion by the thin whitish patches representing elongated phenocrysts.

ANDESITE.

Distribution.—The second division of the volcanic rocks of the Catoctin belt is the andesite. This rock occupies two long, narrow bands west of the Blue ridge, near Front Royal, Virginia, which resemble the interrupted outcrop of a sedimentary bed. Several outcrops of a size too small to show on the map occur at various points along the Blue Ridge. In two localities, 2 miles northeast of Browntown, slaty and massive andesite lies between granite and epidotic schist. Immediately east of Snickers gap in the Blue Ridge slaty andesites occur in

TOP OF CATOCTIN MOUNTAIN, NORTHWEST OF LEESBURG, VIRGINIA.

narrow beds, both in the epidotic schist and between epidotic schist and granite. Six miles south of Harpers Ferry and east of the Blue Ridge, both slaty and massive andesite occur between the granite and epidotic schist.

Appearance.—The rock is intermediate between the diabase and quartz-porphyry and partakes of the characters of both. The color of the rock is a dark blue, which resembles the blue gray of the quartz porphyries and is distinct from the green of the diabase. In its low percentage of silica and prominence of iron oxide it resembles the diabase. The development of its amygdaloids allies it more closely to the diabase than the quartz-porphyry, although amygdules are present in all three rocks. In fineness of texture it is like the rhyolitic grades of the quartz-porphyry. The slaty products of its deformation are strikingly like the slates developed in the quartz-porphyry under similar conditions. Its situation along low ground is analogous to the topography of the quartz-porphyry.

In another publication[1] the author has made a preliminary correlation of these rocks with the quartz-porphyry. This was based upon their microscopic characters in the field, such as similarity of color, texture, topography, slaty products, and relation to the diabase. Subsequent chemical analysis and study under the microscope have resulted in their separation.

Composition.—Analyses of specimens collected 3 miles east of Front Royal, Virginia, were made by Mr. George Steiger, of the U. S. Geological Survey, and give the following composition:

	I.	II.
SiO_2	51·08	52 81
TiO_2	2·67	....
Al_2O_3	11·37	....
FeO_3	11·17	....
FeO	5·64	....
MnO	·22	....
CaO	5·20	....
MgO	3·96	....
K_2O	1·50	....
Na_2O	5·54	....
H_2O above 100°	1·31	....
H_2O below 100°	·19	....
P_2O_5	·39	....
	100·24	....

Microscopic structures.—The prevalent dynamic metamorphism of the andesite has usually destroyed all such structures as flow lines and vesicles. In certain harder portions, such as the amygdaloids, they have occasionally escaped, but are not apparent on the hand specimen on account of the fine grain of the rock.

The ordinary thin section of andesite from this region consists of fine individuals of quartz, sharp feldspar crystals, minute opaque grains of iron oxide, and a little epidote. In most sections marked

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[1] Am. Geologist, December, 1892, p. 366.

poikilitic patches are visible; occasionally an ophitic structure predominates. Both quartz and feldspar form small porphyritic crystals, the latter more commonly. The minerals all look remarkably fresh and sharp, as if entirely unaltered; considerable secondary quartz has been deposited, however, and often appears to replace the crystals of feldspar.

A section from andesite collected east of Browntown, Virginia, shows angular and conchoidal fragments in a groundmass of fine quartz and feldspar; a little epidote is sparingly distributed, and the angular bits, which resemble glass fragments in shape, are now composed of quartz. The same section magnified shows a strong wavy banding. In most sections the groundmass has but a feeble polarization, which is so low in one case as to quite strongly suggest a felsitic nature.

Sections of the amygdaloid east of Front Royal, Virginia, show amygdules of quartz and epidote with iron oxide concentrated around the borders; the groundmass consists of many minute plagioclase crystals in a base of fine feldspar and magnetite. The feldspars are arranged parallel to the amygdules and large crystals and plainly show flow motion. The feldspars also contain many globulites and indeterminate inclusions. From the high percentage of titanium shown in the analysis it is likely that most of the iron oxide is ilmenite.

The eruptive nature of the andesite is sufficiently shown by these examples of structures peculiar to eruptive rocks. Its separation from the other eruptives is justified by its different chemical composition and its different structural habitus. No similar rocks have previously been described in the Appalachian province, within the author's knowledge.

CATOCTIN SCHIST.

The third of the volcanic rocks—the Catoctin schist—is geographically the most important of the three. It occupies three-fifths of the area of the Catoctin belt thus far mapped and a considerable portion of the South mountain belt in Pennsylvania, as described by Williams.

Appearance.—Throughout its entire area the schist is singularly uniform in appearance, so that only two divisions can be made with any certainty at all. These are dependent upon a secondary characteristic, viz, the presence of epidote in large or small quantities. The epidote occurs in the form of lenses arranged parallel to the planes of schistosity, reaching as high as 5 feet in thickness and grading from that down to the size of minute grains. Accompanying this lenticular epidote is a large development of quartz in lenses, which, however, do not attain quite such a size as those of epidote. Both the quartz and epidote are practically insoluble and lie scattered over the surface in blocks of all sizes. In places they form an almost complete carpet and protect the surface from removal. The resulting soil, where not too heavily encumbered with the epidote blocks, is rich and well adapted to farming, on account of the potash and calcium contained in the epidote and feldspar.

Except along the narrow canyons in the Tertiary baselevel the rock is rarely seen unless badly weathered. The light bluish green color of the fresh rock changes on exposure to a dull gray or yellow, and the massive ledges and slabs split up into thin schistose layers. It is quite compact in appearance, and as a rule very few macroscopic crystals can be seen in it.

Composition.—The following analyses show the chemical composition of the rock:

	I.	II.	III.	IV.
SiO_2	41·280	46·14	45·66	46·04
Al_2O_3	18·480			
Fe_2O_3	9·440			
FeO	8·200			
CaO	7·040			
MgO	7·486			
Na_2O	3·523			
K_2O	2·208			
Ign	2·740			
	100·397			

I is quoted by Williams and was made by Mr. C. H. Henderson.[1] II, III, and IV were made by Mr. George Steiger, of the U. S. Geological Survey. I is from the Bechtel copper shaft on South mountain; II is of epidotic schist near Point of Rocks, Maryland; III is of coarse schist 6 miles southeast of Harpers Ferry; IV is of epidotic schist east of Browntown, Virginia.

Varieties.—The varieties of the schist are much fewer than those of the quartz-porphyry, largely on account of the greater initial uniformity of the rock. Subsequent metamorphism, moreover, has been of an extent sufficiently greater to have removed all but the most striking features. A general separation can be made into an epidotic division characterized by an abundance of macroscopic epidote and a non-epidotic division with microscopic epidote. These divisions are accented by the general finer texture of the epidotic schist.

No lithophysæ or spherulites have been seen, nor any traces of volcanic glass. Tufaceous forms occur in several places. One, immediately east of Monterey, contains fragments of diabase; another, 2 miles west of Myersville, Maryland, contains fragments of andesite; other cases, and more doubtful on account of dynamic metamorphism, occur along Bull Run mountain, near The Plains, Virginia.

In the epidotic division there are two varieties—the amygdaloidal and the gneissoid. The latter phase is well shown in Catoctin mountain at Point of Rocks, Maryland, and appears at several points along the line of the mountain farther south. Its rarity may be due to the

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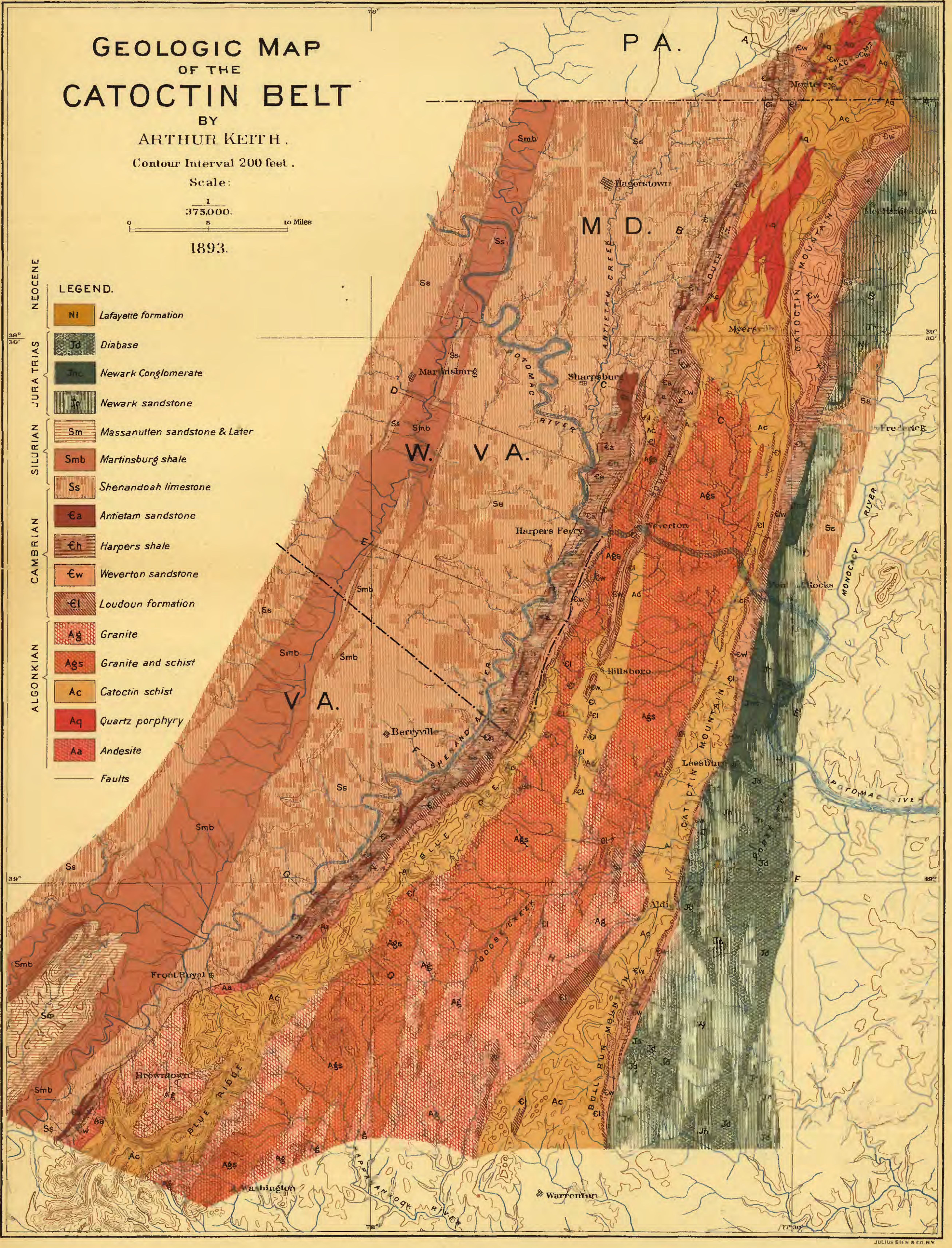
[1] Trans. Am. Inst. Min. Engineers, Vol. XII, p. 82.

lack of clean-cut sections, since the epidotic belts usually make the divides, where weathering is deep. The gneissoid effect is produced by bands in the schist, which vary in their proportions of quartz and chlorite. The quartzose bands carry feldspar, some chlorite, and a considerable amount of epidote, and range from one-eighth of an inch to an inch and a half in thickness. The chloritic bands have the same minerals as the quartzose, with a predominance of chlorite. Interbanded with these are lenses of quartz and epidote. Here, as elsewhere, their number is not great, but the freqnency of their débris results from residnal accumulation during long erosion. The bands have the prevailing eastward dip of the schistose planes, and are also puckered and crumpled in minute folds along these planes.

The other phase of the epidotic schist—the amygdaloidal—is quite common. It is especially developed on the western side of the belt, along the Blue Ridge, and also in Maryland. Along the central portion of Catoctin mountain it occurs but sparingly. The groundmass has the same basaltic arrangement as the coarse schist where not too much modified to show it, and the feldspars have a tendency to parallel arrangement around the amygdules. The amygdules are developed in the body of the rock in addition to the epidote lenses, and both show a marked increase in the vicinity of the quartz-porphyry masses. The amygdules are filled with a variety of minerals, including quartz, epidote, feldspar, jasper, calcite; usually the filling is quartz and epidote. Their usual shape is spheroidal, but frequently they are somewhat drawn out; occasionally two are joined by a narrow neck. They vary in size from one one-hundredth of an inch to half an inch, with an average of one-quarter. The brilliant coloring of the amygdaloids makes them everywhere noticeable. The base ranges from bluish green and green to brown, red, and purple, and in this strong setting are scattered the bright white, green, and red amygdules. Sometimes the minerals in the amygdules are perfectly concentric in many layers; sometimes one mineral alone fills the cavity. Again, a radiating cluster of bright green epidote is surrounded by white quartz or pink feldspar. Usually a dark border of magnetite intensifies the contrast. In fact, the amygdaloids never fail to be beautiful, even in their simplest form of white quartz in bright green schists.

The schists can be definitely called volcanic in many cases, from macroscopic characters, such as the component minerals and basaltic arrangement. In most cases, the services of the microscope are necessary to determine their nature. Many varieties have lost all of their original character in the secondary schistosity. None the less, its origin as diabase can definitely be asserted of the whole mass. In view of the fact, however, that most of the formation has a well-defined schistosity destroying its diabasic characters, and now is not a diabase but a schist, it seems advisable to speak of it as a schist.

Microscopic characters.—Sections of the finer schist in polarized light


GEOLOGIC MAP
OF THE
CATOCTIN BELT
BY
ARTHUR KEITH.
Contour Interval 200 feet.
Scale:
1/375,000.
0 5 10 Miles
1893.
LEGEND.
NEOCENE
Nl Lafayette formation
JURA TRIAS
Jd Diabase
Jnc Newark Conglomerate
Jn Newark sandstone
SILURIAN
Sm Massanutten sandstone & Later
Smb Martinsburg shale
Ss Shenandoah limestone
CAMBRIAN
€a Antietam sandstone
€h Harpers shale
€w Weverton sandstone
€l Loudoun formation
ALGONKIAN
Ag Granite
Ags Granite and schist
Ac Catoctin schist
Aq Quartz porphyry
Aa Andesite
Faults
PA.
MD.
W. VA.
VA.
Hagerstown
Martinsburg
Sharpsburg
Harpers Ferry
Weverton
Frederick
Point of Rocks
Hillsboro
Leesburg
Berryville
Aldie
Front Royal
Washington
Warrenton
Myersville
Mechanicstown
POTOMAC RIVER
MONOCACY RIVER
ANTIETAM CREEK
CATOCTIN MOUNTAIN
BLUE RIDGE
BULL RUN MOUNTAIN
GOOSE CREEK
RAPPAHANNOCK RIVER
SHENANDOAH RIVER
78°
77°30'
39°
39° 30'

show many small areas of quartz and plagioclase and numerous crystals of epidote, magnetite, and chlorite, the whole having a marked parallel arrangement. Only in the coarser varieties is the real nature of the rock apparent. In these the ophitic arrangement of the coarse feldspars is well defined, and in spite of their subsequent alteration the fragments retain the crystal outlines and polarize together. Additional minerals found in the coarse schists are calcite, ilmenite, skeleton olivine, biotite, and hematite. One section of schist from 4 miles southwest of Upperville, Virginia (near the Blue Ridge, east of Front Royal), shows large crystals of fibrous hornblende surrounding cores of pyroxene. A few occurrences of hornblende are also known. Alteration of the original feldspar and pyroxene has been extensive, especially of the latter, and their mutual reactions have produced the excess of chlorite and epidote. To the presence of this secondary chlorite is chiefly due the green color of the rock, and to the parallelism of the micas is due the omnipresent schistosity. It is noticeable that the variety containing the large feldspars occurs almost entirely in the nonepidotic division.

Mineral deposits.—Deposits of copper in the schists have long excited interest and led to mining operations. The amount of ore, however, appears not to have justified any considerable work. Such deposits have been worked on the Blue Ridge east of Front Royal and along the northern end of South mountain. Deposits of cassiterite are locally known, but are of no importance. Specular hematite also occurs in innumerable places in the schist as vein material associated with quartz, but not in sufficient body for economic development.

RELATION OF QUARTZ-PORPHYRY AND SCHIST.

The relation of the quartz-porphyry to the schist receives but little light from the phenomena of the small quartz-porphyry outliers. The outcrop on Goose creek, 1 mile west of Oatlands, Virginia, lies under the fine schist and above the coarse grained schist on a 30° dip and appears to be near the axis of an anticline. It can be traced toward the north for several miles by the fine light colored slaty schists that have resulted from its deformation. At Rohrersville, Maryland, east of the end of the Blue Ridge, the quartz-porphyry lies in contact with the nonepidotic schist and the epidotic schist. The complication of structure at that point renders all relations uncertain. Other occurrences of quartz-porphyry, represented by its slaty products, usually are in contact with the epidotic schist, and appear to dip under it.

In the northern areas the quartz-porphyry appears to occupy the same position relatively to the schist. Of course it is difficult to say that a volcanic rock dips under or over another rock, on account of the absence of bedding planes, but certain features may be taken as indicating superposition. One such means of determining relative age is the relation between the quartz-porphyry and the forms of surface that it produces; another is the nature and composition of the rock itself.

Topographic position.—The topographic position of the quartz-porphyry is along the drainage lines and low ground. As the areas increase in size the width and depth of the valleys increase. It would appear as though the highly siliceous nature of the quartz-porphyry would render it little susceptible to erosion, and that it does resist corrasion strongly is proved by the great numbers of slabs and large blocks strewn about near the streams.

To solution, however, the other agent of erosion, it offers less resistance on account of the large content of feldspar. This ease of erosion is not absolute, but relative with respect to the schist, whose minerals (micas, quartz, feldspar, and epidote) while less siliceous, are equally resistant to corrasion and more resistant to solution. In applying this test of resistance to erosion the comparative values of large and small streams must be considered. The large streams would have courses inherited from the influence of overlying rocks; the smaller ones, depending much on solution, would be most intimately adjusted to the solubility of the present surface. When, therefore, the small streams, which can not be supposed to inherit much of their system, are linear on the quartz-porphyry and random on the harder schist, it is a fair inference that the linear ones play over belts only recently uncovered, else they would be large as well as linear. Also, in the case of a small stream following a soft bed, if the harder rock overlies, the stream will head against a steep rim of harder rock, while if the softer rock overlies, the stream will head on a gradual slope of hard rock. The former is the case in all the southern ends of the quartz-porphyry areas, thus indicating the inferior position of the quartz-porphyry.

The last stage in the removal of a schist cover appears to be represented by the occasional remnants of schist scattered over the larger patches of quartz-porphyry.

The few outliers of quartz-porphyry of small size are only reached by the deeper stream-cutting and are completely surrounded by the schist. These in turn may represent the initial stage in the attack of erosion. At the locality east of Myersville, Maryland, the quartz-porphyry plainly passes under the schist, on a steep slope, and a little farther south the schist swings around and over the point of the quartz porphyry.

Mineralogical nature.—The second line of evidence is based upon the nature of the rock itself, and is twofold. From the banded flow structure often visible in the quartz-porphyry, from the perlitic and spherulitic alterations of its original glassy base, and from its beds of rhyolitic tufa the quartz-porphyry was undoubtedly a surface flow. The tufaceous beds, therefore, would be most prominent at its surface, and conversely, tufaceous beds would approximately define an ancient surface. The few old surfaces discoverable on this basis are near the junction of the quartz-porphyry and schist, apparently at the top of the quartz-porphyry and below the bottom of the schist. Such are the occurrences north and east of Myersville.

A third and perhaps stronger argument arises from the general nature of the diabase. It is obviously a rock whose solidification occurred at no great depth and probably at the surface. Its original width, as evidenced by the location of its remnants, will average over 15 miles, and its length is at least 150 miles. How much more is buried beneath later deposits and how much has been totally eroded can not be told. It is sufficiently evident that its mere size precludes its formation as an intrusive rock, while its unity could result only from simple and unvarying conditions, such as those of a surface flow. It is in every way comparable to the great lava flows of the West. If, therefore, it be a surface flow, it can not underlie the quartz-porphyry.

Summary.—In deducing the relations of the quartz-porphyry and schist, it must be assumed that all the quartz-porphyry masses are of the same age, and the assumption is an easy one, because they are of the same mineralogical nature, have the same varieties, are totally unlike any adjacent rocks, and are for the most part continuous. A determination of relative age in one body, therefore, would bind the whole. Taking the evidence as a whole, it would appear that the quartz-porphyry was the underlying and older rock, because (1) it occupies the low ground of anticlinal drainage in spite of nearly equal hardness ; (2) deep sections reveal small outliers of the quartz porphyry in the body of the schist ; (3) small outliers of schist rest on the large mass of quartz-porphyry ; (4) the quartz-porphyry visibly passes under the schist ; (5) the top of the quartz-porphyry, as marked by the tufa, lies next to the schist; (6) the extent and unity of the schist are incompatible with an intrusive position under the quartz-porphyry. While these considerations are not absolutely determinative, they require strong evidence to controvert them and are ample ground for concluding that the quartz-porphyry is older than the schist.

RELATION OF ANDESITE TO SCHIST.

Concerning the original nature of the contact of the andesite and schist little evidence can be found. The andesite appears to dip under the schist, and the contours of the contact in crossing spurs show that such is the case. At the contact there is an apparent interbedding in some places. Whether this is due to repetition by the prevalent dynamic action of the region or whether it is an original feature is quite uncertain.

The same line of evidence can be followed in this instance as in the case of the quartz-porphyry-schist contact, but to a less extent. The structural position of the andesite around the edges of synclines of schist, its topographic position on the anticlinal lowlands, its actual dip under the schist, furnish a fair probability that it underlies the schist.

MUTUAL RELATIONS OF THE IGNEOUS ROCKS.

From study of the granite schist contacts it was evident that the granite was intruded into large bodies of nonepidotic schists. Areas of epidotic schists contained no granite intrusions. From the relations of schist to quartz-porphyry it was deduced that the epidotic schist was younger than the quartz-porphyry. From the relations of andesite to schist it was deduced that the epidotic schist was younger than the andesite. The chief remaining relations are the relation of the granite to quartz-porphyry and andesite, and of the epidotic schists to non-epidotic schist, andesite and granite. The key to them all is the relation of the epidotic schist to the other rocks.

Prominence of amygdules.—Almost the only recognizable horizon in the schist is the amygdaloid. Other prominent features are the quartz and epidotic lenses, but these do not appear to be confined to one horizon enough to distinguish it. It becomes of importance, therefore, to discover whether the amygdules are constant features of one horizon or are more haphazard developments.

The cause of the amygdules is rather obscure. In the cases in which they are few in number they are quite irregular in form. Where they are numerous they are highly developed and approximately spheroidal. The amygdaloids are slightly more siliceous than the other schists, and the percentage of amygdules is apparently a function of a secondary silicification of the original diabase. With the increase in silica has come an added strength which has resisted deformation. The schists containing few amygdules are little removed in appearance from the ordinary green schists. The schistosity is well defined and the amygdules drawn out or shapeless. The highly amygdaloidal forms, however, range in color through green, purple, red, and gray, and have a minor development of schistosity and perfectly formed amygdules.

Amygdules and lenses compared.—The other principal feature of the schists, the quartz and epidote lenses, come into a different category from the amygdules. The lenses show at a glance by their complete parallelism with the micas and the grading of the schistose into the lenticular structure that they were produced by the same force as the schistosity. The occurrence of the lenses, moreover, is regional in its nature, while the amygdules are essentially localized. These relations show a genetic difference between the amygdules and the lenses, although both are largely made up of the same minerals. If the amygdules had resulted from mechanical deformation of the rock their distribution would have been more uniform, both geographically and stratigraphically.

Under the microscope, especially, the amygdules are plainly seen to be original structures, for around them the feldspar crystals have a somewhat parallel arrangement and the lines of flow bend and wind between them.

Amygdaloidal débris in sediments.—From the evidence of the sedimentary rocks the conclusion in regard to the primary origin of the amygdules is stronger. The movements that produced deformation in its present form of folding and cleavage, as will be discussed under the head of structure, followed Paleozoic deposition for the most part. Paleozoic sediments, however, in numerous places contain recognizable fragments of the amygdules, such as jasper, indicating the existence of an amygdaloidal structure before sedimentation. It follows, therefore, that while the lenses accompanied deformation the amygdules preceded it, and a constitutional explanation of their origin must be sought.

Distribution of amygdules.—The amygdules, with respect to their distribution in the schists, are grouped with the epidotic schist and do not occur in the others. A second general relation is that the amygdaloids occur near the contacts of the epidotic schist with other rocks, including nonepidotic schist, quartz-porphyry, andesite, and granite. There would appear, therefore, to have been an initial chemical difference at that horizon that has expressed itself at first in an amygdaloidal form and secondarily by abnormal growth of epidote.

Flow contacts.—In the contacts with the quartz-porphyry the conditions are simplest and may yield soonest to analysis. The quartz-porphyry was a surface flow followed by a flow of diabase. Either, then, the quartz-porphyry was still liquid at the time of the second flow, or it was hard. If still liquid, the chemical reaction set up between an acid and a basic rock in liquid condition would produce a zone of mixture and alteration. If not liquid, there would be no union of materials, but there would still remain the reaction of a cold acid rock upon a molten basic one, resulting in contact alteration in the basic rock and fragments of acid rock caught up by the basic flow. Breccias of basic rock due to sudden cooling might also be produced. The latter condition accords better with the marked change in the lower portion of the schist nearer the quartz-porphyry. A few breccias of basic rock occur, no mixture of acid and basic is known, strong vesicular development marks this from superior horizons, and occasional fragments of foreign rocks are found in the bottom of the schist.

Granite-schist contact.—On applying this method to the granite contacts with the epidotic schist a similar result obtains. Epidote and amygdaloid are prominent in the schist nearest the contact. Here again the diabase flow was in contact with an acid rock apparently producing a contact zone in the basic rock.

Schist-schist contact.—Extension of the analysis to the contact of the epidotic schist with nonepidotic schist discloses no such marked contrast. The amygdaloidal variety seldom or never occurs along this contact. The zone of contact can usually be told with little difficulty by the sudden increase in amount of epidote, with, however, no special concentration at the bottom. Lenticular epidote in moderate degree is characteristic of the whole body of epidotic schists, and does not indicate a special chemical difference at the contact. There appear to be, therefore, no special contact phenomena in this case, and explanation of their absence could be found in two ways. It could be interpreted as a mere absence of reaction between two basic rocks, following the evidence of the other contacts, or as a want of difference between the two series, a purely negative conclusion. In support of the latter alternative is the similarity of the two groups of schists in appearance and origin. In support of the former is the coarser texture of the nonepidotic schist and the reappearance of amygdaloid wherever the epidotic schist passes from the nonepidotic schist into contact with granite or quartz-porphyry.

Schist-andesite contacts.—The phenomena of the epidotic schist-andesite contacts are quite limited. They consist of the development of amygdaloid, epidote and jasper in both rocks, but especially in the schist, whose great epidote masses strew the surface and stand out in massive cliffs. The principal occurrences of andesite are not in contact with the coarser schist. Some of the minor and doubtful outcrops occur next the granite series, where coarser schists are included.

Andesite-granite contacts.—Between andesite and granite no contact features appear to be developed, and their contacts are too few and too obscure to present a fair illustration of their original relations.

Hypothesis of alteration by granite.—Out of these varied facts several hypotheses may be framed. The schist bodies may represent but a single formation whose differences are due in some way to the intrusion of granite. The schists may represent two formations, the epidotic being the younger. The second formation may have either preceded or followed the granite injection. If it preceded the granite, its separation from the earlier schists practically begs the question; if it followed the granite, a marked difference in age is implied. The two hypotheses worthy of extended consideration are those of a granite eruption into a single schist formation, and of a diabase flow later than the other formations.

One view would be taken first of the difference of the schists in epidotic content, and that is based upon the occurrence of granite in nonepidotic areas. As has been stated, the granite is intrusive in the nonepidotic schist at numberless places, but does not come within the mass of the epidotic schist, although sometimes in contact with it. The natural inference is that the schists are all one mass with granite intruded into certain portions.

A presumption that the schists are separate formations is furnished by the quartz-porphyry. That formation occupies the same position as the nonepidotic schist with reference to the epidotic schist, and is not penetrated by the granite, at least within the area mapped, although they are sometimes close together. Yet the quartz-porphyry, being the under bed, should naturally show more frequent intrusions of granite than the diabase.

On the assumption that the diabase was but a single mass, the form of granite eruption was simple, consisting of two focal lines of eruption, one just east of the Blue Ridge, the other a little west of Catoctin mountain. There would seem to have been a series of radial and parallel

GENERALIZED SECTION.

PERIOD.	FORMATION NAME.	FORMATION SYMBOL.	COLUMNAR SECTION.	THICKNESS IN FEET.	CHARACTER OF ROCKS.
NEOCENE.	Lafayette formation.	Nl.		20 +	Sand and gravel.
JURATRIAS.	Newark formation.	Jnc			Red sandy shale and sandstone, with large beds of limestone conglomerate.
		Jn.		3000 ±	Red sandy shale and sandstone, with sheets and masses of eruptive diabase.
		Jd.			
SILURIAN.	Massanutten sandstone.	Sm.			Massive white sandstone.
	Martinsburg shale.	Smb.		700 to 1000	Black and gray calcareous shale.
					Blue and gray massive limestones.
CAMBRIAN.	Shenandoah limestone.	Ss.		2500+	Blue limestones with thin bluish-black slate beds.
					Blue and gray limestones.
	Antietam sandstone.	Ꞓa.		500	White calcareous sandstone and quartzite.
	Harpers shale.	Ꞓh.		800 to 1200	Bluish-gray and gray sandy shales, with thin beds of sandstone.
	Weverton sandstone.	Ꞓw.		100 to 900	White sandstone and conglomerate.
	Loudoun formation.	Ꞓl.		0-800	Slates, with beds of conglomerate, sandstone, and limestone.
ALGONKIAN.	Catoctin schist.	Ac.		1000+	Epidotic and chloritic schists, with eruptive granite beds.
	Quartz-porphyry.	Aq.		500+	Grayish-black and bluish-black quartz-porphyry and rhyolite.
	Andesite.	Aa.		300+	Bluish-black and grayish-black schistose and massive andesite.

dikes upward into the diabase, and beyond their terminations a species of crust of undisturbed diabase, from which the present epidotic schist is derived. The chemical differences which later produced epidote lenses in one portion and not in the other would be attributable to contact metamorphism by the eruptive granite. Either the conditions favorable to subsequent epidote development were removed from masses within the influence of the granite or were added to masses outside its greatest heat. The latter seems inadmissible on account of the extreme extent to which the contact phenomena would need to be carried, an extent quite without parallel. The former is more plausible, because the phenomena are more within the range of other contact phenomena, though even here they are perhaps excessive.

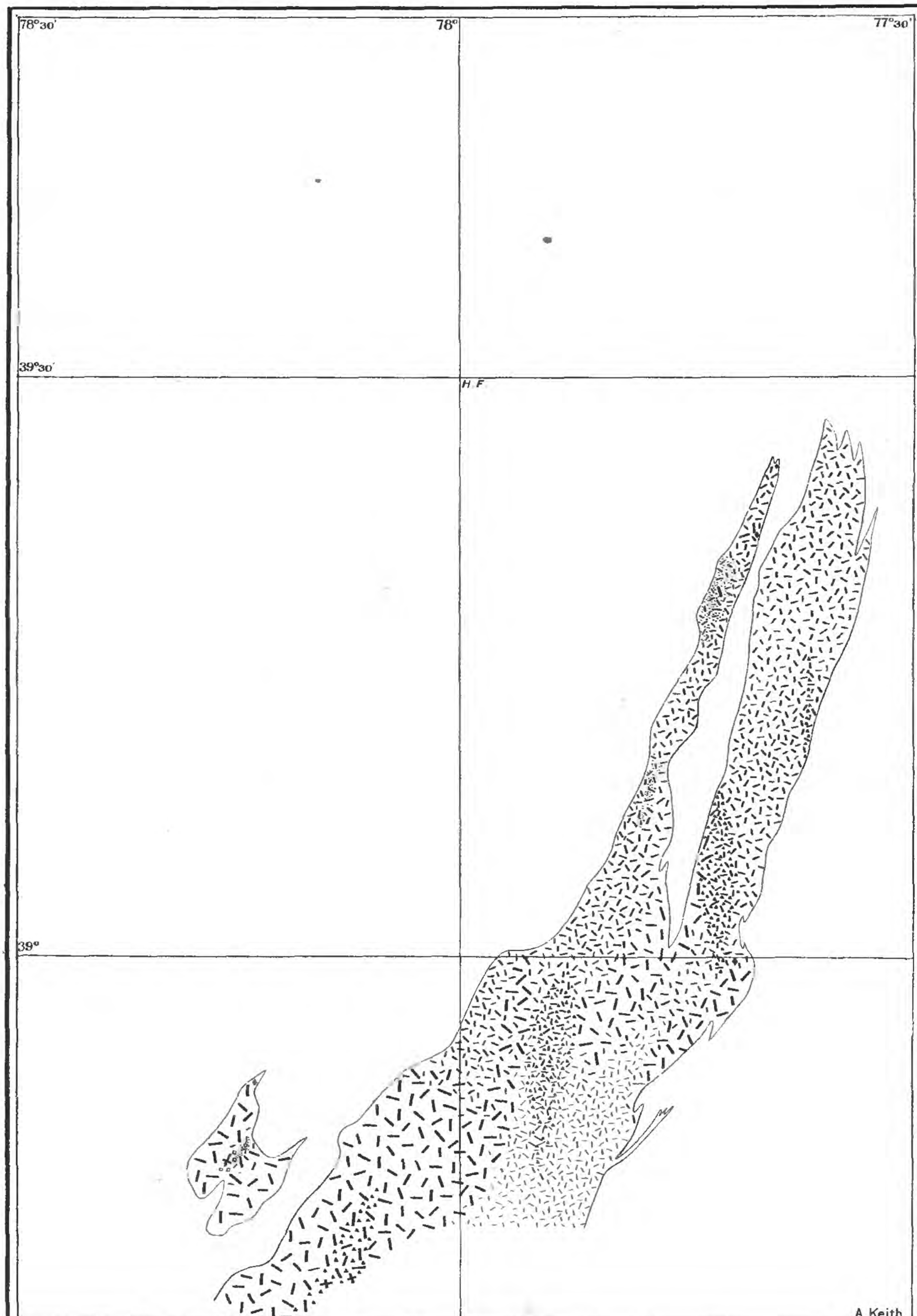
The hypothesis that the epidote masses and amygdaloids represent contact alteration has less value as the distribution of these features is analyzed. If they were contact features they would accompany all contacts to a greater or less degree. This, however, is distinctly not the case. In the southern areas of granite one side of a granite body may be bordered by epidotic schist, the other side by nonepidotic schist or coarse grained schist. Amygdaloid on one side has no correlative on the other. In other areas, where the granite is inclosed in the coarser schist, the alteration extends only for a few inches from the contact. In the northern areas where no granite occurs the epidotic feature still remains and, of course, can not be due to the granite. It might be attributed to the metamorphic action of the quartz-porphyry, were not the quartz-porphyry extruded before the diabase. It must, therefore, be inherent in the diabase. In that case, if the difference in the schists is due to the action of the granite, this initial epidotic tendency must have been obviated by later contact action of the granite. Contact action has been observed in numberless places, however, and only on a very limited scale, entirely out of proportion to the result demanded under the hypothesis. Observed alteration by inches hardly fulfills the required alteration by miles. The contact hypothesis therefore is inadequate to explain the differences in the schists.

Hypothesis of two flows of diabase.—The alternative hypothesis that the schists represent two lava flows meets with no a priori objection. The flows might have been separated either by a long or short interval; and the later flow have followed or preceded the granite injection. If it preceded the granite injection, then the absence of granite in the later flow must be accounted for, especially where the larger granite areas abruptly disappear under the epidotic schist; if it followed the granite injection, then the later flow would have covered granite, diabase, quartz-porphyry and andesite alike.

The occurrence of small outliers of quartz-porphyry and andesite between the epidotic and nonepidotic schist furnishes presumptive evidence of a separation into two schist formations at that horizon. If they were connected with the main quartz-porphyry and andesite flows, they would settle the matter at once by bodily separating the nonepidotic from the epidotic schist; and the same purpose would be served by finding a body of nonepidotic schist under the quartz-porphyry or andesite. The outliers might be regarded as anticlines of quartz-porphyry appearing under the schist, were it not for the discordant sequence on either side, epidotic schist replacing nonepidotic schist in some cases, and granite replacing schist in others. The boundary of the epidotic schist is thoroughly characteristic of an unconformity. Along Catoctin mountain the beds appear against it in the following order: At the north end quartz-porphyry, then granite and nonepidotic schist, coarse granite, and fine granite. Along the Blue Ridge–South mountain line they lie, quartz-porphyry, granite and nonepidotic schist, granite, coarse granite, granite and nonepidotic schist, coarse granite. On the west side of the Blue Ridge the sequence is andesite, granite, andesite. In all these stretches there is no change in the epidotic schist, except local addition of amygdules and greater or less concentration of epidote, while practically only one horizon of the epidotic schist is in contact with the other rocks. Such discordance could be produced only by unconformable deposition or by faults. If the latter were the cause, three-fourths of the present contacts would be abnormal, and it would be impossible to tell which was the normal and which the abnormal sequence.

One feature of the sequence in the southern portions of the area is worthy of special notice, and that is the occurrence of coarse granite in contact with the diabase. Granite of this texture was produced only at great depth, or by slow cooling of large bodies, but the diabase was a surface flow. The points of the occurrence are, first, that the coarse granite passes directly under the epidotic schist without intruding any dikes into the schist, and second, that the depth or body that produced the coarse grain of the granite ought to have had a similar effect upon the texture of the fine diabase. If the coarse mass of granite only touched the diabase in one area without sending off dikes, it might be considered merely an unusual feature, but that arrangement of the formations is so often repeated that the irregularity demands explanation. Also, the bulk of the diabase, which should have influenced its texture very largely, is much greater than that of the granite.

The value of this comparison of texture can be tested in adjacent regions. At first sight the granite-schist areas would seem to furnish a measure, because the rocks crystallized at approximately the same depth. The validity of the comparison is affected, however, by the doubt whether the diabase was extruded in successive small flows which cooled quickly, or whether it was a single flow and represents the maximum coarseness for its composition. In any event there is much less discordance of texture here than in the epidotic schist-granite sequence. In the Newark areas the diabases offer a fair comparison, because they are intrusive like the granite, and because their bulk can be roughly



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VARIATIONS IN GRANITE.

estimated. The larger diabase bodies of the Newark are of nearly equal size with the granite and are also nearly as coarse in texture. The fine grained varieties occur in the small dikes and the borders of large dikes. Hence it appears that under equal conditions of size and intrusion the Newark diabase and the granite crystallize with similar texture, and that the texture is largely dependent upon the mass to be cooled. Apply this to the granite-schist combination and it follows that where the diabase is fine grained it had small bulk; hence that the epidotic diabase was a succession of small flows, because if it had been a single flow its bulk would have produced coarser texture.

It also follows that the bulk of the granite was in itself sufficient to produce its coarse grain, if it had been intruded under the amount of diabase now visible, so that the discordance of coarseness does not prove that the granite was earlier than the epidotic schist. If, however, the boundary of the epidotic schist was the bottom of a second flow, then the granite next to it was at that time on the surface, although of deep seated origin, and could have gotten there only after removal of the outer beds of finer granite.

These criteria of coarseness can be applied with profit to the epidotic and nonepidotic schist, although usually the differences in texture are not great. When, as often occurs, the fine epidotic schist touches the coarser schist, a change of conditions obtains with the boundary. The general difference of the two schist bodies in texture indicates a general difference in conditions during their formationwhich tends to show that they are distinct formations.

Summary of evidence.—The epidotic schist viewed as a whole contains all the features of an overlying unconformable deposit. It is distinguished as a whole from the nonepidotic schist by its finer grain, which indicates a prevalent difference in conditions at formation. It is also distinguished as a whole by an original chemical difference which gave rise to the epidote development. It appears only in connection with synclinal basins. Its bottom beds have marked characters which prevail over various underlying rocks. This horizon occasionally contains fragments of underlying formations. It passes from one formation to another, one horizon resting upon both formations. This horizon is continuous from one end of the field to the other and in many places definitely marks the fact that the beginning of the epidotic schist is the beginning of a new formation.

On the other hand, the two groups of schist are the same in origin and can be separated only in a broad way, on account of the merging of their types. The coarse varieties, moreover, may represent the lower and more slowly cooled beds of a single formation.

The evidence in favor of unity is thus entirely negative and depends upon lithologic similarity. The evidence in favor of bipartition has the broader foundation of general phenomena and comprises all of the direct evidence.

In short, the preponderance of evidence in favor of the theory of separation is so great as to demand its adoption.

Erosion interval.—With the acceptance of two flows of diabase must also come the recognition of a great time gap between the two. In the evidence for bipartition there is a discordance of texture representing a difference in conditions of formation of the rocks. This could have arisen from erosion, faulting, or igneous intrusion. By the conclusion that the bottom of the epidotic schist was a plane of deposition, the last two are eliminated and erosion of earlier beds stands as the cause. The amount of this removal is uncertain, but from the extent of the evidence it seems to have been general over the southern part of the Catoctin belt and to have increased toward the southwest. In the interval between the diabase flows there took place the andesite and quartz-porphyry flows and the granite intrusion. That a considerable period intervened between these and the second diabase is likely, for the reason that their various outcrops are in places so scattered and in bulk so small as to suggest that they were remnants of a much larger body. At all events, that a considerable period elapsed between the diabase flows is proved by the same evidence that proves their separate origin.

Pre-Cambrian sequence.—The sequence of events in pre-Cambrian time stood, therefore, as follows:

(1) Diabase eruption.
(2) Granite intrusion.
(3) Erosion interval.
(4) Quartz-porphyry and andesite flows.
(5) (Erosion interval.)?
(6) Diabase flow.
(7) Erosion interval.

SEDIMENTARY ROCKS.

The second great class of rocks occurring in the Catoctin belt is the sedimentary series. It is all included in the Cambrian period and consists of limestone, shale, sandstone and conglomerate. The two border zones of the Catoctin belt, however, contain also rocks of the Silurian and Juratrias periods, which will be discussed in their bearing upon the history of the Catoctin belt. In general, the sediments are calcareous in the Shenandoah valley, sandy and calcareous in the Juratrias area, and sandy in the Catoctin belt. Their order and detailed character are shown in the stratigraphic section (Pl. XXIII).

LITERATURE

These sediments have been the theme of considerable literature, owing to their great extent and prominence in the topography. Until recently no fossils have been found in them excepting *Scolithus*, and various hypotheses as to their age have been put forward. W. B.

Rogers[1] calls them sandstones and conglomerates, alluding to the Weverton sandstone, and classes them as "Formation I" under "Silu-ro-Cambrian." The Loudoun formation is often mentioned[2] and its "slates" and "limestones" discussed; but it is classed with the altered lavas as "Archean (the old metamorphic and primary)" both on the accompanying map and the descriptions of sections. In a later publication[3] in 1877 he tabulates the Weverton sandstone as "No. 1, Lower Cambrian, Potsdam group." In 1875[4] W. M. Fontaine recognized the clastic nature of the Weverton sandstone in the Blue Ridge and Southwest mountain. Its prominent outcrop just east of Harpers Ferry was alluded to[5] as "a massive rock in structure, having all the features of an eruptive igneous material."

In 1882[6] J. L. Campbell properly characterized the Weverton sandstones and gave many details in regard to the slates and limestones of the Loudoun formation, but, like Rogers, classified them with the altered volcanics. His classification is: "the Archæan or Eozoic age includes numerous and extensive beds of granite, gneiss, mica-slates, talc-slates, chlorite-slates, sandstones, crystallized limestones, and other minerals, called metamorphic rocks;" and "the Primordial or Lower Cambrian age." Rocks of this age are chiefly sandstones and shales, and form the numerous broken ridges that skirt the northwestern slope of the Blue Ridge [near James river]."

In Maryland Tyson described the Weverton sandstone[7] as "sandstone (Potsdam sandstone of New York)."

In Pennsylvania H. D. Rogers[8] speaks of the Weverton sandstone in Jacks mountain and South mountain as "sandstone" and notes as associated "gray slates" the altered quartz-porphyry.

In 1875 Persifor Frazer describes many cross sections[9] of the South mountain group and says: "Hence, it is made apparent that the great South mountain chain is composed essentially of two groups of rocks, the lower (and along this line the northwestern) consisting of various modifications of the quartz conglomerate above spoken of and in which quartzite occurs under various forms. The upper and southeasterly group is felsitic in character, but contains also large beds of hydro-mica and chlorite schists, intersected by veins of milk quartz." By all these observers the sediments were considered to be of Potsdam age, a determination based entirely upon physical relations.

In 1890 Geiger and Keith discussed the Blue Ridge[10] and Catoctin mountain near the Potomac. Various differences of sandstone and

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[1] Geology of the Virginias.

[2] Ibid., p. 81 et seq.

[3] The Virginias, Vol, III, p. 61.

[4] Am. Jour. Science, 3d Ser. Vol. IX, pp. 19, 366.

[5] Op. cit., p 17.

[6] Geology and Mineral Resources of the James River valley, pp. 8–9.

[7] Report of Agricultural Chemist, p. 34.

[8] Fourth Annual Report of the State Geologist, 1840, p. 375.

[9] Second Geol. Survey of Pennsylvania, C. C. 1875, p. 285.

[10] Bull Geol. Soc. America, Vol. II, p. 155.

slate were pointed out, and two members were separated and mapped. In regard to the age of the series, after structural evidence was adduced in considerable detail, the two alternatives of Cambrian or Silurian age were presented. The present attitude of the beds, together with the simplicity and uniformity of their structure, furnished a preponderance of evidence in favor of Silurian age that seemed to the author too strong to be controverted except by fossils.

C. R. Keyes in 1890[1] says of the Weverton sandstone in Catoctin and Sugarloaf, "Both mountain crests are formed of hard sandstone shown in thin sections to be of unmistakable clastic origin. * * * Sugarloaf sandstone is seemingly identical with that of the Catoctin. * * * Below the sandstone the shales are more or less disturbed, while above the argillites are not at all affected and appear interstratified with the upper portions of the arenacons formation. This would point strongly to the conclusion that the plane of movement or thrust was at the bottom rather than at the top of the great Sugarloaf sandstone." Neither in his section nor text does Mr. Keyes give any statement of the age of the sandstone or its relation to the Shenandoah limestone at Frederick. His description of the phyllite belt lying to the east, in connection with Williams's description,[2] strongly suggests the Loudoun formation.

In. 1892 J. P. Lesley reaffirmed Frazer's[3] conclusions as to the sequence of sandstone and overlying orthofelsite in South mountain. He also saw that South mountain could not be considered an overturned anticline, thus recognizing the break along its western front. In regard to the age of the sandstone he hesitates between "Huronian" and "Cambrian."[4]

In 1892 C. D. Walcott found fossils in the topmost or Antietam sandstone which determined it to be of lower Cambrian age, and traced them from Monterey to Harpers Ferry, in company with the author. Soon afterwards the same fossils were found by the author as far south as Front Royal. These fossils were described by Mr. Walcott,[5] and a preliminary statement of the structure and stratigraphy was made by the present author.[6] At the same time G. H. Williams[7] says of the South mountain sandstones and volcanic rocks: "It may, however, be regarded as an open question whether the volcanic rocks represent a much older horizon, which was already eroded before the sandstone was deposited, or whether they were, in part, at least, contemporaneous with the sandstones."

The foregoing extracts present great diversity of opinion, and conclusions drawn from one set of observations are opposed to conclusions

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[1] Bull. Geol. Soc. America, Vol II, p 320-322.

[2] Ibid., Vol II, p. 307.

[3] Final Report, Penn. Geol. Survey, Vol I p. 144.

[4] Op. cit., p. 144, 147-148.

[5] Am. Jour Science, Vol. XLIV, Dec., 1892

[6] American Geologist, Dec.. 1892.

[7] Am. Jour. Sci., Vol XLIV, Dec., 1892, p. 493.

from another set, until they are four and five deep upon a single question. The inference is inevitable and true that without fossils a solution was impossible, because the original relations were so thoroughly obscured by a complicated structure. With the discovery of a definite fossiliferous band the situation changed, and the lever was furnished with which to lift the mass out of obscurity.

SEQUENCE.

Fossils are abundant in the Antietam sandstone and were discovered by slight search. Some of the sandy beds of the Harpers shale also contained a few fossils; elsewhere none were found, although considerable search was made. The problem of connecting this fossiliferous band with the rest of the series was found to be quite difficult on account of the complications of structure. As will be explained later in detail, the different formations occur in parallel synclines, and these synclines are separated from each other by faults.

Section at the north end of the Blue Ridge.—The full section is very rare, and, in fact, no one complete section is known far north from the James river. Portions of sections, however, complete for two or three members each, can be pieced together and a tolerable result secured. The Shenandoah limestone in its normal relation to the Antietam sandstone is of decidedly exceptional occurrence and observable at only one place, namely, at the north end of the Blue Ridge. This section comprises the Shenandoah limestone, Antietam sandstone, and a small part of the Harpers shale. It could with perfect justice be regarded as a faulted syncline instead of a normal monocline, and from a physical standpoint fails to prove itself as the normal relation.

Monterey and Front Royal sections.—Sections of the Loudoun formation and the Weverton sandstone are very common, and those two formations make up by far the greater part of the outcrops of the Cambrian beds along the Catoctin belt. In only two places is the Harpers shale to be seen above the Weverton sandstone; the first is about 6 miles northeast of Front Royal, in Virginia, along the Blue Ridge; the second is immediately west of Monterey, in Pennsylvania, near the Maryland line. In both these places the synclinal trough of the Weverton sandstone deepens for a few miles and includes a few hundred feet of the Harpers shale.

Frederick section.—Along the east side of Catoctin, in the latitude of Frederick, Maryland, the section is presumably complete; and in one case, immediately west of Frederick along the main turnpike, the Shenandoah limestone rests conformably upon the upper part of the siliceous series. The outcrop, however, is very limited in extent, only about a quarter of a mile long, and is covered over north and south by the later Newark deposits. In either direction the structure of Catoctin, which here is monoclinal, becomes synclinal and is complicated by faults, so that it is questionable, at least, whether the true sequence is really seen here or not. Its value lies, however, in its corroboration of the sequence established elsewhere. It is true that the section at the north end of the Blue Ridge is about as limited in extent as the section west of Frederick; but the relations of the latter sequence can be studied for considerable distances north and south, and a fair probability established that it is a normal sequence.

The fact remains, however, that from the Pennsylvania boundary south nearly to the James river there is no section of the upper part of the Cambrian which is indubitably normal. Direct tracing of the beds from known areas would not suffice, because the beds are disconnected in all directions. Therefore, before the discovery of fossils, correlation within those limits must have had its foundation in structure or in analogies with far distant sections, either of which methods is liable to error.

Balcony Falls section.—Elsewhere the position of this fossiliferous band is well determined, and it corresponds with that established at the north end of the Blue Ridge. At Balcony Falls, Virginia,[1] a similar sequence obtains and the bed of lower Cambrian fossils lies immediately beneath the Shenandoah limestone. In York county, Pennsylvania, several repetitions of this sequence were found.

It would seem safe, then, to accept the apparent section at the north end of the Blue Ridge as the true one. The assignment of the other members of the series becomes easier after that. Setting aside the Shenandoah limestone, Antietam sandstone, and Harpers shale as established in position, only two others remain to be assigned, the Weverton sandstone and the Loudoun formation. These must necessarily be below the Harpers shale unless, indeed, they are equivalent to the Antietam sandstone and the Harpers shale. The evidence in favor of the latter sequence is very restricted, and lies chiefly in the facts that each of the two series is a sequence of sandstone following shale, and that they occupy parallel synclines.

Equivalence of Weverton and Antietam sandstones.—The two sandstones differ from each other materially, however, and the two shale formations likewise. The Harpers shale is very uniform in character; the Loudoun formation is extremely varied. Certain portions of the Loudoun formation, indeed, resemble the Harpers shale very strikingly, but as typically developed both are unmistakable. The Weverton sandstone is quite unlike the Antietam sandstone. The latter is a thin bed of calcareous white sandstone, has a maximum thickness of 500 feet, and marks a period of quiet deposition and large development of life. The Weverton sandstone, on the contrary, varies from a fine quartzite 100 feet thick to a conglomerate 1,000 feet thick containing quartz pebbles and bits of slate. Its cross-bedding, ripple marks, and variety show its accumulation under changeable conditions. The finer portions of the Weverton sandstone, indeed, resemble the Antietam

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[1] C. D. Walcott: Am. Jour. Sci., July, 1892, p. 53; Dec., 1892, p. 474.

sandstone quite strongly; in these intermediate types the former is usually feldspathic and the latter calcareous. The difference between the two, while sometimes not so marked to the eye, is always apparent in topography. The calcareous matter in the Antietam sandstone causes it to disintegrate rapidly, and ledges of it are rarely seen. This susceptibility to weathering consigns it to a subordinate position in the make-up of the mountain range, so that it occupies rows of lesser knobs. The Weverton sandstone, on the contrary, especially where it is heavily developed, forms bold ridges, with frequent cliffs, and dominates the entire mountain range. These differences could be explained as shore variations of a single bed without straining probabilities. In fact, they are matched by the variations of the Weverton sandstone itself, and can not be considered final.

An equally important and much more decisive difference between the Antietam and Weverton sandstones lies in the organic contents of each. As has been stated, the Antietam sandstone is highly fossiliferous. The Weverton sandstone, on the contrary, carries not a trace of life. The two beds lie in parallel outcrops for many miles along the Blue Ridge, and if the two were similar it seems scarcely possible that the fossils so abundant in one should not be found also in the other.

The possibility of equivalence of the two sandstones was removed, however, by the discovery of shales above the Weverton sandstone similar to the Harpers shale. Obviously the Weverton sandstone, 1,000 feet thick and with 500 feet of shale above it, could not be equivalent to the Antietam sandstone, 500 feet thick, with the Shenandoah limestone above it. The sequence then was established as it has been described in the stratigraphic section. The only factor of doubt remaining is the amount of Harpers shale between the two sandstones, and this must always remain in doubt, inasmuch as no complete section of the two is known. Further south, it is true, in the vicinity of Balcony Falls, the section is complete, but the section which would hold good there would not of necessity be true at Harpers Ferry.

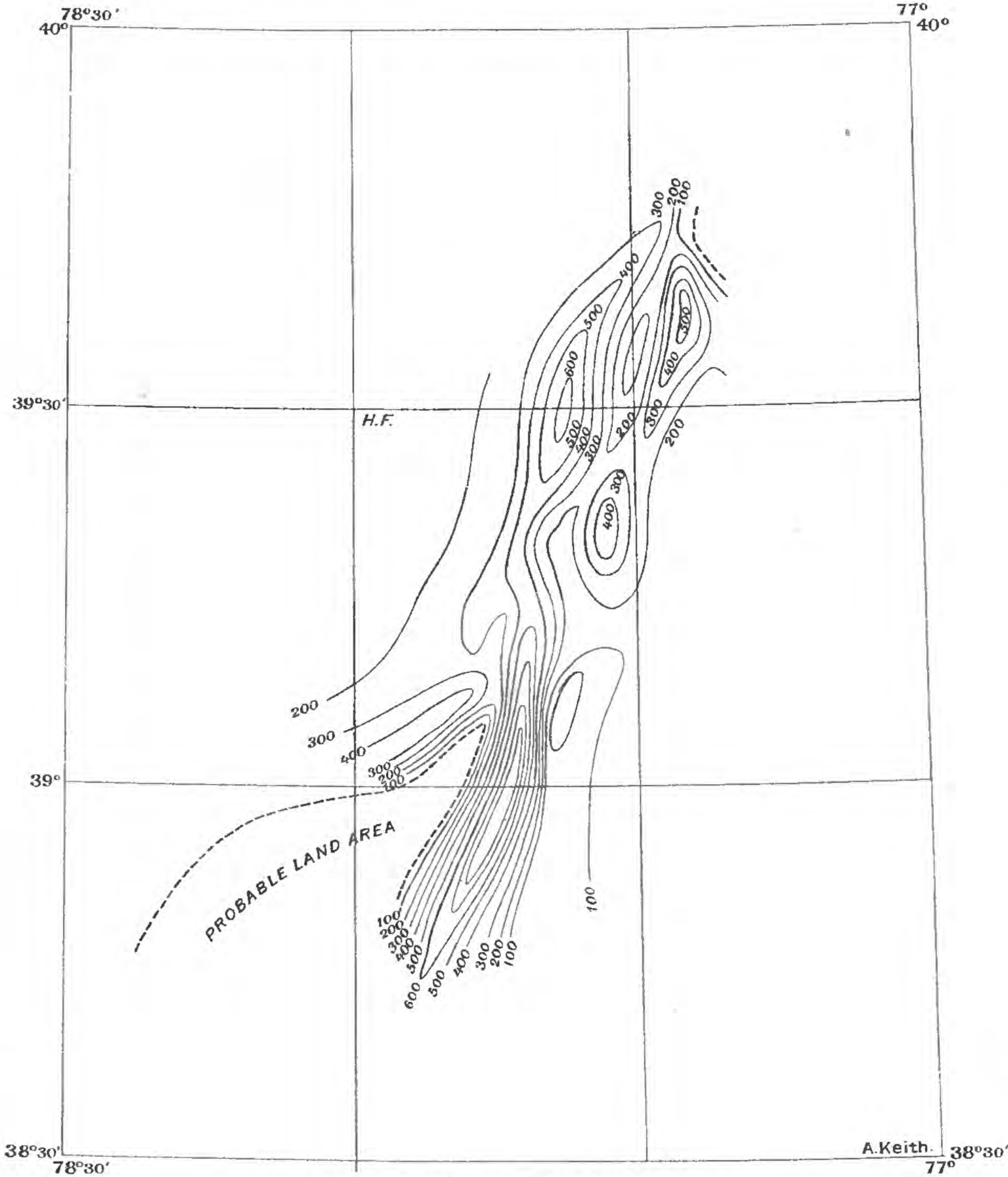
Importance of fossils.—In establishing the sequence of these beds the importance of the fossils can not be overstated. Were it not for their presence the one remaining normal section could not for a moment counterbalance the hundred uniform sections giving another relation. Were it not for their repeated establishment elsewhere in a zone immediately beneath the Shenandoah limestone, the one normal section in this region could not be identified as normal, since the fact that the Antietam sandstone was Cambrian did not establish its position next beneath the Shenandoah limestone.

Were it not for the establishment of this Antietam-Shenandoah sequence the shale overlying the Weverton sandstone could not be identified as Harpers shale, but might equally represent a shale overlying the Antietam and Antietam be equivalent to Weverton. Thus it is evident that not only were fossils in this region necessary to establish the *general* age of the formations, but also they were needed in other places to establish a *sequence* for use here.

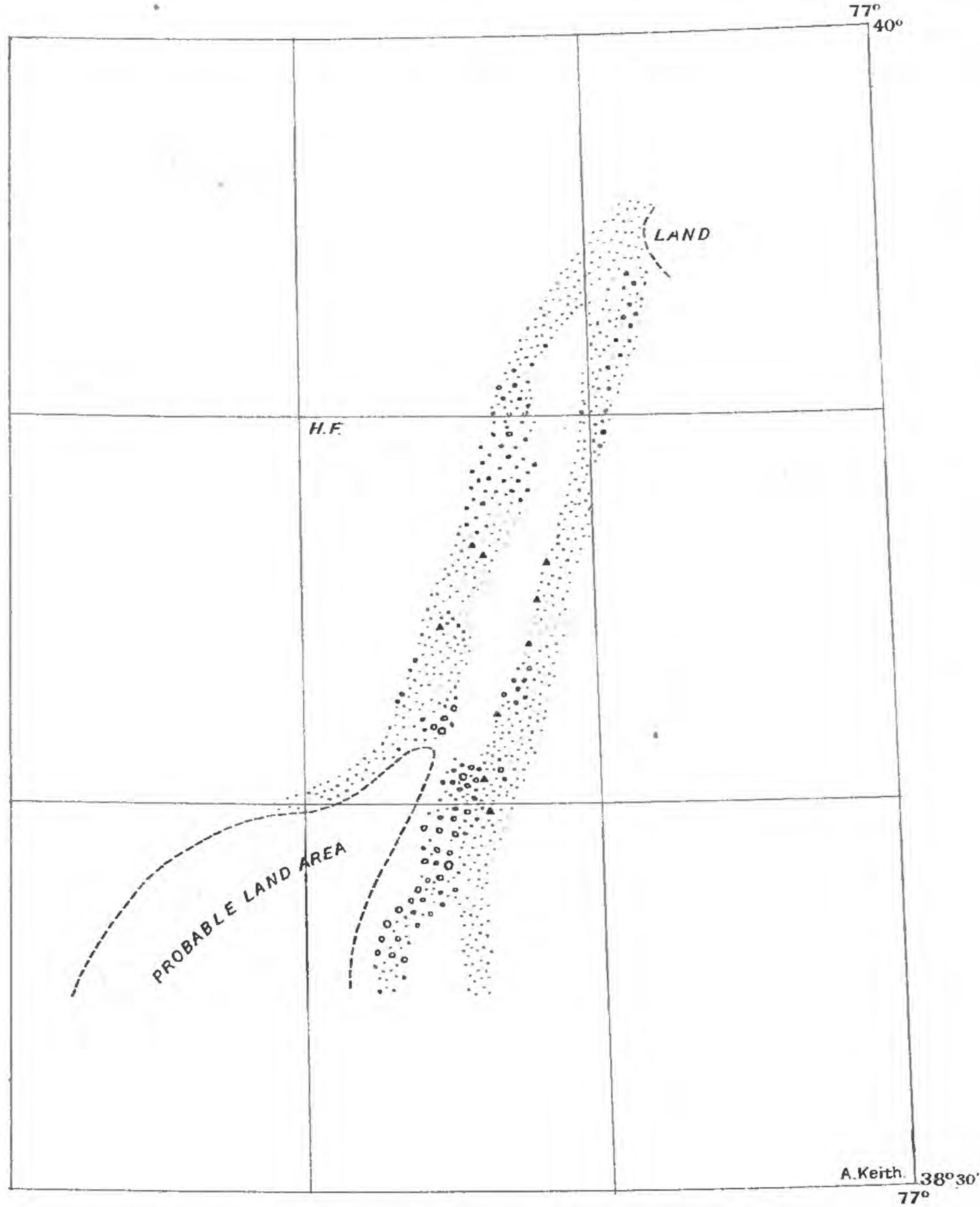
LOUDOUN FORMATION.

Variability.—Among the various Cambrian formations of the Catoctin belt there are wide differences in uniformity and composition. In none is it more manifest than in the first or Loudoun formation. This was theoretically to be expected, for first deposits upon a crystalline foundation represent great changes and transition periods of adjustment among new currents and sources of supply. The Loudoun formation, indeed, runs the whole gamut of sedimentary possibilities, and that within very short geographical limits. Five miles northwest of Aldie, in Virginia, the Loudoun formation comprises limestone, slate, sandy slate, sandstone, and conglomerate with pebbles as large as hickory nuts. These amount in thickness to fully 800 feet, while less than 3 miles to the east the entire formation is represented by 8 or 10 feet of black slate. On the accompanying diagram (Pl. XXV) these variations are represented.

Limestone.—The name of the Loudoun formation is given on account of the frequent occurrence of all its variations in Loudoun county, Virginia. Throughout the entire extent of the Catoctin belt, and especially through its central portions, the Loudoun formation has frequent beds of sandstone, conglomerate, and limestone. The limestones occur as lenses along two lines; one immediately west of Catoctin mountain, the other 3 or 4 miles east of the Blue Ridge. Along the western range the limestone lenses extend only to the Potomac. There they are shown on both sides of the river, and have been worked in either place for agricultural lime. Only the refuse of the limestone now remains, but the outcrops have been extant until recent years. Along the eastern line the limestone lenses extend across the Potomac and into Maryland for about 1 mile, and it is along this belt that they are the most persistent and valuable. As a rule they are altered from limestone into marble, and at one point they have been worked for commercial purposes. Nearly every outcrop has been opened, however, for agricultural lime. Where Goose creek crosses this belt a quarry has been opened and good marble has been taken out, but want of transportation facilities has prevented any considerable development. Among the varieties at the quarry are included pure white, white and pink, blue and white, white and green, serpentinized, and chloritic serpentinized marble. These marbles are of great beauty and susceptible of a good polish. The calcareous bed here is about 50 feet thick and reaches southward for 3 miles with increasing thickness. At its southern end it is not entirely metamorphosed into marble, but retains its original character of fine blue limestone. Northward along this range the thickness of the marble constantly diminishes and rarely



VARIATIONS IN THICKNESS.



VARIATIONS FROM CONGLOMERATE,° TO SLATE,· AND LIMESTONE ▲

DIAGRAM OF LOUDOUN FORMATION.

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exceeds 10 feet. Sometimes there are two beds, sometimes only one. At Taylorsville, just south of the Potomac, the bed is about 3 feet thick; on the north side of the Potomac about 4 or 5 feet. Here, as elsewhere, the beds of marble are inclosed in a bluish green micaceous schist, which has been thoroughly transformed by mechanical pressure. The relation between marble and schist is very perfectly shown at an old quarry west of Leesburg. The marble occupies two beds in schist, and between the two rocks there is gradation of composition. In none of the western belts are the calcareous beds recrystallized into marbles, but all retain their original character of blue and dove-colored limestone. None of them, however, are of great thickness and none of great linear extent.

From the diagram (Pl. xxv) it will be seen that the formation is especially developed with respect to thickness and coarseness along two lines, the one lying a little west of Catoctin mountain, along the present line of the limestone outcrop, and the other roughly following the course of South mountain, and for a distance beyond its present extent. Outside of these two general basins the outcrops of the Loudoun formation are almost entirely black slate. This is true along the Blue Ridge, through almost its entire length, and also through the entire length of the Catoctin mountain. On the latter range it is doubtful if this formation exceeds 200 feet in thickness at any point. Along the Blue Ridge it may, and probably does, in places, reach 500 feet in thickness, especially in the vicinity of Turners gap, 10 miles north of the Potomac.

Conglomerate and sandstone.—The distribution of the coarse varieties coincides closely with the areas of greatest thickness and also with the synclines in which no Weverton sandstone appears. In fact, with two exceptions, the conglomerate phase of the Loudoun formation is never associated with the Weverton sandstone in any place. The two exceptions are immediately east of the Harpers Ferry gap and south of Rohrersville, in Maryland, 7 miles north of the Potomac. These conglomerates are made up of epidotic schist, andesite, quartz, granite, epidote, and jasper pebbles embedded in a matrix of black slate and are very limited in extent. Of the sandstones occurring northwest of Aldie, Virginia, in certain places almost the entire deposit is made up of reconsolidated débris of the adjacent biotite-granite, so little changed in aspect that it is extremely difficult to separate the granite from the derived sandstone, and the services of the microscope are necessary to determine the identity. The coarse conglomerate lying west and northwest of Aldie is made up chiefly of fragments of the granitic rocks immediately adjacent, namely, the white and the blue quartz. This blue quartz, as has been stated, is the constant accompaniment of the granite in certain regions, especially here, and can be readily identified wherever seen. The sandstones of the Loudoun formation in the northern outcrops contain only grains of white quartz, which may be derived either from the Catoctin schists or from the white quartzes of the granites themselves. In those regions the granites contain no blue quartz at all. East of Ashby gap, on the Blue Ridge, there is a limited outcrop of sandstone containing fragments of white quartz and of jasper, which, of course, were derived from the Blue Ridge to the west, where jasper is abundantly developed in the Catoctin schist. No jasper occurs to the east of this locality of sandstone, and therefore its source can be quite positively identified.

Mode of deposit.—It appears plain, therefore, that the coarser materials of the Loudoun formation were of local derivation and were accumulated according to different local conditions. The separate basins seem to be entirely independent of each other, and the individual beds have but little continuity even in their own basins. In fact, they are precisely analogous to modern beach deposits in shallow waters, and are just such as would be formed by waters advancing over a territory which had hitherto been land and exposed to the disintegrating effects of the atmosphere. That this submergence was irregular is proven, of course, by the existence in the lower beds of the Loudoun formation of fragments of the same crystalline rocks upon which the formation was deposited: part of the crystallines must have been above water at first. Yet, before the close of the formation, submergence was complete, because at no point does the next succeeding formation—the Weverton sandstone—rest directly upon the crystallines. The nearest approach to that condition is along the south end of Catoctin mountain, especially in the vicinity of Goose creek, but even there the Loudoun formation has its representative in 8 or 10 feet of black slate. At the north end of Catoctin a very few feet of slate separate the Weverton from the crystallines. In the latitude of Front Royal, also, the amount of slate below the Weverton is extremely small.

Unity of the formation.—The general grouping of the Loudoun formation into two classes of deposit, (1) the fine slates associated with the Weverton sandstone and (2) the coarse sandstones occurring in deep synclines with no Weverton, raises the question of the unity of the formation. The evidence on this point is manifold and apparently conclusive. The general composition of the two is the same—i. e., beds of feldspathic, siliceous material derived from crystalline rocks. They are similarly metamorphosed in different localities. The upper parts of the thicker series are slates identical in appearance with the slates under the Weverton, which presumably represent the upper Loudoun. Along South mountain and the north end of Catoctin, the Loudoun thickens considerably and approaches the volume of the coarser basins. Finally, the phenomenon of limestone lenses, which is commented upon by Rogers and Fontaine, in many other parts of Virginia, is displayed in connection with the Weverton sandstone near Weverton, Maryland. There the syncline of Weverton sandstone rests upon shales which in turn rest upon a lens of limestone. The limestones, as has been said, are not now visible, but were removed to burn on the spot for lime and are well authenticated. Around Mechanicstown, Maryland, also, is a series of limestone lenses in slate adjoining the Weverton sandstone. These slates may possibly represent the middle slaty portion of the Shenandoah limestone, but the lenticular character of the limestone and predominence of slate make that unlikely. Negative evidence in the same direction is the completeness of the sequence from the Weverton up to the Devonian in northern Virginia, and the lack of another suitable horizon for the coarse Loudoun sandstones until the end of the Paleozoic.

On the solution of this question depends the entire interpretation of the history of the Loudoun formation and of the crystallines for a small period preceding the deposition of the Loudoun. In the following pages it will be assumed that the two phases are but parts of a whole, a conclusion which appears amply founded on fact.

Pre-Loudoun geography.—The Loudoun formation, of course, followed a period of erosion of the Catoctin belt, since it is the first subaqueous deposit. The shape of the Catoctin land area just before submergence is the first definite information obtainable of the geography of that period. The form of deposit produced by that submergence would vary according to the relief of the areas submerged, so that, from the variations of the deposits, something can be inferred of the relief. It may be assumed that strong relief would produce varied sediment, simply by the differentiation of distributing currents, and low relief would give uniform sediment. Interpreted on that basis, the Loudoun formation gives most decisive evidence of varied relief. Also, strong relief would produce basins with thicker accumulations, while low relief would produce uniform deposit. On this basis, too, the formation proclaims strong relief with basins of at least 800 feet in depth, as measured by the thickness of the formation west of Aldie. That there were any actual land areas at the end of the Loudoun period is an inference from later formations, as the top of the Loudoun formation has no characters that decide the question. The small thickness of the formation between the crystallines and Weverton in certain places indicates that land areas persisted through almost the whole period at any rate.

Pre-Loudoun erosion.—From the relatively strong relief preceding the Loudoun submergence we can infer a considerable period of erosion. The depth of the valleys—over 800 feet—was in fact very closely comparable to that of the present valleys and coincided to an almost equal extent in location on the granite and nonepidotic schist. The ridges also, as indicated by areas where the slates are thin, corresponded roughly in location and were closely dependent upon the epidotic schist. In the south part of the belt, especially, the intermediate valley and flanking ridges were decidedly similar.

In short, if the present surface were submerged gradually the history of Loudoun sedimentation would be precisely repeated. Small irregular basins would first be filled by varying deposits; as sedimentation kept pace with sinking, larger hollows would be filled, until only the major heights of hard rock remained. Final submergence would produce a uniform deposit over all places.

Looking back of the record left by the Loudoun formation, the next indication of surface forms is found in the acid and basic lava flows. These, as previously shown, were surface productions. Between the surface that their nature assumed and the pre-Loudoun surface there was a recorded denudation. May there not have been other deposits between the two periods? On this point there is no evidence whatsoever, except that in the synclines, which have preserved the highest rocks, there is nothing but the Cambrian and the diabase flow. The sequence of deposits, therefore, must be assumed to be complete between diabase and Loudoun, as it shows to-day.

Regarding the diabase as the latest pre-Loudoun bed, then the amount of degradation of the diabase is the measure of the erosion interval. That the interval was considerable will be deduced from the forms of the land before submergence. This conclusion is amply supported by the fact that the cover of epidotic diabase was denuded over much of the area and the sediments deposited directly upon the granite. The fact, also, that the coarse or deep seated granite is in contact with the sediments is direct proof of deep erosion. Along one zone, near the course of the present Potomac river, this removal of the upper diabase was nearly complete in Catoctin mountain, and quite complete in South mountain and the Blue Ridge. The excess of the degradation there, for nowhere else were the pre-Loudoun mountains cut through, indicates that the stream which produced the degradation was there located. The amount of the cutting was a little more than the thickness of upper diabase—700 to 1,000 feet—and is thus commensurate with the depth of valley deduced from the thicknesses of the Loudoun formation—800 feet.

The duration of this period of erosion can be compared roughly with more modern events of like character. The slopes of the ancient surface seem steep, if considered in their present relations, but they have suffered the usual Appalachian compression, which has brought the sides of the basin nearer to each other. This compression in most parts of the Appalachians is about one-half, so that a present slope northwest of Aldie, of 800 feet in 3 miles, represents an original slope of 800 feet in 6 miles, or 116 feet per mile. This is a very moderate slope, and when it is considered that it represents one of the deepest valleys it will be seen that erosion had made great progress toward baseleveling the region. If judged by the infrequency of steep slopes, the proportionate perfection of reduction appears greater in the pre-Loudoun than the present surface. If judged by actual depth of erosion, the 800 feet between the lower Cretaceous baselevel and the

Tertiary baselevel is not unlike the 800 to 1,000 feet of the pre-Loudoun valleys. If judged by the resistance of the rocks to erosion then the reduction of the upper diabase in pre-Loudoun time required a longer period than its comparative immunity in Tertiary time. The duration of the pre-Loudoun erosion, therefore, was probably considerably greater than the duration of similar Tertiary erosion, which will be hereafter considered.

To sum up, the surface lava flows were extensively denuded during a period much longer than the Tertiary. Degradation was closed by submergence, and over the uneven surfaces of the ancient rocks were deposited the residual accumulations of local material. Continued submergence filled the valleys until only traces of land remained.

WEVERTON SANDSTONE.

Composition and color.—The formation next succeeding the Loudoun formation is the Weverton sandstone. It is so named on account of its prominent outcrops in South mountain near Weverton, Maryland. It consists entirely of siliceous fragments, mainly quartz and feldspar. Its texture varies from a very fine, pure sandstone to a moderately coarse conglomerate, but as a whole it is a sandstone. As a whole its color is white and varies but little; the coarse beds have a grayish color in most places. Frequent bands and streaks of bluish black and black are added to the white sandstones, especially along the southern portion of the Blue Ridge. The appearance of the rock is not modified by the amount of feldspar which it contains. The variations of the formation, both in texture and thickness, are shown in the accompanying diagrams, Pl. XXVI.

From the distribution of these various fragments, inconspicuous as they are, considerable can be deduced in regard to the environment[1] of the Weverton sandstone.

As stated above, the submergence of the Catoctin belt was practically complete, because the Weverton sandstone nowhere touches the crystalline rocks. Perhaps it were better stated that submergence was complete in the basins in which Weverton sandstone now appears. Beyond these basins, however, it is questionable if the submergence was complete, because in the Weverton sandstone itself are numerous fragments which could have been derived only from the granite masses. These fragments consist of blue quartz, white quartz and feldspar.

Source of blue quartz fragments.—In that portion of the Catoctin belt known to the author the origin of these fragments can not, it is true, be very definitely located, but the blue quartz fragments at least can be assigned to the granite areas which produce blue quartz; that is to say, to the southern portion of the area mapped. The blue quartz fragments are confined almost exclusively to the outcrops of the Weverton sand-

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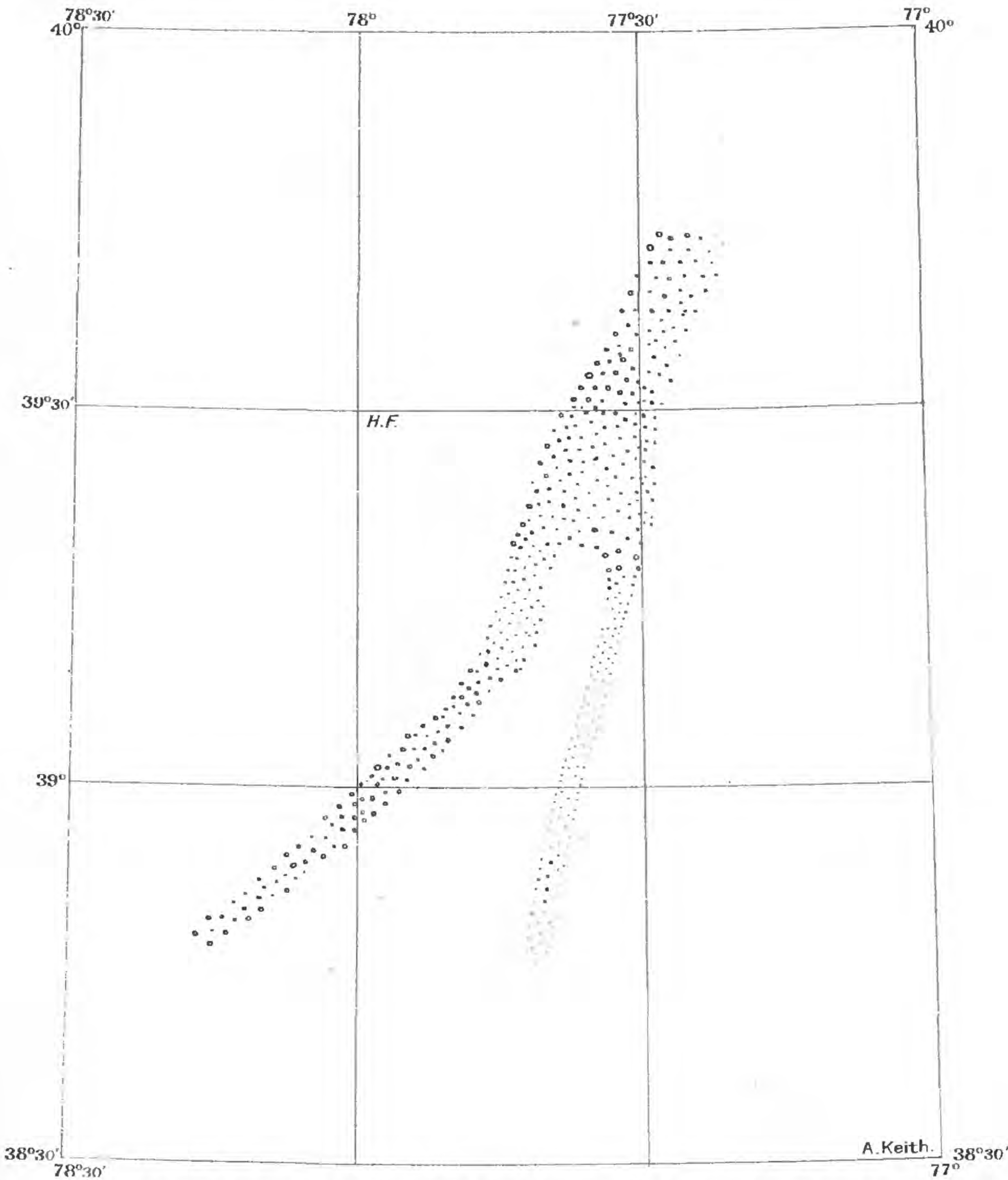
[1] The term "environment" is proposed to indicate the surroundings of a formation, such as the shape of the surface, the distributing currents, and the amount and nature of the material.

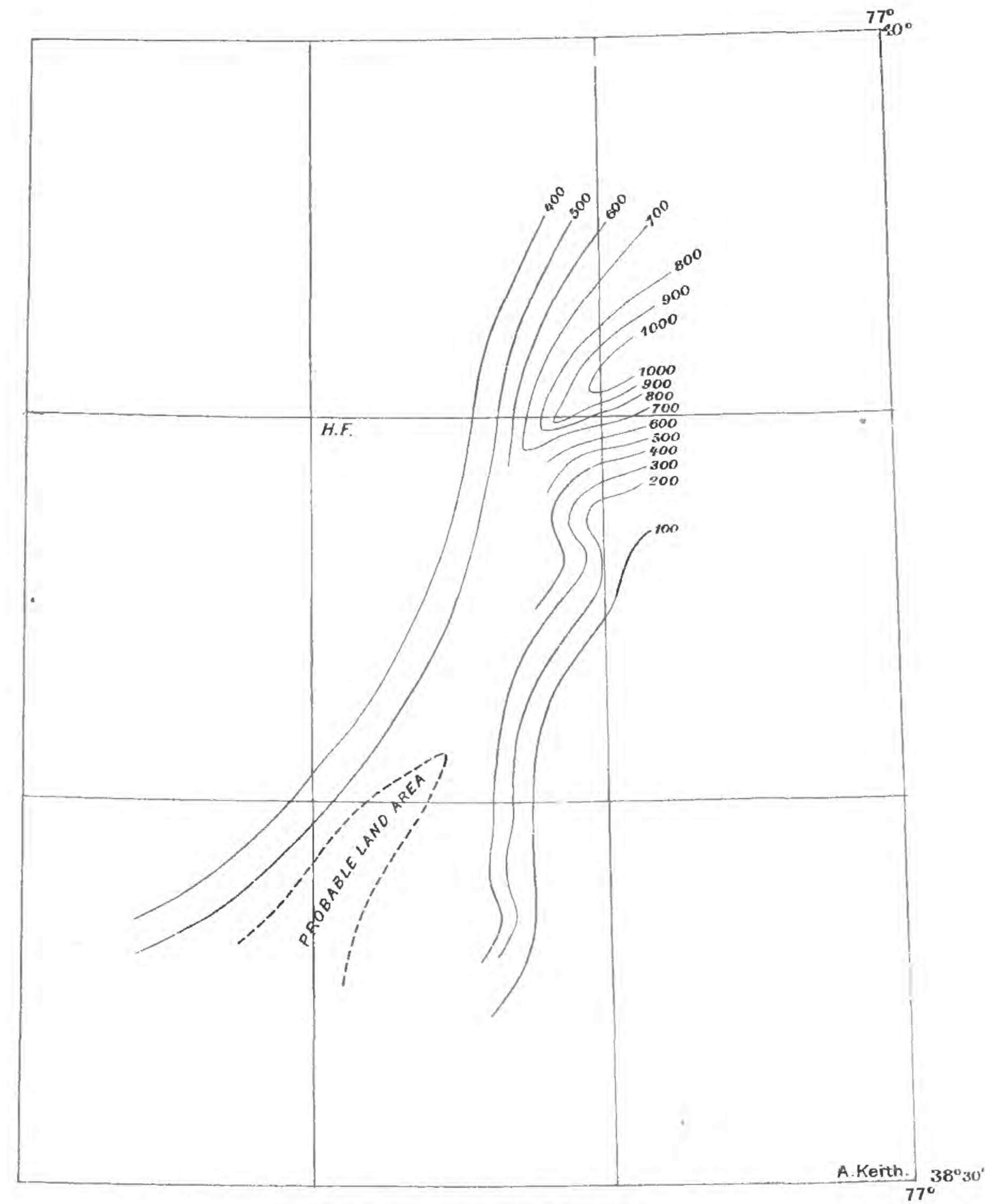
stone in the Blue Ridge south of the Potomac, and are rarely found on Catoctin. Where the blue quartz fragments occur, there the Weverton sandstone is apt to be most coarse and conglomeritic. They would appear therefore to represent the location of the shallow waters and the strongest currents. They lie west of the blue quartz granite and their prominence ceases at nearly the same latitude as the outcrops of blue quartz granite. The blue quartz conglomerate therefore seems to represent the shore accumulation of débris from the blue quartz granite, and the direction from the latter to the former is the general direction of the Weverton drainage system, i. e., from southeast to northwest. The absence of blue quartz in the sandstones of Catoctin and Bull Run mountains points to the existence of a divide between the land areas of blue quartz and the Cacoctin-Bull Run basin, and also indicates the submergence (previously deduced from the Loudoun formation) of the blue quartz granites just west of Catoctin. Within the area mapped, therefore, only the southwestern blue quartz areas could have furnished blue quartz for the sandstones. Since the blue quartz fragments range much further toward the north than their source it follows that the distributing currents ran from south to north, or, more strictly, northeasterly along the shore.

Source of iron oxides.—Another component of the Weverton sandstone, the iron oxides derived from the volcanic rocks, deserves mention, although it can not be used to establish a definite geography. Iron oxide in the form of magnetite and ilmenite is a universal constituent of the schists and quite common in the quartz-porphyry. As a prominent feature of the sandstones it is confined to the west side of the Catoctin belt and to the coarser beds, as should be the case with so heavy a mineral. It can not be assigned to any particular area of the volcanic rocks, but it serves to show that they existed above water at that time and furnished much of this class of débris to the western sandstone basins. Its scant development along the Catoctin-Bull Run range might indicate either that only small areas of volcanic rocks were above water then or that the shore was too distant and water too deep to permit the transportation of such heavy material. Probably both conditions existed; for, during Loudoun deposition, the areas lying west of Catoctin consisted chiefly of granite, even these being submerged near Catoctin, and the distance from shore is also attested by the thinness of the Weverton sandstone. That the distance from shore is not the sole factor is shown by the absence of iron oxides in the shore developments of Weverton sandstone at the north end of Catoctin mountain. One thing appears clear, however, and that is that the barrier between Catoctin and Blue Ridge deduced from the distribution of the blue quartz is corroborated by the difference in magnetite content.

Source of feldspar.—A third constituent of the Weverton sandstone of great importance is the feldspathic débris. It occurs to a limited extent in most of the outcrops of the formations along the Blue Ridge, but it is most prominently developed at the northern end of Catoctin



VARIATIONS FROM FINE SANDSTONE TO CONGLOMERATE.



VARIATIONS IN THICKNESS.

DIAGRAM OF WEVERTON SANDSTONE.

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mountain. This feldspathic débris, of course, could have been derived only from the igneous rocks, presumably from the granite in this case. With the exception of the phenocrysts in the quartz-porphyry, the size of the feldspar individuals in the Catoctin schist and quartz-porphyry is very small indeed, and could not have furnished fragments of any size whatever. The feldspars in the granites, however, are of considerable size. The rock is easily disintegrated and would have furnished large amounts of this detritus to erosion.

The granite areas end, as has been stated, in about the center of the belt in Maryland, and it is about at the same latitude that the amount of feldspar in the Weverton sandstone on Catoctin begins to be noticeable; south of this point there is practically none, and the formation is almost entirely pure quartz. Judging from this coincidence, it would seem at first sight that the course of the current was nearly north; but it is hard to account for the paucity of feldspar near the points of derivation if the current ran in that direction. It is possible, however, that the feldspar in the Weverton sandstone at this point came from other granites or feldspathic rocks; and the increase of the amount of feldspar away from the granite in the Catoctin belt appears to favor this conclusion. Indeed, the amount of feldspar itself would indicate a current running from north to south; in other words, toward the Catoctin granite areas.

There are considerable granite and gneiss areas in Maryland and Pennsylvania, east and northeast of Catoctin mountain, and it is possible that the débris came from these. They are far distant, however, and it would be almost necessary to find some nearer source than that, because feldspar is not a mineral which bears long transportation, least of all, among the conditions which characterize this formation. Cross-bedding is a frequent phenomenon in the Weverton sandstone, especially at the northern end of Catoctin mountain, where the amount of feldspar is most prominent. Beach action and current-scouring, therefore, were at work upon the formation and would soon have reduced any feldspar to clay. We must assume, therefore, either that the feldspar came from the granite areas of the present Catoctin belt, or that some body of gneissoid or granitoid rocks lay near at hand and is now covered over by the Newark formation. The latter alternative assumes a land area that can not be directly proved or disproved. Still, it is far preferable, both because the feldspar débris is not disposed around the Catoctin granite areas as if derived from them, and because the set of currents deduced from the blue quartz débris would produce an opposite arrangement of feldspar débris from that which obtains.

Evidence favoring the existence of this sub-Newark land area is the thinness of the Loudoun formation at the north end of Catoctin, amounting almost to overlap. From this it is evident that land was exposed almost to the end of the Loudoun time, and a presumption is furnished that an actual land may have continued in the vicinity during Weverton time. The existence of this sub-Newark land mass is also favored by the variations of the sandstone in thickness. As shown on Pl. XXVI, a marked change in thickness occurs along Catoctin mountain, the formation diminishing from 1,000 to 200 feet in a few miles. This plainly indicates shore conditions, and the nature of the accompanying change of constituent material locates the direction of the shore. This change is a decrease of the feldspar amounting to elimination at the Potomac. As the feldspar, which is granular at the shore, is soon reduced to fine clay and washed away, the direction of its disappearance is the direction of deep water. Thus the constitution and thickness of the Weverton sandstone unite in showing the existence of land not far northeast of Catoctin mountain during Weverton deposition.

Aside from this marked change in thickness none of unusual extent appears in the Weverton sandstone over the remainder of the Catoctin belt. While this is partly due to lack of complete sections, yet such as are complete show a substantial uniformity. The sections of the Blue Ridge outcrops range around 500 feet and those of the Catoctin line are in the vicinity of 300. This permanent difference in thickness along the two lines can be attributed to an eastward thinning of the formation, thus, however, implying a shore to the west of the Blue Ridge line. It can also be attributed to the existence of a barrier between the two; and this agrees with the deductions from the constituent fragments.

Cause of Weverton deposition.—When the nature of the movement that initiated the deposition of the Weverton sandstone is considered, various hypotheses present themselves. During Loudoun deposition there was continuous depression, culminating in wholesale submergence. This period was closed by a marked change and by deposition of Weverton sandstone. Did this change occur in further submergence, in elevation, in source of sediment, or in distributing currents? If the change was further submergence, it could not have been great, for the Weverton is plainly a shoal-water formation along the Blue Ridge and the north end of Catoctin. If the change was elevation, it could not have been great, else portions of the Loudoun formation would have been exposed or eroded. This might be the case, it is true, over the center of the belt, where neither Loudoun nor Weverton occur, but to assume it would beg the question. The change could not have been a shifting of the source of sediment, for both Loudoun and Weverton were derived from neighboring rocks. The remaining hypothesis, that of change in distributing currents, is the most tenable. During Loudoun time the absence of any systematic distribution is attested by the conspicuous irregularity of the deposits. Toward the close of Loudoun time the fine black slates immediately under the Weverton give evidence of tolerably uniform environment, also of quiet deposition. The succeeding sandstones of the Weverton are uniform over large areas, thus showing uniform environment. They show strong currents by the size of the pebbles and the distance to which they were carried; they show permanence of environment by the perfect assortment of material and the considerable thickness of deposit. In short, development of a system of currents would have transformed the disorder of Loudoun into the order of Weverton environment. The conclusion seems well founded, therefore, that the introduction of a system of distribution followed the Loudoun deposition and differentiated the Weverton from the Loudoun deposits.

When the considerations of the preceding pages are summed up, the following episodes appear to have been established in the early history of the Catoctin belt: Prior to the Cambrian deposition the lava flows were cut through by erosion and reduced to a surface similar to the present. Over this somewhat irregular surface the sea encroached more and more with continued depression. Local débris was slightly worked over and deposited as limestone, shale, sandstone and conglomerate—the Loudoun formation. Then a system of currents ensued, worked over similar débris, sorted out the finer parts for deposition in deep water, and left the harder, larger fragments along the shores. The improvement in system that was manifest in the Weverton sandstone over the Loudoun formation, is further accented in the subsequent deposit.

HARPERS SHALE.

Composition.—The formation next succeeding the Weverton sandstone is the Harpers shale. It is so called from its fine exhibition at Harpers Ferry, West Virginia, along the gorge of the Potomac. Its outcrops are more limited in extent than the Weverton sandstone, and are confined almost exclusively to the Blue Ridge belt; they extend, however, along its whole length, and show remarkably little variation. The shales when fresh are a dull bluish gray and weather out to a light, dirty, greenish gray. In composition they are argillaceous and sandy, although the sandy feature is not pronounced except at certain horizons. Taking the southern half of the belt, that is to say, as far north as Harpers Ferry, there is scarcely any variation from one bed to another, and the whole is a uniform, argillaceous, slightly sandy shale. Northward from the Potomac, beds of sandstones and sandy shales begin to appear, especially in the upper portion of the shale. In the northern portion of the belt, toward the Pennsylvania line, these beds of intercalated sandstones attain a considerable thickness, varying from 4 or 5 up to 50 feet. They are never, however, of sufficient importance to make a decided change in the formation.

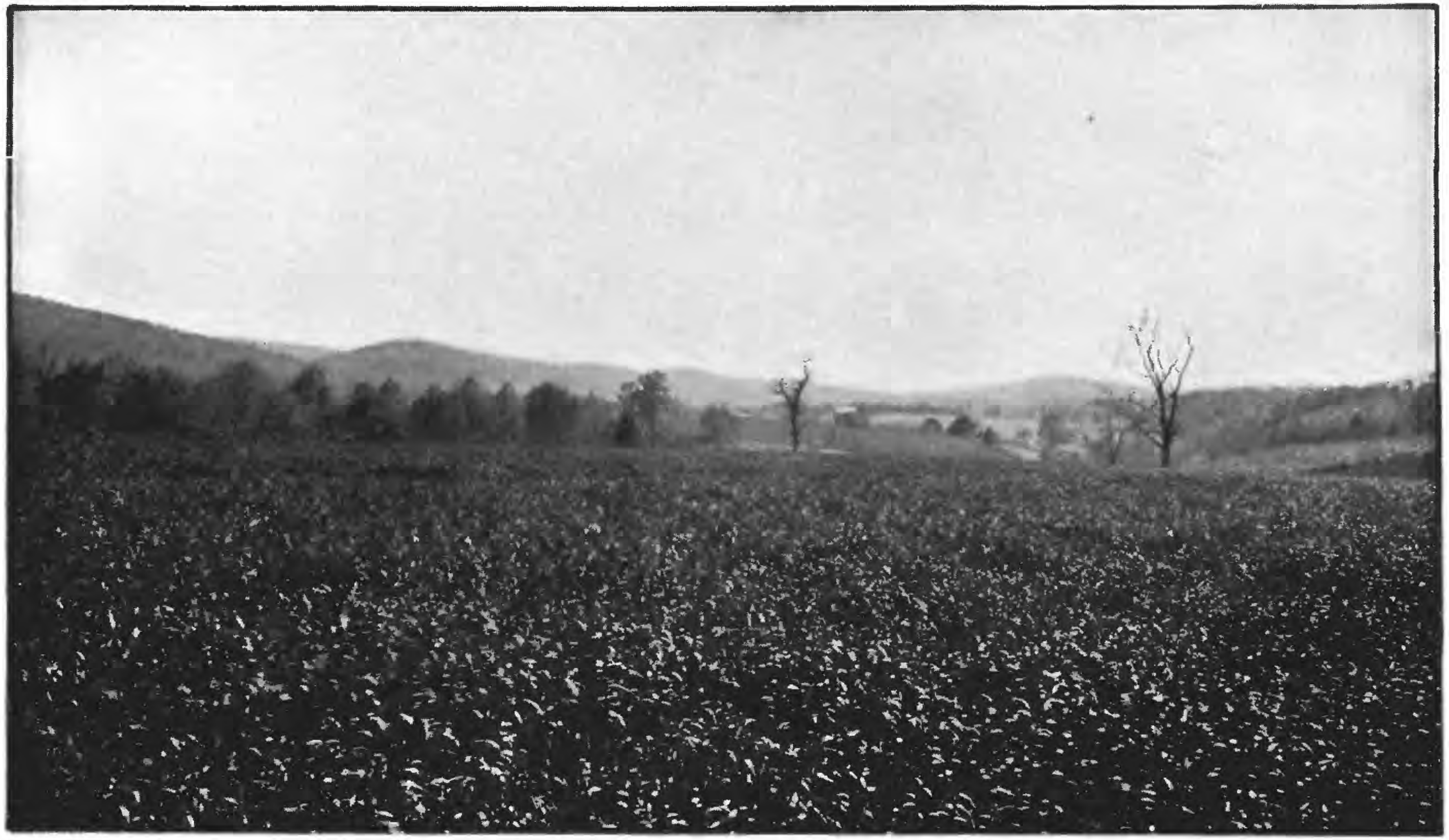
The topographic features derived from the Harpers shale are valleys; that is to say, they are valleys in comparison with the mountains formed by the Weverton sandstone and the knobs of Antietam sandstone; in comparison with the flat valleys of the Shenandoah limestone they form low foot hills and rolling slopes. The photograph (Pl. XXVII) shows the typical topography of this formation. The foreground is the smooth surface of the formation, incised in the middle distance by recent drainage. At the left appear the Weverton sandstone knobs fronting the Blue Ridge, and in the distance is an isolated knob of Antietam sandstone.

Thickness.—Fresh sections of the formation are very rare and only appear where recent stream-cutting has been energetic; and there are probably not more than half a dozen in the entire length of the belt shown on the map. In no one of them can the thickness be measured with any degree of certainty, for they are folded and twisted beyond description. At Harpers Ferry, where the lithological exhibition of them is complete, the section is a hopeless tangle. The cleavage planes dip 60° to 80° to the southeast, but the bedding can readily be traced in every direction and at every angle. No measure of thickness of any value whatever can be obtained here. The section on South mountain, east of the end of the Blue Ridge, shows less variety of dip, but since the section is included between faults its thickness probably is not the total.

Halfway from this section to Monterey, Pennsylvania, a partial section between fault lines gives 500 feet. West of Monterey another partial section gives 700 feet. Making a liberal allowance for unrepresented portions and judging somewhat from the breadth of its outcrops, a probable thickness of 1,200 feet can be assigned to the formation.

Catoctin area.—On the east side of the Catoctin belt the Harpers shale occurs in only one area, beginning near the Potomac and running north for 12 miles. Here, along the east side of Catoctin mountain, a series of phyllites and sandy schists lie above the Weverton sandstone. The omnipresent metamorphism of the region has produced in them a great amount of sericite and lenticular quartz with consequent schistosity. Their correlation as Harpers shale is open to question. They may represent Harpers shale, or possibly a portion of the time occupied elsewhere in deposition of the Weverton sandstone. The latter is unlikely, for the reason that the schists extend northward to the maximum development of the sandstones and still lie above them. The area of schists rises on a high syncline toward the north end of Catoctin mountain, so that erosion has removed them. West of Frederick the basin deepens and becomes a monocline, letting the schists down below the reach of erosion. These shales and slates appear above the Weverton sandstone in the position which the Harpers shale should occupy. It is a reasonable inference, therefore, that they are the Harpers shale. Their thickness, however, is not great, not over 700 or 800 feet, which is in keeping with the lesser thickness of the Weverton sandstone in that position.

Source and environment.—Deductions as to the source of the Harpers shale can scarcely be drawn from such measures of thickness. The



HARPERS SHALE VALLEY, WEST OF SNICKERS GAP, VIRGINIA.

other factors of variation, the lithologic composition and texture, promise but little more. The only unusual elements in the formation are the small sand beds in its upper part. These show a tendency to increase in the more northerly sections. This development is in line with the increase of the Weverton sandstone in that direction, and may be attributed to a similar cause, a sub-Newark land area. Beyond this conjecture, however, the facts of its uniformity and absence of marked characters will warrant the statement that the Harpers period was marked by extreme permanence and perfection of environment.

The nature of the change that put an end to the deposition of Weverton sandstone and produced Harpers shale is not well defined. The Weverton was developed as a shoal water deposit by strong currents. The change, therefore, could have been submergence, cessation of the currents, or both. Shoal water with slack currents would have produced local accumulations of débris similar to the Weverton and repeated the results developed in the Loudoun period. Under those conditions the uniformity of the Harpers shale could not have been produced. Submergence would in itself have changed the currents and their consequent deposits, shifting the locus of the coarse forms to the newer shore. Also, in the area under discussion, submergence of great amount would have obliterated the small land bodies existing during Weverton time and necessitated long carriage of material. The carriage was undoubtedly long, because the material is all finely divided and because it is so well assorted. It can, therefore, be inferred with a fair degree of certainty that the deposition of Weverton sandstone was closed by submergence of its source of supply. Transfer of the latter elsewhere carried with it the coarse shore deposits and produced in their stead fine and well-assorted sediments due to long carriage. That this new period was the most considerable yet developed is evident from the amount and fineness of its sediments in comparison with those of the preceding periods.

ANTIETAM SANDSTONE.

Composition.—Next in the sequence is the Antietam sandstone, and of this even less can be said. It is everywhere a white sandstone, and is usually calcareous. The sand particles are usually very fine, never approaching conglomerate in texture. Its occurrences have exactly the same range as those of the Harpers shale, and it is found in synclinal remnants lying on that shale. On the east side of Catoctin mountain, in the same belt which holds the Harpers shale, there are certain small, schistose, sandy beds lying above the Harpers shale, which may represent the Antietam sandstone, but this is very doubtful. In one portion of their line, where the Shenandoah limestone touches Catoctin mountain, they lie adjacent to the lowest portion of the limestone; that is to say, they are in the proper position for the Antietam sandstone. If these sandy beds represent the Antietam sandstone they show a much diminished volume; and this, again, is in accord with the change in the Harpers shale and in the Weverton sandstone in that region. The passage from Harpers shale to Antietam sandstone is usually marked by transition beds, sandstone in the shale and shale in the sandstone.

Thickness.—In all the occurrences of Antietam sandstone there are only one or two measures of its thickness. The best one is at the north end of the Blue Ridge, where the dip is very light and the strata are but little disturbed. It has there a maximum thickness of 500 feet. Shortly northeast of Front Royal it has a probable thickness of 600 to 700 feet. No better measures than these are known, and it would be hazardous to draw deductions from them.

Source.—In regard to the coarseness of the Antietam sandstone the facts are a little more abundant, and they show but small variation in the formation. There is a distinct gradation in coarseness in the Antietam sandstone from south to north. The coarsest and most massive varieties occur a little north and east of Front Royal. The deposit is there a firm, white, massive sandstone, with very little calcareous matter. From that point north the amount of calcareous matter is constantly on the increase, resulting in the more easy destruction of the sandstone by erosion. In the vicinity of Harpers Ferry outcrops of Antietam sandstone are very rare indeed, and only scattered fragments betray its existence. This greater coarseness of the Antietam sandstone toward the south shows that the disturbance which produced it, as distinguished from the Harpers shale, was at its maximum at that point. This again agrees with the maximum coarseness of the Weverton sandstone in that region, the only difference in the two sandstones in that respect being that the diminution in the Antietam sandstone is more rapidly manifested than in the Weverton sandstone.

Relative length of its period.—Just as the Harpers shale was inferred to represent a period of subsidence, so by a similar course of reasoning the inverse change may be inferred at its close, repeating in some measure the incidents of the Weverton period. The relative importance of the Antietam and Weverton periods can be compared with some profit, inasmuch as they represent similar environments. In the northern part of the Catoctin belt there are not enough facts available. The Weverton sandstone is there twice as thick as the Antietam, but different portions of the respective sediments are compared. There is no assurance, moreover, that the beds were produced by the same conditions. Along the Blue Ridge, however, where the formations were evidently derived from nearly the same source and produced by similar conditions, approximate measures of the period values may be deduced. Over this region both represent denudation of a neighboring crystalline land mass, but the Antietam is the fine, off-shore product; the Weverton is the coarser shoal water deposit. The two do not differ materially in bulk, but the Weverton represents quicker accumulation. In point of time, therefore, the Antietam was greater than the Weverton epoch. In amount of denudation represented, the balance again favors the Antietam, for the thin portions of Antietam are compared with the thick parts of the Weverton. A crude ratio of the times of the different periods would be: Loudoun, 1; Weverton, 1; Harpers, 8; Antietam, 2.

With the close of the Antietam formation ended the siliceous deposits in the region of the Catoctin belt.

SHENANDOAH LIMESTONE.

Composition.—The next succeeding formation, the Shenandoah limestone, marks the inauguration of a totally different environment. It does not occur within the strict limits of the Catoctin belt, but the history of the belt is so much involved in the history of the limestone that the two are inseparable. This formation is too well known to need here any extended description. It forms the great Cumberland, Shenandoah, and East Tennessee valleys, and is in general a series of blue and gray limestones and dolomites, with occasional mottled blue limestone. In regard to the precise composition of the beds Lesley[1] finds from numerous analyses of interbedded dolomites and limestones that insoluble matter is commonest in the dolomites. The average of one hundred and fifteen beds yields:

	Per cent.
Carbonate of lime	80·662
Carbonate of magnesia	14·215
Insoluble matter, silicates	4·715

Varieties.—An exceptional feature of this limestone mass is the intercalation of slate beds, especially along the east side of the valley. Owing to the weathered condition of the surface of the limestones under the Tertiary baselevel, and owing to the complicated structure of the region, it is impossible to work out the details of these slate beds with any accuracy. Their general horizon, however, is about 1,000 feet below the top of the limestone. Other unusual features of less extent are the thin beds of white marble that occur on the east side of the Shenandoah valley. Their horizon is probably below the slaty series, although the complicated structure in the regions of their occurrence makes this uncertain. A third and most definite exception to the regularity of limestone succession is the limestone conglomerate of the Frederick valley beneath the slaty series.

Cause of deposition.—The cause of the change from siliceous to calcareous sediment at the beginning of Shenandoah time receives but little elucidation from the facts of this region. It is obvious, however, that the change was continental, so that the solution which fits other areas will also be suitable here.

At first thought subsidence will be appealed to as the cause, since

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[1] Summary Geol., Vol. I, p. 334.

limestones are more in the nature of sea than shore deposits In the region of the Catoctin belt subsidence was but another step in the direction previously pursued. The evidence of other areas also strongly supports this view. In southern Tennessee[1] the deposition of Knox dolomite (equivalent to Shenandoah limestone) began with a subsidence. In northeastern Tennessee[2] the Knox dolomite follows an overlap of Middle Cambrian beds, and thus followed submergence. In Lancaster county, Pennsylvania,[3] the limestone was the first sediment to rest upon the crystalline rocks, hence followed submergence. In northern New Jersey, the limestone rests in places upon the granitoid rocks, hence followed submergence. The unavoidable inference from these facts is that with the beginning of Shenandoah deposition came depression and submergence of considerable areas of land.

Age and fossils.—The Lower Silurian age of the Shenandoah limestone has long been known, as far as its upper portion was concerned. The precise age of its lower portions was undetermined until the past summer, when fossils were found[4] in its eastern slaty beds near Natural Bridge, which indicate that it is middle Cambrian. In 1892, additional fossils were found which are of lower Cambrian age.[5] These fossils were in the limestone below the slate beds and between them and South mountain, in Maryland. Fossils were found in York county, Pennsylvania, in the slaty limestones occupying a similiar position in the series and these, too, were lower Cambrian.

A considerable body of limestone occurs in the Frederick valley east of Catoctin mountain and in two places touches the Catoctin belt. Fossils were found by Mr. C. R. Keyes[6] in the eastern portion of this limestone which proved their horizon to be lower Silurian and equivalent to the upper part of the Shenandoah limestone.

Physical breaks.—Within the limestone body at some horizon came the change from Cambrian to Silurian. In most cases organic breaks of this magnitude are accompanied by breaks in the continuity of the sediments. It is well, therefore, to consider the sequence of the formation with the object of detecting a break that may be connected with the organic epoch.

First inspection seems to reveal no satisfactory distinction. There is the broad distinction everywhere to be made, however, of a lower slaty series and an upper limestone series. In the slate series in Frederick valley came the unusual event of erosion and conglomerate deposition. This was matched in the Shenandoah and Cumberland valleys by deposition of sand at the same horizon. These indicate an instability of environment at that time which would affect organisms,

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[1] Phil. Soc. of Washington, Vol. XII, p. 71-88, Geol. of Chilhowee mountain; Arthur Keith.

[2] U. S. Geol. Survey, Roan mountain atlas sheet, Arthur Keith.

[3] Second Geol. Survey maps.

[4] C. D. Walcott: Am. Jour. Sci., July, 1892, p. 53

[5] Ibid., Dec., 1892, p. 478.

[6] Johns Hopkins, Circular No. 84, Vol. x, Dec., 1890, p. 32.

and with this period may have come the change from Cambrian to Silurian forms.

The attitude of the series in the Frederick valley as a whole is monoclinal, with the oldest rocks at its western edge touching the Catoctin belt. The eastern portion of the belt is composed chiefly of the upper gray and blue limestones. The middle portion, under and west of Frederick, consists of beds of limestone and slaty limestone closely interbedded. Below these to the west are several beds of limestone conglomerate interbedded with the limestone, formed of pebbles of blue and gray limestone and intermingled sand grains, which range in size up to 6 and 8 inches. Of these pebbles some are angular and some are rounded and show considerable carriage. West of and below these limestone conglomerates are more blue limestones and gray limestones, to the foot of the Catoctin range.

The slaty beds overlying the conglomerate in the Frederick valley occupy about the same position as the slaty beds in the Shenandoah valley; with these latter, however, no conglomerates have been noticed. Such a fact is not remarkable, as the bowlders of limestone must necessarily be somewhat evanescent under any conditions of transportation. The conglomerate beds in the Frederick valley extend for 5 or 6 miles, but are covered in either direction, north and south, by the later Juratrias beds, also limestone conglomerates, so that their original extent can not be determined. They represent, of course, a period of erosion of preceding limestones, not necessarily of great duration, since the total thickness of the deposit is perhaps not more than 20 feet. Even this thickness is divided in the Frederick valley into several portions with intervening limestones and slates, the whole series perhaps occupying a thickness of 100 feet. The fact that several small periods of degradation are represented in the Frederick limestone that do not appear in the main body of the Shenandoah limestone leads to the conclusion that they were minor features of no great duration. Their occurrence at wide intervals shows that they were due to widespread conditions. Their nature of necessity demands shore formation. They would appear, therefore, to represent a minor disturbance along shore and small disturbances of the limestone areas between periods of deposition. Land, either temporary or permanent, existed then somewhere in the vicinity of the present Frederick valley.

A sequence identical with that at Frederick was found[1] in Lancaster county, Pennsylvania, near Columbia. There the slaty beds, limestone conglomerate, and limestones were repeatedly interbedded with each other, and the bowlders of the limestone attained a thickness of 5 and 6 feet. The conglomerate at this point contains also many large bowlders of white marble, a feature which does not appear in the Frederick valley conglomerate. These bowlders have no representative in the bedded rocks at that horizon. In the Emigsville section at a lower

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[1] Am. Jour. Sci., Dec., 1892, p. 470-471.

horizon near the sandstone-shale series occur beds of white marble[1] that could readily have furnished such débris. They represent, of course, erosion of a marble bed, and, from the size of the fragments, of one not far distant. It is not improbable, therefore, that the extension of the Emigsville marble in this region supplied the material of the conglomerates.

These fragments might have been derived from the large areas of crystalline marble in the eastern parts of New Jersey, Pennsylvania, and Maryland. That is not likely, however, because the fragments would not have endured the transportation and because they are much less crystalline than these main marble belts.

The chief elements of variation in the Shenandoah limestone, the intercalated bands of slate and sandy shale, have some bearing upon the question of environment. They are most prominent, as before stated, along the eastern side of the Shenandoah valley. Through the southern and western parts of the valley they exhibit no change which is perceptible. Northward from the Potomac, however, and along the east side of the valley, there is a slight change; the slates grow more argillaceous and less calcareous, and a slight element of sand appears within them. West of the northern end of the Blue Ridge there is a considerable proportion of sand; and near Smithsburg, in Maryland, 20 miles farther north, sand beds are quite conspicuous, although of small thickness. The accompanying shales also change color from a light bluish gray to a deep red and purplish gray. In Pennsylvania similar shales, slates, and sandstones, are noted by Lesley[2] as occurring in the lower part of the limestone. In central Virginia, near Staunton,[3] 1,500 feet of Shenandoah limestone appears with no bottom limit. The lower portion of this contains beds of shale. In southwest Virginia[4] the Shenandoah limestone has 1,000 feet of limestone at bottom, a central portion of red slates and thin sandstones 500 to 1,000 feet thick, and an upper member of limestone 1,000 to 1,500 feet thick.

A closely similar section occurs in northeastern Tennessee[5]. Several similar cases have been studied by the writer in Tennessee, and the introduction of red and purple shale has been found in nearly every case to be due to the proximity of a land mass and to increased erosion. Here, too, the increase in amount of shale toward the east and north seems to indicate a land mass in the same direction during the deposition of the shale. The increase of sandy materials, so distinctly the product of land erosion, points to a change in environment at that time either in the form of a new land mass or a readjustment of the old. These facts, taken in connection with the elevation and

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[1] Am. Jour. Sci., Dec., 1892, p. 472.

[2] Summary Report, pp. 497-498.

[3] U. S. Geol. Survey, Staunton atlas sheet, by N. H. Darton.

[4] The New River-Cripple Creek Mineral Region in Va., McCreath and d'Invilliers, pp. 8-10

[5] U. S. Geol. Survey, Roan mountain atlas sheet, by Arthur Keith.

SHENANDOAH VALLEY AT BERRYVILLE, VIRGINIA.

erosion demonstrated by the Frederick conglomerates at the same horizon, are sufficient evidence of a movement whose effects were widely felt.

Source of material.—In regard to the location of this readjusted land body, the evidence is but slight. Shale beds and sand beds both indicate a derivation from the northeast, and both give evidence of a rather distant shore by their gradual introduction and their fine grain. In the Frederick conglomerate horizon sand is present in approximately the same amounts as the sand débris in the limestone of Shenandoah valley, and probably was produced by the same system. While its grains are coarser than those of the valley beds, they are, nevertheless, small, well rounded, and brought from afar. This fact in connection with the coarseness of the limestone débris indicate that their sources were widely separated. While the limestones were exposed to erosion in the latitude of Frederick, they still extended for a considerable additional distance over the siliceous rocks, and the main area of siliceous rocks defining the shore lap of the Shenandoah limestone was at a distance.

As to which formation produced the sand, little can be said. It might have been worn from the Antietam or Weverton sandstones or from granitoid rocks. It could scarcely have been derived from the Antietam sandstone, because the grains of sand in the Frederick conglomerate are larger than any in the Antietam. As far as size goes they might have been worn from the Weverton, but that would imply previous erosion of all the overlying formations, a very unlikely condition in the face of the submergence accompanying the Shenandoah deposition. In fact, the identity of the limestone series on either side of the Catoctin belt is strong evidence that they were originally continuous over the anticline that separates them. Evidently, from its increase northward, it did not come from the area which supplied the Antietam sandstone, but rather from that which caused the chief development of Weverton sandstone at the north. It goes without saying that there was a shore line to the Shenandoah limestone, and in this case its influence seems to have been felt.

Physical and organic breaks compared.—In these series of facts several general relations stand forth between organic and inorganic systems. The lower limestones contain lower Cambrian fossils. The medial slate and sandstone group gives evidence of instability of environment, and a slight reversal of the process of submergence. These rocks contain a fauna of lower Cambrian age with other forms suggestive of middle Cambrian. The upper limestones are defined by lower Silurian fossils. Breaks of the organic series occur in the slate-sandstone horizon, therefore, from lower to middle Cambrian, and from middle through upper Cambrian to Silurian. It is natural to infer a causative connection between these breaks and the orographic movements occurring at the same time. That the second break is due to these movements is rendered probable by the occurrence of the same connection over most of the Appalachians. There is not the same probability in the case of the first break, because the physical movement does not always accompany the same organic break. In Tennessee the lower Cambrian fossils rise no higher than the Rome sandstone,[1] and a large series of shales and limestones of middle Cambrian age come between the Rome sandstone and the bottom of the Knox dolomite (Shenandoah limestone). In upper Virginia and Pennsylvania the lower Cambrian forms range well up into the body of the Shenandoah limestone. There would appear to be, between Tennessee and Pennsylvania, a more speedy differentiation of the Cambrian forms at the south and a divergence of physical and organic development. At this stage of knowledge, however, it is unwise to form conclusions on the subject, and little more can be done than to point out possibilities.

To sum up, the Shenandoah limestone resulted from the perfect adjustment of erosion and sedimentation, giving a uniform product over very wide areas and lasting for a very long time. It was initiated by depression which must have been great to allow for its considerable thickness, 3,000 feet, and which was not simultaneous, since it was interrupted by erosion along its eastern margin. Its land masses must have been of considerable height to escape submergence, yet the fine sediment that they furnished shows perfect stream adjustment and good progress in degradation to baselevel. It marks, in short, the culmination of the process of depression and degradation which was initiated in Loudoun time.

MARTINSBURG SHALE.

Composition and range.—That the next succeeding formation, the Martinsburg shale, represents a widespread change in the perfection of the previous system is quite evident. The replacement of limestone by shale at the end of the Trenton period is one of the most persistent and uniform changes in the stratigraphy of the Appalachians. In Tennessee the development of shale is most prominent on the east side of the valley and is an evident shore feature. In Virginia the evidence is inconclusive, chiefly for the reason that the formation does not outcrop near the probable shore. Throughout its entire range, except the western part of the Tennessee valley, it is a uniform argillaceous shale. Its bottom beds are calcareous and carbonaceous, and vary in color from black to bluish gray. Its upper layers are brown and yellow argillaceous shale, with increasing development of sand.

It does not outcrop in the Catoctin belt. There is a probability, however, that the shale lying east of the Shenandoah limestone near Frederick is of Martinsburg age, but it is far from assured.

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[1] C. D. Walcott, Am. Jour. Sci., July, 1892, p. 54.

In Buckingham county, Virginia, near the James river,[1] are slates of Hudson age associated with sandstone and conglomerate. This slate belt has a great range, both northeast and southwest, and similar slates occur in various portions of Piedmont Virginia. In Pennsylvania doubtful Hudson slates occur at Peach Bottom associated with sandstone beds.

Environment.—In all these occurrences the slates rest directly upon the crystalline rocks. Their extent indicates that they depend upon conditions of widespread importance. The fact most obvious from their contact with the crystallines is the absence of Shenandoah limestone, setting a limit to the Shenandoah shore. The deduction from this contact is submergence at the end of the Shenandoah period, since these shales were the first beds to be deposited over these regions.

The geography deduced for the later part of the Shenandoah period was a land body not far east of the Catoctin belt, with mature drainage and partial baseleveling. In order to have accomplished this there could not have been much depression in the later part of the Shenandoah. Additional depression of no great amount would therefore have submerged considerable crystalline land masses and shifted the shore far to the east. That the change was sudden can be inferred from its sharpness. Hence no time would have been allowed for transfer of coarse shore material, and coarse deposits would appear only near their point of origin. The localization and nature of the conglomerates in the Buckingham slate[2] is corroborative of this, and in this respect, as well as that of primary submergence, the Martinsburg period strongly resembles the Loudoun.

During the Shenandoah epoch depression was the rule. Could continued depression have been the only change in order to produce the Martinsburg shale? Possibly not. A change inevitably rising out of such wholesale alteration of geography would be readjustment of currents. Additional change following would be a greater proportion of clay material in the sediment, due to greater proximity to the sea of the high lands which furnished débris to both formations. This additional clay is manifest throughout the formation, but its distribution is highly suggestive. Argillaceous matter is initially a land product; with the comminution along shore and with the decay of time it becomes extremely fine and transportable to great distances. Under the conditions of transportation obtaining in Shenandoah time the clay material represents about 5 per cent of the mass of the deposit, except in the vicinity of the shore. Obviously, therefore, the transporting currents were not sufficiently active to carry much clay. Presumably they were slackened by deep water, and the sediment dropped below the reach of the currents; for if concentrated into shoal water, bringing the bottom within their grasp, they would have carried it almost indefinitely. It

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[1] N. H. Darton, Am. Jour. Sci , July, 1892, p. 50.

[2] Ibid., loc. cit.

needs merely an indefinite extent of shoal water to secure indefinitely long carriage. Examples of this are the Gulf Stream and the Mississippi. The former carries no sediment, though deeper, swifter, and wider than the latter. The former's sediment once dropped is out of reach; the Mississippi never releases its hold till it reaches deep water.

Reasoning inversely from this, we can conclude that, as the Shenandoah land was near, and yet the deposits contained only a small percentage of clay sediment, the currents were deadened by deep water. Also, since the Martinsburg land was distant, and yet its sediments contained 80[1] per cent of clay, we may infer that the water was not deep and the currents scoured actively. The great increase of the forms of life which are favored by shallow water lends great support to this deduction. Such are the crinoids and trilobites especially.

To account for this seaward shallowing of the water, an elevation over those regions was necessary. To account for Martinsburg deposition over previous land areas, submergence must have taken place. The two motions combined constitute tilting of the entire area, with downthrow at the east.

The period of disturbance giving rise to this movement was continenental, and its effects are often seen in the Appalachians. In Alabama[2] extensive chert breccias give evidence of erosion at this horizon. In east Tennessee[3] limestone breccias occur at the same horizon.

In Pennsylvania[4] perfect conformity of limestone and shale obtains.

In parts of New York[5] the Hudson slate is almost unrepresented, which is probably due to "upward movement, temporary or otherwise."

In Canada[6] the Hudson formation unconformably overlies the serpentine beds (Chazy?). In Ohio, on the Cincinnati arch the Cincinnati (Hudson) formation is supposed by Newberry, Shaler, and J. F. James to represent shallow-water deposition. N. W. Perry[7] figures rain marks, ripple marks and mud cracks in this formation.

From the above facts it is clear that the close of the Shenandoah limestone was caused by widespread dynamic action and continental movements. In the region under diccussion the movement was plainly tilting, elevation in Ohio and depression in eastern Virginia. In other cases it was mainly elevation of smaller tracts along the shore.

In regard to the history of the Catoctin beds during the latter part of the Martinsburg period there is not much to be said. The gradual increase in sandy material, culminating in the Massanutten sandstone, is clear evidence of decreasing depth of water either by absolute filling of the basins or elevation of their floor. The latter is more

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[1] J. P. Lesley: Summary Report, Geol. Pa., Vol. I, p. 567.

[2] C. W. Hayes, Geol. Survey of Alabama, Bull. No. 4. 1892. p. 43.

[3] U. S. Geol. Survey, Greeneville atlas sheet, by Arthur Keith.

[4] J. P. Lesley, op. cit., Vol. I, p. 531.

[5] J. P. Lesley, op. cit., p. 529.

[6] Geol. Mag., notice, 1879, p. 139.

[7] Am. Naturalist, Dec., 1889.

probable from the observed unconformities by erosion in Tennessee,[1] in Virginia,[2] and in New York[3] closely following the deposition of the siliceous materials.

Thus was closed the first cycle in the sedimentary record, from erosion to quiescent deposition and back to erosion. Of the succeeding cycles recorded in the Devonian and Carboniferous no trace is found in the Catoctin belt, and discussion of them with reference to its history is idle. Suffice it to say that after their close the Catoctin belt passed, in common with the rest of Appalachians, into the immense period of deformation and degradation that has produced the "Appalachian" types of structure and surface.

NEWARK SYSTEM.

The next epoch of which a sedimentary record remains in the region of the Catoctin belt is one of submergence and deposition, the Newark or Juratrias. The formation is not developed in the Catoctin belt itself, but it bears upon the history of the belt by throwing light on the periods of degradation, deposition, igneous injection, and deformation that have involved them both.

Much attention has been devoted to the phenomena associated with the Newark system. It is not the purpose of the present author to review this, however, for the reason that the facts here presented are merely a contribution to the stock of knowledge and are insufficient to settle any of the mooted questions.

Distribution.—The Newark formation is the eastern limit of the Catoctin belt in its northern portion, and through much of northern Virginia and Maryland occupies the western portion of the Piedmont plain. For a space of 1 mile, west of Frederick, Maryland, the belt is entirely cut through by erosion, which brings to the surface the underlying Shenandoah limestone. In either direction, north or south, from this point the width of the belt increases: at the Potomac river it is about 4 miles in width, at the latitude of Leesburg about 10 miles in width, and thence it spreads towards the east until its maximum width is perhaps 15 miles. The area of the Newark formation is, of course, a feature of erosion, as far as its present form is concerned. In regard to its former extent little can be said except what can be deduced from the materials of the formation itself.

Composition.—As a whole the formation is a large body of red calcareous and argillaceous sandstone and shale. Into this, along the northern portion of the Catoctin belt, are intercalated considerable wedges or lenses of limestone conglomerate. At many places also gray feldspathic sandstones and basal conglomerates appear. Aside from these the formation is singularly uniform from North Carolina to New York.

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[1] U. S. Geol. Survey, Knoxville atlas sheet, by Arthur Keith.

[2] N. H. Darton, Am. Geologist, July 1892, p. 16.

[3] Lesley, Summary Report, vol. I, p. 707.

Limestone conglomerate.—The limestone conglomerate is best developed from the Potomac to Leesburg, in Virginia, and from that region southward rapidly diminishes until it is barely represented at the south end of Catoctin mountain. The limestone conglomerate is but sparingly developed north of Frederick, and has not been studied in enough detail to be represented upon the map. A considerable body exists near Fairfield, Pennsylvania, just north of the end of the Catoctin belt.

The conglomerate is made up of pebbles of limestone of varying sizes, reaching in some cases a foot in diameter, but, as a rule, averaging about 2 or 3 inches. The pebbles are usually well rounded, but sometimes show considerable angles. The pebbles of limestone range in color from gray to blue and dark blue, and occasionally pebbles of a fine white marble are seen; with rare exceptions also pebbles of Catoctin schist and quartz occur. In appearance these limestone pebbles are precisely analogous to the various forms of Shenandoah limestone seen at Frederick. They are embedded in a red calcareous matrix, sometimes with a slight admixture of sand. As a rule the entire mass is calcareous. The irregular assortment of the conglomerate is shown in the photograph, Pl. XXX.

It occurs, as has been said, in lenses or wedges in the sandstone ranging from 1 foot to 500 feet in thickness, or possibly even greater. They disappear through complete replacement by sandstone at the same horizon. The wedge may thin out to a feather edge or may be bodily replaced upon its strike by sandstone; one method is perhaps as common as the other. The arrangement of the wedges is very instructive indeed. The general strike of the Newark rocks is a little to the west of north, while the strike of the Catoctin belt is a little to the east of north. The two series, therefore, if extended, would cross each other at an angle of 20 to 30 degrees. The conglomerate wedges are collected along the west side of the Newark belt and in contact usually with the Weverton sandstone. The thick ends of the wedges along the line of contact usually touch each other. Going south by east the proportion of the sandstone increases with rapid extermination of the conglomerate. The thin ends of the wedges therefore resemble a series of spines projecting outward from the Catoctin belt.

Many of the pebbles seem to have been decayed even before their incorporation into the mass, inasmuch as the matrix does not show decay of equal amount with the pebbles; but this decayed condition of the pebbles may be due to their greater susceptibility to solution. As a rule, however, there appears to have been no action of weathering until they attain the present surface. The result of weathering upon the conglomerate is a very uneven and rugged series of outcrops projecting above the rolling surface of the soil. In Pl. XXIX, the photograph shows a typical series of these outcrops. The ledges show little definite stratification and very little dip. The topography of the conglomerate is inconspicuous and consists of a slightly rolling valley

NEWARK CONGLOMERATE VALLEY, NORTH OF LEESBURG, VIRGINIA.

without particular features. It approaches nearer to the level of the present drainage than any other formation, and decay by solution has gone on to a very considerable extent. Where the draining streams have approached their baselevel, scarcely an outcrop of conglomerate is seen. Where the areas of conglomerate lie near faster falling streams, the irregular masses of unweathered rocks appear.

When but slightly weathered the conglomerate forms an effective decorative stone and has been extensively used as a marble with the name of "Potomac marble," from the quarries on the Potomac east of Point of Rocks, Maryland. While it is in no sense a marble, yet the different reds and browns produced by unequal weathering of the limestone pebbles have a very beautiful effect.

Sandstone and shale.—By far the greater body of the formation consists of fine red and brown shale and sandstone. Its color is seen to be constant even where the rock is unaffected by weather, as in the recent stream cuts, and can be assumed, therefore, to be an original characteristic. The rock is particularly uniform in appearance throughout the belt, and its maximum variations are but slight differences in the proportion of sand to other materials. In the upper portion of this sandstone deposit are intercalated the conglomerate beds, and, further to the south, beyond the actual areas of the conglomerates, their general horizon is marked by calcareous sandstone and shale, showing the prevalence of the lime-producing conditions. The proportion of sand in the sandstone shows a tendency to increase toward the south, and this result has its effect upon the topography by the production of greater eminences; only rarely, however, is this proportion sufficient to be detected by the eye.

Feldspathic sandstone and conglomerate.—Two miles east of Aldie, Virginia, two coarse deposits occur in the red sandstone. One consists of gray feldspathic sandstone interbedded with red and greenish shale; the other is a real conglomerate containing pebbles of feldspar, quartz, slate, and Catoctin schist. The feldspar pebbles are fresh and little worn and plainly have traveled but a short distance. As nearly as can be determined this conglomerate just below the Leesburg development of limestone conglomerate. The nature of the fragments is very interesting in showing the existence above water at that period of portions of the Catoctin belt. The feldspar, judged by its unworn condition, could only have come from the granitic rocks to the west, for even as now narrowed by erosion the Newark has covered the granite for 12 miles to the east; and the schist could have come only from the Catoctin schist, which, so far as known, lies only to the west of the Newark area. About 2 miles east of the south end of Bull Run mountain a feldspathic conglomerate occurs in the red sandstone that is comparable with this in every way, and similar sandstones and conglomerates on a smaller scale lie 4 miles north of Aldie. A considerable thickness of gray feldspathic sandstone is exposed and quarried half a mile east of Point of Rocks. Here the sandstone lies directly under the great mass of limestone conglomerate, with a light dip toward the west. Further study of the formation toward the south will undoubtedly bring to light other occurrences of this feature. It is evident from these fragments that pre-Newark erosion had progressed as far as to remove the cover of Shenandoah limestone and lower formations from the crystalline areas. From the greater prominence of the fragments in the more southern sections erosion appears to have progressed deeper at the south.

Basal conglomerate.—The third departure from the characteristic red sandstone type is at its extreme base, where it rests unconformably upon previous deposits. They are noted by Rogers and Fontaine at various points in central Virginia. Within the region under discussion they are but few in occurrence—one at Herndon, in Virginia, east of Leesburg, upon the eastern side of the Newark belt and at its contact with the granitic rocks of the Piedmont plain. Its basal member here contains large rolled quartzite and quartz pebbles, the quartzites being derived from the Weverton formation lying to the west. The other and chief instance of variation from the type occurs in the vicinity of Frederick, Maryland, and thence north to Mechanicstown, Maryland. In this distance of about 15 miles the Shenandoah limestone twice appears from beneath the Newark sandstone; once at Frederick, already noted, and a second time midway between Mechanicstown and Frederick. In four out of five of the observed contacts between these two formations there are present one or two beds of white quartz conglomerate and gray sandstone at the bottom of the red sandstone. These are composed of rolled grains and pebbles of quartz ranging in size up to an inch; they are thoroughly rounded and evidently have traveled for a long distance. North of the extreme end of Catoctin mountain the Newark has not been studied by the writer to any extent, and this conglomerate may or may not exist there. The conglomerate beds are only a few feet in thickness—from 1 to 20—and that limited amount indicates that the source of supply was early removed.

Environment.—In regard to the derivation of the material of the main body of the Newark formation—the red sandstone and shale—but little can be said, on account of the uniformity and noncommittal character of the material itself. Even its thickness is most uncertain. The rocks dip at a light angle to the west with hardly an exception, and the sections all appear to be continuous. Faulting is known to be commonly associated with this period; the rocks, however, have no distinguishing features by which to discover repetitions of strata by faulting. Sections drawn with no allowances for faulting give the most tremendous thickness. Even with liberal deductions for frequent faults nothing less than 3,000 feet will account for the observed areas and dips.

As has been said, the sandstones are formed of sand with a little lime, iron, and feldspathic material. Studies of microscopic sections by Russell[1] have shown the sand grains to be incased in a thin coating of ferruginous clay, and he has drawn from that the inference that they were derived from immediately adjacent land-masses that had long been exposed to erosion and decay. Whatever the source was, it was of wide extent, because the formation is uniform over such great areas. If the sand came from the granitic rocks, it was evidently far carried and worn into small grains, unless, as before said, the land was at a low level and transportation was weak and long protracted. The sands might equally well have been derived from the lower portions of the lower Cambrian series, the Weverton sandstone in particular. On that supposition the whole of the Shenandoah limestone and the upper part of the lower Cambrian formation must have been eroded in order to give access to the Weverton. This must have been the case over certain portions of the Catoctin belt, at any rate, because in the gray sandstones are fragments of feldspar, quartz, and Catoctin schist, which underlie the Cambrian. The occurrence of quartzite pebbles at the base of the formation at Herndon also indicates that toward the west, where the quartzites outcrop, they were above water immediately before the Newark deposition. Inasmuch as the gray sandstone horizons contain fragments of schist and feldspar, they show the recurrence, perhaps the continuation, of a Catoctin land area. By the ripple marks on the shales, included with the gray sandstones and the shale fragments in the sandstone, there is shown an elevation of portions of the Newark mass into the reach of erosion. The deposition of one of the main bodies of limestone conglomerate, that on the Potomac, directly upon the gray sandstone, also shows elevation by its evident shore deposition.

From the conglomerates of the Newark our chief knowledge of its environment is derived. Conglomerate, at its best, is a variable unit, and must be used with caution in drawing inferences. The limestone conglomerates are extremely variable, and are of value only so far as their actual composition goes. The gray sandstone and conglomerate has more of the appearance of a definite horizon, but is still uncertain. The basal conglomerate, however, especially around Frederick, seems to be as much a unit as conglomerate ever is, and can be treated as such for this region at any rate. Its maximum seems to be a few miles north of Frederick; its southward end about 5 or 6 miles southwest of Frederick; and its north end apparently is near Mechanicstown, though the disappearance may be due to lack of information. Over this range of 15 miles, then, one can infer from the similarity of sequence a similar condition of deposition throughout, so that comparison of different areas has an actual value.

That the quartz pebbles are not of local material is plain, for they are perfectly rounded and are well assorted by long transportation. Moreover, the local underlying rock is the Shenandoah limestone. As

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[1] U. S. Geol. Survey, Bull. No. 52, I. C. Russell, pp. 45, 46.

far as mere material goes the pebbles might have been derived from the quartz veins and lenses common in the metamorphosed Harpers shale along Catoctin mountain or equally well from the quartz lenses of the Catoctin schist. In the latter case the absence of epidote, equally hard and more abundant than the quartz, must be accounted for, and greater pre-Newark erosion must be assumed. Objection to their derivation from the Harpers shale is their lack of the angular fragments which would be expected from its propinquity, and yet any source in this shale must have been near, for only the eastern shales are metamorphosed and contain quartz masses.

Over its northern extension near Frederick a source to the north appears to be obvious, but again the lack of information along the eastern border of the Newark renders this doubtful. For this area might represent a local westward extension of a conglomerate from the east similar to the coarse deposit at Herndon. Therefore the only deductions to be made from the northern basal conglomerate are the certainty of a quick, uniform submergence of this northern part of the Newark and the possibility of erosion into the Harpers shale at some point along the eastern edge of the Catoctin belt. The basal conglomerate at Herndon, Virginia, shows that erosion had brought the Weverton sandstone to the surface in some places at any rate.

The evidence of the limestone conglomerates in regard to their environment is more definite than that of the basal conglomerates because their fragments can be more definitely traced to their origin. As has been stated, their maximum is in the vicinity of the Potomac river and their most southern representative is about 6 miles south of Leesburg. Northward from the Potomac to the latitude of Frederick they maintain about the same proportion to the sandstone. Northward from Frederick their occurrences are rare and limited; one body lies immediately east of Mechanicstown, but is very small in extent and thickness. Around Fairfield, Pennsylvania, north of the end of the Catoctin belt, there is a considerable development of the conglomerate.

It is evident that their source was not very far distant, for the pebbles are large and occasionally angular, which, of course, is compatible with but slight transportation in the case of a limestone. One element of their increase, that toward the west, points to a source over the Catoctin belt; the other element, that of increase toward the north, points to a source toward the north. One available source is the present Frederick limestone, which fulfills one condition, that of increase toward the north; also another condition, that of suitable material. In the unconformity of the limestone itself to the beds of conglomerate and sandstone is found another element which goes far to confirm this conclusion.

As has been said, the limestone conglomerates form the upper part of the Newark formation as seen here. Another horizon, of more limited extent, is at the extreme bottom of the formation, underlying in some places the beds of quartz conglomerate, which have been cited near Frederick. This latter horizon of limestone conglomerate is confined almost exclusively to the region south of Frederick, and has a thickness of perhaps only 50 feet. It is not strictly continuous, for occasionally the quartz conglomerate overlying comes down upon the limestone itself. From Frederick southward toward the Potomac, the sequence of the Newark is perhaps at its simplest and the thickness is the least to be seen anywhere. For the 6 miles north of the Potomac the thickness is reasonably constant; in the last 2 miles, however, there is considerable change, and the two conglomerates—upper and lower—rapidly approach each other in vertical thickness with a considerable diminution of the amount of red sandstone. It may be due to the actual overlap or nondeposition of the red sandstone, or it may be due to an increase in relative amount of the limestone débris due to a neighboring source. Whichever be the cause, there would appear to have been in this immediate vicinity a bottom sloping up toward a land body of the limestone.

At this point, west of Frederick, there is actual conformity of the overlying on the underlying series. The extension of the limestone toward the west is attained by erosion along a small cross axis from east to west. The elevation along this line was but slight and has produced little effect upon the highly inclined Shenandoah limestone, which strikes northeast parallel to the Catoctin belt. The Newark formation, however, strikes east and west or parallel to the line of contact of the two. This conformity of the Newark upon the limestone is manifested in other places as well, toward the north, although there does not appear to be any conformity in attitude of the limestone itself to the boundary.

Initiative subsidence.—Previous to the deposition of the Newark in the limestone conglomerate areas there was, therefore, a considerable period of erosion during which the Martinsburg shale, if ever deposited upon this region, was removed, as well as considerable portions of the Shenandoah limestone, and over the irregular surface thus produced the Newark was deposited. Its cause, of course, was subsidence, and the advancing waters, reaching over irregular areas of the older rocks, would produce different deposits as different areas of the rock were reached. The first result, as has been seen, was, in the vicinity of Frederick and southward, a thin bed of limestone conglomerate; following that was the red sandstone with its basal bed of quartz conglomerate; following this, again, was the heavy deposition of limestone conglomerate along the edge of the Catoctin belt.

Cause of variations.—This return of the conglomerate may be interpreted to mean either a reversal of the new environment, or attainment of a new source of supply, or derivation from the same source by a repetition of currents. The first hypothesis is possible and is supported by the appearance of ripple marks in the gray sandstone and shale under the limestone conglomerate. The second is conceivable but improbable, for the areas furnishing débris to the second would have also furnished it to the first conglomerate. The third is a condition likely to occur in the changing environment of subsiding land bodies, and may therefore be considered the true reason. The approachment of the two limestone conglomerates west of Frederick fixes one portion of the land mass as immediately north of that city. Southward from this region also the upper conglomerate forms a trail of limestone pebbles gradually thinning southward. Northward from this there is scarcely any conglomerate whatever. It would appear, then, that the set of the current was toward the south, and that the limestone conglomerates were derived from regions immediately north of Frederick, or possibly also to the west. In this respect the history of the limestone conglomerate agrees closely with the history deduced from the quartz conglomerate at the base of the sandstone, which pointed to a greatest elevation near or north of Frederick. This is paralleled by the history of the Weverton sandstone, which gave evidence in that region—the northern portion of the Catoctin belt—of a land barrier and a rapid diminution of sediments toward the south.

Summary.—To sum up, Newark deposition began with subsidence after long erosion. Its constituent materials were derived from several foci; one along the Catoctin belt at the south, one at a latitude north of Frederick, and an indefinite one along the eastern Piedmont plain. The subsidence preceding deposition reduced the height of the land and slackened erosion. The waters were usually shoal and currents ran from north to south. At one later period at least elevation took place, causing emergence and rapid erosion of most of the pre-Newark formations and some of the Newark deposit. Of the nature of the elevation that closed Newark deposition there is no evidence in this region.

NEWARK DIABASE.

Nature and composition.—Description of the lithified deposits would hardly be complete without reference to the later diabase which is associated with the Newark rocks. Its characters have often been described, and they are singularly uniform in appearance from one end of the Appalachians to the other.

B. K. Emerson describes intrusive and extrusive traps in Massachusetts.[1]

Their occurrence in Connecticut is described by W. M. Davis[2] as twofold, extrusive and intrusive.

In New Jersey similar extrusive and intrusive traps are described by N. H. Darton.[3]

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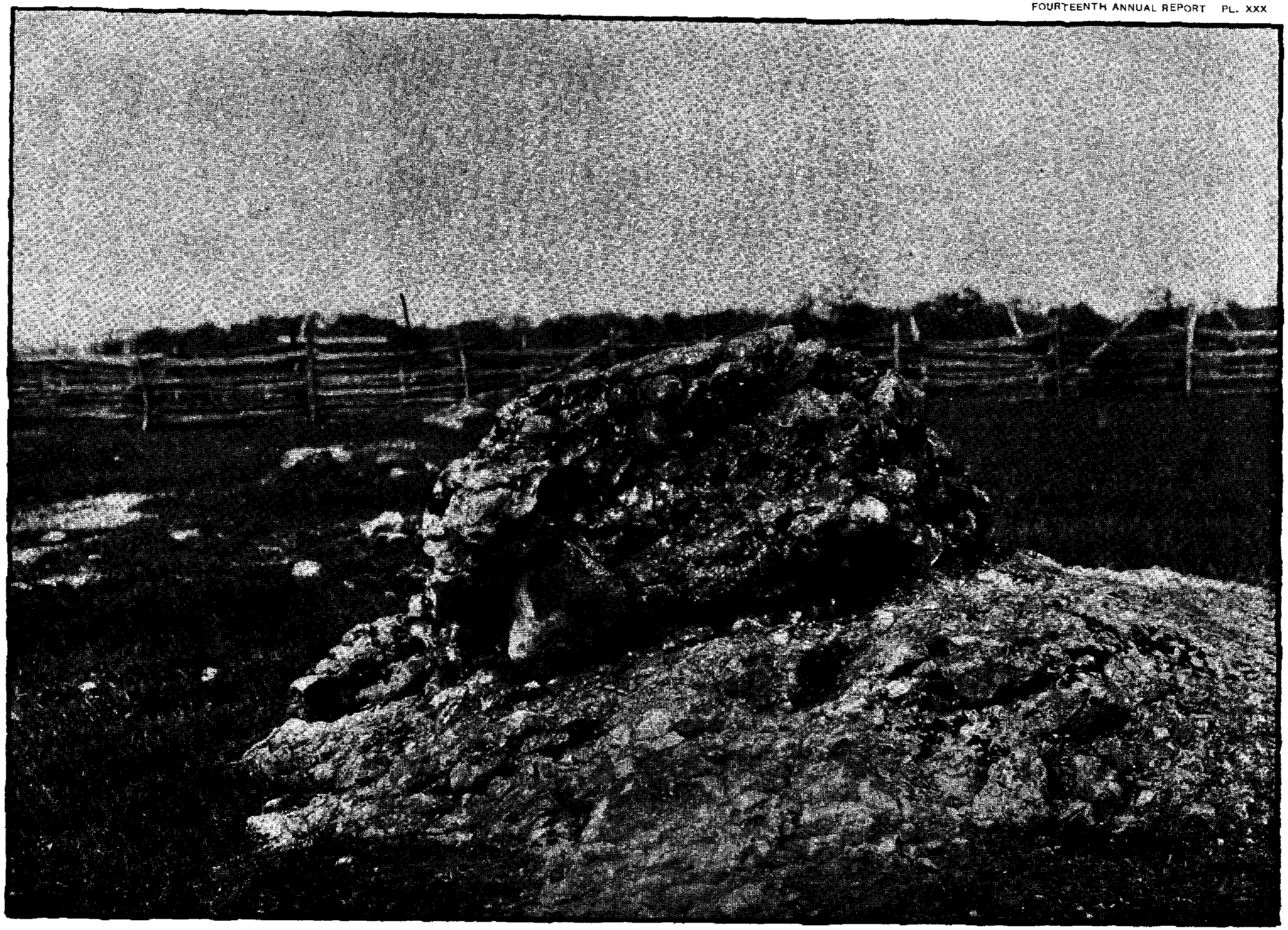
[1] Bull. Geol. Soc. America, Vol. II, p. 451.

[2] Seventh Ann. Rep. U. S. Geol. Survey, pp. 455-490.

[3] Bull. U. S. Geol. Survey, No. 67, 1890.



NEWARK CONGLOMERATE LEDGE.

Like occurrences have been mapped in Pennsylvania.[1] In Virginia they are described by Campbell and Brown.[2]

These writers and many others have described the rocks as traps, dolerites, diabases, and basalts. The latter authors first called attention to the presence of hypersthene in some of its varieties. It is not the purpose of the present author to discuss their composition in detail, but to point out their chief physical relations to the adjacent rocks.

These diabases, as they will be called generically, are usually composed of plagioclase feldspar, and diallage or augite; additional and rarer minerals are quartz, olivine, hypersthene, magnetite, ilmenite, and hornblende. Their structure is ophitic in the finer varieties, and to some extent in the coarser kinds as well. They are holocrystalline in form and true glassy bases are rare, rendering the term diabase more appropriate than basalt.

There is greater variety in texture, from fine aphanitic traps up to coarse grained dolerites with feldspars one third of an inch long. The coarser varieties are easily quarried and are often used for building stone under the name of granite.

Alterations.—These forms are retained to the present day with no material change except that of immediate weathering, but to alterations of this kind they are an easy prey, and yield the most characteristic forms. The narrow dikes produce ridges between slight valleys of sandstone or shale, the wide bodies produce broad flat hills or uplands. The rock weathers into a fine gray and brown clay with numerous bowlders of unaltered rock of a marked concentric shape. The close grain of the resultant clay and the flatness of all the typical diabase slopes renders the soil cold, damp, and unproductive. To the same result the shallowness of the soil and the numbers of round residual bowlders contribute largely. A sketch from a photograph (Pl. XXXI) taken southeast of Leesburg shows the smooth contour of a diabase hill and a small number of residual bowlders.

Distribution.—While the diabase dikes are most prominent in the Newark rocks, they are also found occasionally in the other terraces. In the Catoctin belt they appear irregularly in the granite, schist, and Harpers shale, the last being at the edge of the Shenandoah valley. Rare cases also occur in the Shenandoah limestone and the rocks of the Piedmont plain. The diabase of the Newark areas is almost exclusively confined to the red sandstone, and the dike at Leesburg cutting the limestone conglomerate is almost the only occurrence of that combination. The significance of that feature is discussed under the head of structure.

Form of occurrence.—The diabase occurs only as an intrusive rock in the vicinity of the Catoctin belt. Of this form of occurrence, however, there are two types, dikes and massive sheets or masses. The dikes

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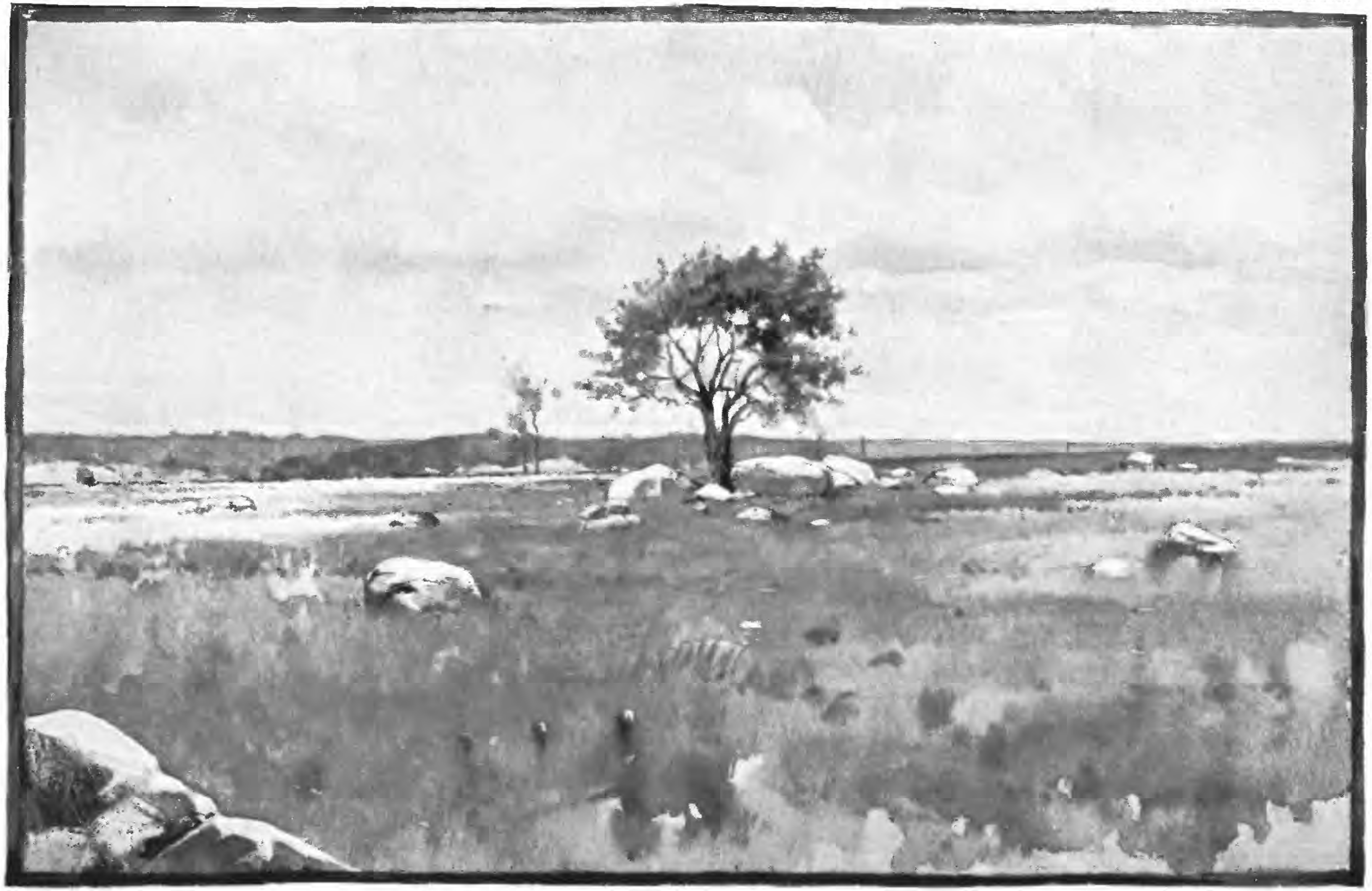
[1] Second Geological Survey of Penn. Reports.

[2] Geol. Soc. America, Bull. Vol II, p. 339.

are parallel to the strike of the inclosing sandstone as a rule, and appear to have their courses controlled by it on account of their small bulk. The large masses break at random across the sandstone in the most eccentric fashion. No dislocation can be detected in the sandstones, either in strike or dip, yet of course it must exist by at least the thickness of the intrusive mass. That this thickness is considerable is shown by the coarseness of the larger trap masses, which could occur only in bodies of considerable size, and also by the width of their outcrops in the westward dipping sandstones. The chief mass in point of size is 3 miles wide. This mass fast decreases in width as it goes north, without losing much of its coarseness, and ends in Leesburg in a hooked curve. The outline of the diabase is suggestive of the flexed trap sheets of more northern regions, but this appearance is deceptive, since the diabase breaks directly across both red sandstone and limestone conglomerate, which have a constant north and south strike. An eastern branch of this mass crosses the Potomac as a small dike and passes north into Pennsylvania. The diabase dikes in the Catoctin belt are always narrow, and, while many outcrops occur along a given line, it is probable that they are not continuous.

Contact phenomena.—If any proof of the intrusive nature of the diabase were needed other than its irregular course through the Newark rocks, it would be found in its contact phenomena. In all cases of contact observed, and they have been many on each diabase area, the Newark rocks are indurated for distances ranging from 5 to 100 feet from the contact. The chief macroscopic effect of the induration is the removal of the red oxide of iron, leaving the sandstone a dull white. Frequently, and especially in the shales, dark patches and spots are formed and even cellular structures produced. These give little indication of their nature under the microscope, but seem to owe their prominence to structural rearrangements brought out by weathering. At Leesburg the limestone conglomerate next the diabase is indurated, its iron oxide is driven off, and the limestone partly crystallized into marble.

Method of formation.—The occurrence of these contact features at both top and bottom of a diabase mass is frequently to be observed, and proves its intrusive origin beyond a doubt. The cause and method of its injection receives very little explanation from the facts of this region. Its general associations are the same as those of the faults, and it occupies breaks in the sandstone. This might indicate either simultaneous productions of faults and diabase fissures or repeated yielding in the same areas of weakness. The former is less likely, because not all the breaks are accompanied by diabase intrusion, and because some intrusions at least have produced no dislocation except the thickness of their beds. In other areas, moreover, diabase intrusions and extrusions both preceded the system of faulting. The conclusion is, therefore, best founded that the system of fractures filled



NEWARK DIABASE HILL, SOUTHEAST OF LEESBURG, VIRGINIA.

by diabase was early, perhaps during deposition of the sandstone, and that the system of faulting and tilting succeeded the solidification of the formation.

STRUCTURE.

Previous pages have been devoted to the history of the Catoctin belt as recorded in the hard rocks. From their variations certain movements of the crust of the earth were deduced, none, however, involving more than broad changes of attitude. With the close of Paleozoic time, if not sooner, began a different epoch, one of destruction by deformation of the accumulated system. Indications of similar deformations in previous epochs are completely dwarfed in comparison with the magnitude of this. Sections across the Catoctin belt are shown in Pl. XXXII, which illustrate the main structural features.

TYPES.

In the region of which the Catoctin belt is the center two broad types of deformation occur, the Newark type of monoclinal tilting and faulting and the Appalachian type of highly compressed folds and faults. The latter type can be divided still further, according to its effect upon different rocks, into folding, faulting, and metamorphism. The difference is one of effect, however, and not of cause.

The structure of the Catoctin belt is not genetically connected with the Newark structure. Doubtless Newark structures are present in the Catoctin belt, but the means are not at hand for detecting them. The Catoctin belt is defined by one of the Newark faults along its eastern limit. Otherwise its manifestations are confined to the Newark belt itself.

NEWARK STRUCTURE.

This structure is elswhere exemplified in the basin ranges of the West and in the Newark areas in Pennsylvania, New Jersey, and Connecticut. It consists of a large series of strata, all dipping in the same direction from one side of the basin to the other. At first sight the series seems unbroken and the thickness of sediment tremendous. In certain areas, notably in Connecticut, where the different parts of the series are well differentiated, faults have been determined which repeat the strata many times and give the semblance of continuous sequence.[1]

In this region such determination can not be made, unless, possibly, with an excessive amount of detailed work, on account of the paucity of distinct horizons. That faults must exist here is evident from the apparently immense thickness of strata and from the great differences in the apparent thickness. To determine their presence two things are necessary—distinctive strata and persistent strata. At first sight the beds of limestone conglomerate seem well adapted to the purpose, and they are sufficiently distinct from the red sandstones. The feature of

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[1] W. M. Davis, Seventh Ann. Rep. U. S. Geol. Survey.

persistence necessary to establish a serviceable sequence is conspicuously absent. Their formation as shore deposits and intercalated wedges makes them structurally meaningless, their appearance and disappearance along a given line, characteristic of fault structure, being partially produced in the very deposition of the beds.

One fault has been observed by Mr. N. H. Darton, about 15 miles south of Leesburg, where the underlying crystallines are brought up against the red sandstones on a vertical fault plane.

BULL RUN FAULT.

Another and principal fault is that outlining the Catoctin belt on the east. With a probable exception—the area west of Frederick—it runs the whole length of Bull Run and Catoctin mountains and then cuts across the end of the Catoctin belt. This fault is chiefly detected by the arrangement of the rocks along its line. In a broad way the attitudes of the series on either side indicate a fault. The Cambrian series strike N. 10° to 20° E.; the Newark strata, except in the northern part, strike N. 10° to 20° W. The Cambrian rocks dip southeast at high angles; the Newark rocks dip west at low angles. Between Leesburg and Aldie the actual motion on the fault is shown in the crushing and compression of the Weverton sandstone.

Dip.—In several places the dip of this fault has been determined. Two miles north of Aldie, Virginia, it dips 60° southeast; 4 miles north of Aldie it dips 50° southeast; 2 miles northwest of Leesburg it dips 30° southeast; between the Potomac and Frederick its dip is about 50° southeast; west of Mechanicstown it is 60° southeast, and north of the end of Catoctin mountain it is 50° northeast.

Throw.—The direction of its throw can rarely be determined on account of the total difference in the ages of the adjacent rocks. In two places a minimum displacement can be inferred with certainty. At Catoctin Furnace, 2 miles southwest of Mechanicstown, Maryland, a small body of Shenandoah limestone east of the fault lies against the Loudoun slate west of the fault. The east side is therefore the downthrow, since it contains the younger formation. Again, 4 miles southwest of Mechanicstown, Shenandoah limestone east of the fault lies against Loudoun slate west of the fault. Here, too, the thrown side is on the east. West of Frederick the Cambrian sequence under the Newark is apparently normal. If there is any fault, it is probably only in the form of a slip on the bedding planes of the schist below the Shenandoah limestone. Southwest of Mechanicstown its minimum throw is the thickness of the formations between the Loudoun slate and the Shenandoah limestone, a measure of 2,400 feet. It is probable that this is not much too small, for the fault has a high dip. In no other cases has it been possible to measure the throw.

Connection with Catoctin syncline.—The features of this fault were plainly controlled by the Weverton sandstones. It follows their syncline with great fidelity and its plane is closely parallel to their dip.

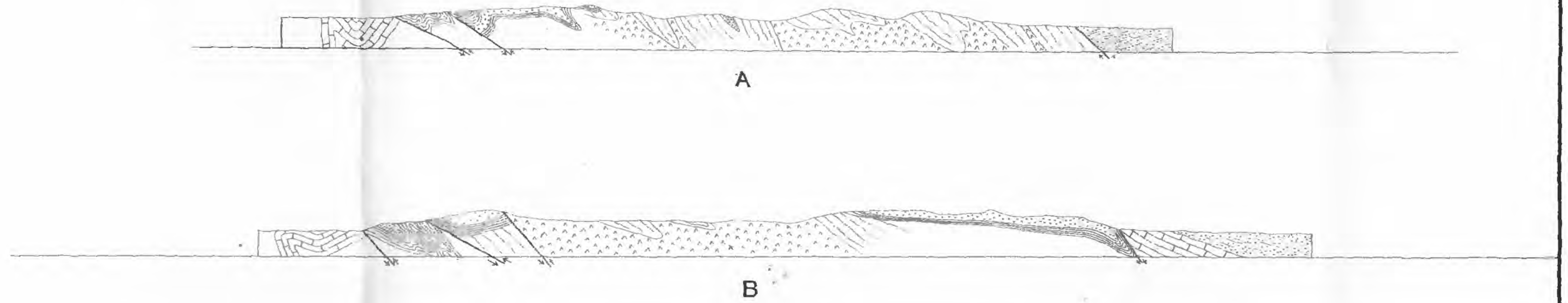
STRUCTURE SECTIONS

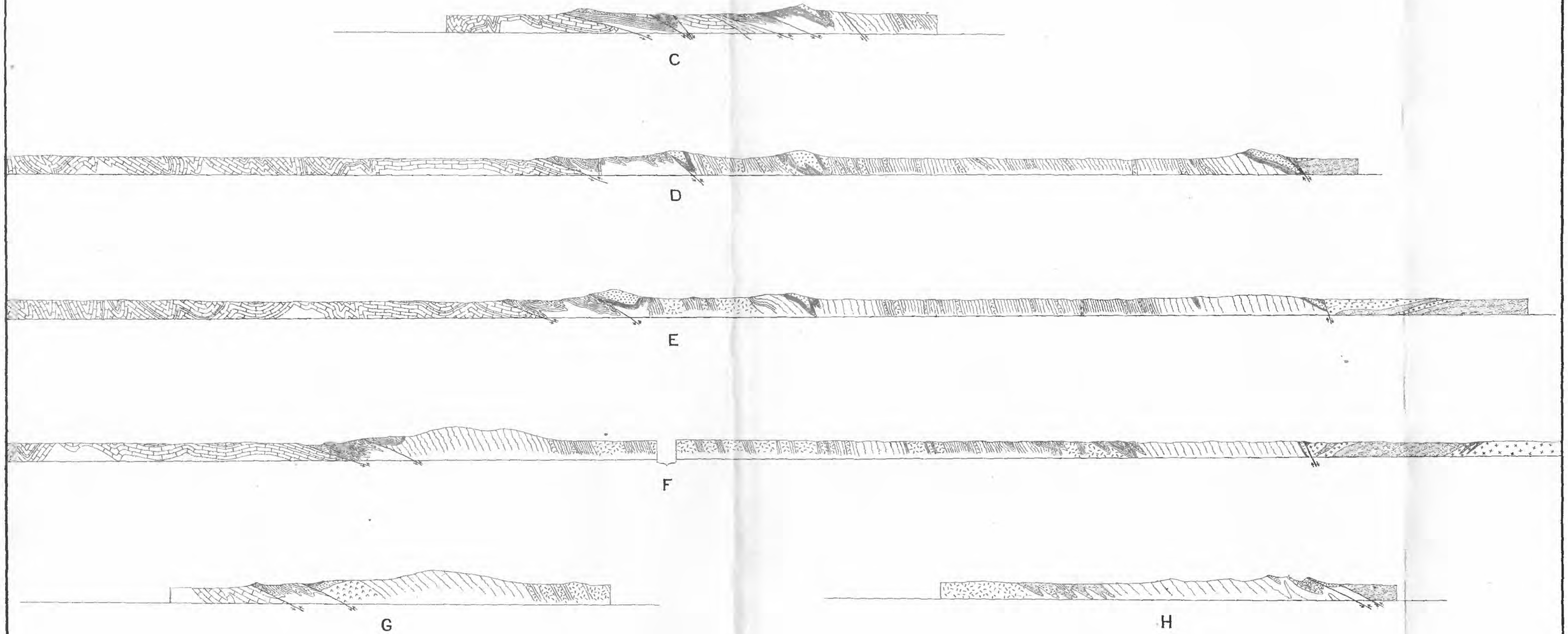
OF THE

CATOCTIN BELT

Scale $\frac{1}{125000}$

0 1 2 3 4 Miles





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On the southern portion of the range, where the southeast dips are steep, it lies in the western half of the syncline. Where the southeast dips become light, it shifts eastward to the vertical or steeply overturned dips. The syncline of Appalachian type preexisted and in places is plainly accompanied by overthrust faults; the aspect of this fault is that of an overthrust fault. Immediately the idea occurs that the Newark fault simply followed an old overthrust plane. This is an attractive hypothesis, but there is no proof of it beyond the character of the plane, so unlike the characteristic Newark breaks.

OTHER RUPTURES.

In regard to the formation of the normal Newark faults but little evidence presents itself. Evidently their cause lay outside their own mass, and from the occasional presence of the older crystallines against the faults, it probably lay in them. It may be connected with the other system of breaks, those which are filled with eruptive material. They, too, are independent of the Newark series, for instance the crosscut dike at Leesburg and the various curving dikes in evenly dipping rocks. The distribution of the dikes has some bearing on this question. South of the latitude of Leesburg they are extremely common, and the Newark series is plainly broadened by faults. North of Leesburg, to Frederick, only one dike occurs, while in this region the Newark area rapidly narrows to its smallest dimensions and the Newark-Catoctin fault is nearly extinguished. At this point there is developed a cross axis in the Newark formation, the only one which occurs in the area examined. By it the underlying Shenandoah limestone is brought to the surface along a northwest-southeast belt, and the Newark rocks strike nearly east and west. The amount of throw on the fault, if it exist at all at this point, is lessened by the amount of this arch. North of Frederick the Newark area widens, the Newark-Catoctin fault increases, and dikes more often occur.

Relation of limestone conglomerate to rupture.—Over areas strictly complementary to these the limestone conglomerate is strongly developed. This rock is decidedly stronger than the red shales and sandstones, and would certainly diminish the frequency of breaks. These relations, while very suggestive, may be only fortuitous. From the separation of the fault system and diabase-fissure system in other regions, it is probable that they are here, too, of different age. The relation of limestone conglomerate, faults, and dikes shows one thing, however, and that is the small measure of strength necessary to resist this type of rupture successfully.

On the assumption that the strength of the limestone conglomerate controls the development of the ruptures, some of the broader relations of the Newark series can be explained. Over the area of greatest conglomerate development the Newark is small, its outlines simple, and its strike is the same as that of the Catoctin belt. Where the development of the conglomerate wanes the Newark area widens tremendously, the outlines of its formations become complicated, and the strike diverges from the Catoctin exactly as if changed by progressively greater faulting.

To such progressive rupture of the stronger conglomerate the curious spine-shaped arrangement of the formations along Catoctin mountain might be due, especially as the initial strength of the conglomerate is there assisted by the rigid schists and Cambrian sandstones. In the region east of Bull Run mountain there is practically no conglomerate, and the Newark series, while very wide, strikes parallel to the Catoctin belt. These general phenomena all point to the limestone conglomerate as the controlling factor in their production. The suggested relation has no demonstration, however, and depends entirely on the coincidence of the different facts.

With this limited analysis of the structure of the Newark area one must perforce be satisfied. Normal faults do occur, dikes have broken erratically through the sandstones, and the whole series have been tilted into a continuous westward dipping mass.

APPALACHIAN STRUCTURES.

By far the majority of the structures in the Catoctin belt are of the Appalachian type. In discussion of the problems of Appalachian structure the prime center of discussion is the epoch that followed Paleozoic deposition. Previous epochs have been suggested in Algonkian, Cambrian, and Silurian time, but the production of typical extreme deformation seems to have been reserved until their close.

GENERAL FEATURES.

The three phases of Appalachian deformation, folding, faults, and cleavage, have well-defined maxima, between which there is considerable gradation and intermingling. The maxima are situated in regions of widely different strata, and are dependent largely upon the different behavior of these rocks under compression. It is not a new idea that compression caused Appalachian structure, and there is no reason to question its verity.

Folds are developed throughout the entire area under discussion. In the Piedmont plain and eastern side of the Catoctin belt, they are combined with metamorphism in the form of cleavage; in the western part of the Catoctin belt they are combined with faults; in the Shenandoah valley they are almost the sole feature of deformation. Faults are prominent along the western border of the Catoctin belt and nowhere else. A fault along the east side of the belt has been mentioned, and others may occur, but it is not possible to trace them. Metamorphism is evident throughout the Catoctin belt, but in the eastern portion especially it pervades all the formations. The great range of folds, compared with other types, is due to the fact that folds are the first and simplest results of deformation.

The general structure of the Catoctin belt is anticlinal. On its core appear the oldest rocks; on its borders, those of medium age; and in adjacent provinces the younger rocks. In the location of its system of faulting, also, it faithfully follows the Appalachian law that faults lie upon the steep side of anticlines.

After the initial location of the folds along these lines, compression and deformation continued. Yielding took place in the different rocks according to their constitution. The shales and limestones of the Shenandoah valley, being divided by the partings of bedding into many thin layers, yielded by flexing and slipping along these planes. The Harpers shale, also well supplied with parting beds, yielded in the same fashion, and the Antietam sandstone was flexed along with them, because unable to resist alone. The Weverton sandstone, especially where supported by the Catoctin schist, was comparatively inflexible, and yielded by fracture when compressed beyond its strength. This was notably the case along the Blue Ridge-South mountain lines, where it had a general dip to the west from the main uplift of the belt and consequently less transverse strength to resist rupture.

Into this system of folds the drainage lines carved their way. On the anticlines were developed the chief streams, and the synclines were left till the last. The initial tendency to synclinal ridges was obviated in places by the weakness of the rocks situated in the synclines, but even then the tendency to retain elevation is apt to cause low ridges. The drainage of the belt as a whole is anticlinal to a marked degree, for the three main synclinal lines are lines of great elevation, and the anticlines are invariably valleys.

FOLDS.

General characters.—The folds of the Shenandoah valley are very uniform in appearance, being long and closely appressed. In the western part of the valley the dips are often parallel on either side of a fold, and the repetition in a cross section is very monotonous. In the majority of synclines the eastern strata are turned up till nearly vertical. Along the eastern side of the valley there is a belt of relatively little deformation, which is probably due to relief from pressure afforded by the neighboring overthrust faults. The crests of the folds rise to about the same height, so that in the entire width of the valley only one fold contains any formation except the Shenandoah.

The folds of the Piedmont plain are numerous where the means are at hand for their detection, and they undoubtedly exist in other portions as well. They are rarely shown by actual arrangement of dips, but are inferred from the inclosure of belts of younger rock in the areas of older.

The folds of the Catoctin belt are discovered both through actual dip and through such arrangements of strata as on the Piedmont plain. Three principal lines of folds appear in the Catoctin belt—one along the Blue Ridge, composed of two synclines; one along South mountain and its axis southward, also composed of two synclines at the north; and a third along Catoctin and Bull Run mountains, also composed of two synclines. Beside these main lines there are subordinate folds brought out by small patches of the Loudoun formation in the granite-schist areas. These smaller folds can be traced only as far as the sediments extend, but from their frequency they may be inferred to represent a general condition which would appear if degradation had been less deep. There is a great difference in the prominence of these main axes in the field on account of the different topography caused by their component rocks. In continuity and depth, however, there is not much to choose between them.

South mountain-Blue Ridge line.—The two western lines of structure have identical features and represent the same condition. The western syncline in each line contains Harpers shale and Antietam sandstone; and loss of the sandstone through its easy erosion has generally removed the means of locating the fold. These rocks have offered little resistance to deformation by bending, so that their synclines are usually closed or overturned. The eastern syncline of this line contains the Weverton sandstone, Loudoun slate, and Catoctin schist, and to their resistance to erosion are due their continuity and topographic prominence. The great resistance of this combination to deformation by bending is shown by the light dips prevailing in many areas and in the development of the great fractures. The South mountain line is continued in synclines of the Loudoun formation for some distance beyond the termination of the mountain. In this extension the rocks of the synclines are Catoctin schist, rapidly reducing in amount southward, and Loudoun formation of the type accompanying its thickest development. The weakness which this change engenders is expressed by the reduction of the fold to the Tertiary baselevel.

Catoctin line.—The eastern line of synclines presents the same contrast as the South mountain line. Its eastern member contains the resistant Weverton sandstone and Catoctin schist, with the result of prominent ridges and continuous outcrop. Its western member contains the maximum development of the Loudoun formation and but little Catoctin schist, with the result of small topographic relief and rather irregular outcrop. The contrast between the two synclines is exactly the same as at the south end of South mountain under the same conditions. The eastern syncline is interrupted near the north end of Catoctin mountain, but its axis is practically continued by another axis with a slight offset. In Bull Run mountain the main axis developed several minor folds, which developed small independent faults.

FAULTS.

Grouping.—The second phase of Appalachian structure in the Catoctin belt is the system of faults. These are developed so extensively in the Blue Ridge and South mountain that other structures have been partly obliterated by them. It is possible that faults exist also in the folds of Shenandoah valley, since they would be extremely difficult of detection. The perfect development of the folds, however, renders that less likely, for the reason that compression was satisfied by the flexure. No faults have been discovered outside of this main zone, except the one along Catoctin mountain already noted under Newark structure, and two small ones in Bull Run mountain. It is possible, also, that there are other faults in the Catoctin belt which remain undiscovered. That is not likely, however, on account of the lack of differential hardness of the rocks and their observed deformation in the shape of schistosity. Certain zones of yielding by minute fracture are visible in the granites, which have the same effect as faults. The motion is distributed through a considerable thickness of rock, however, and not along a single plane, as in a fault. It is really an intermediate form between faulting or megascopic rupture and schistosity or microscopic rupture.

Formation.—These faults, like others of the Appalachian type, are the extreme stages of a deformation which began in folds. Rupture of the formations along the anticlines allowed deformation with less flexure and thrust of one fold upon another. So completely has their zone been concentrated by thrust that the anticlines are raised high above the plane of erosion, till barely a trace of their existence remains. While the original order is preserved, with the oldest rocks toward the center, yet their attitude is reversed, and the oldest rocks are piled upon the younger. Since the folds had the initial Appalachian straightness and continuity, the regularity of the faults derived from them is not at all surprising.

Breccias.—The existence of the fault planes seldom has ocular demonstration. In some places, however, fault breccias occur which characterize them beyond a doubt. None of these occur in the area of the Harpers Ferry atlas sheet, but come in within 5 miles both north and south. Along the west face of South mountain they are developed sparingly and consist of angular fragments of sandstone cemented with a little lime. They occur where the limestone and sandstone have been faulted together, until the inflexible sandstone has been fractured and the two rocks ground together. In the vicinity of Front Royal breccias appear in great force and continue to the south. Here, too, they mark the contact of limestone and sandstone and are often 50 feet thick. The fragments of sandstone are entirely angular in shape and vary in size from 8-inch blocks down to mere grains.

Iron ores.—Along the fault planes of these synclinal lines occur the chief iron-ore deposits of the region. The ore is brown hematite of varying quality. One form occurs in most of the fault breccias, replacing the original calcareous matter, and thus from the very mode of its formation in a siliceous breccia is too siliceous for use. Another form consists of nodules and lumps in clay along the fault plane which bounds the Shenandoah limestone. This ore is of good quality and fairly plentiful, so that it was much used during the early iron-making of the region. The fault line bounding Catoctin mountain on the east is also the site of similar ores, and the Newark limestone conglomerates and calcareous shales have filled the same office in its development as the Shenandoah limestone.

Dip.—The planes of thrust dip almost universally to the southeast and usually at low angles. Wherever they can be measured they are almost parallel to the dip of the strata with such regularity that the latter can be taken in other places as about the dip of the plane. The dip ranges from 20° to 50°, with an average of rather less than 30°.

The simplicity which characterizes the fault planes throughout the belt is noticeably wanting in one case, namely, the end of the Blue Ridge. The dips and sequence of strata are shown in section C, Pl. XXXI. At this point a nearly closed syncline of Weverton sandstone underlain by Loudoun shale lies upon the Shenandoah limestone in apparent conformity. No explanation of its position can be deduced from the attitudes of the surrounding beds, and the faults are introduced in the map solely from the necessities of the sequence. Instances of similar structure are extremely rare in the Appalachians. Out of hundreds of fault planes only ten cases occur in Tennessee[1] and Alabama,[2] and in all but one the dip of the plane is very light and slightly undulating. The sole other instance where the dips are steep is situated 8 miles north of Greeneville, Tennessee, and is identical with this in character. The occurrence of this anomalous structure at such a critical point was unfortunate, to say the least, in its influence on inferences from structure.

Throw.—The amount of throw in these faults can not be measured on account of the obliteration of the anticlines from which they arose. If these remained in any place the amount of their asymmetry with the synclines would measure their throw; as it is, only a minimum limit can be assigned. In the north end of the western Blue Ridge fault the throw probably diminishes to nothing. The eastern fault at the end of the Blue Ridge has a *minimum dislocation of the entire series from* Loudoun to middle Shenandoah, or 3,600 feet. South of Front Royal, where the two faults coincide, the minimum throw is 3,200 feet, and is probably over 5 miles. In other places it has a probable thrust of from 2 to 5 miles. When the Blue Ridge faults end, the South mountain faults begin, and the amount of compression is practically the same throughout. Taking the two faults together, with the folds along either of these lines, the amount of contraction has been about 10 miles, from a width of 14 into one of 4 miles.

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[1] U. S. Geol. Survey, Maynardville and Greeneville atlas sheets, by Arthur Keith

[2] C. W. Hayes, Bull. Geol. Soc. America, Vol. II, p. 149.

METAMORPHISM.

Development in the sediments.—The third phase of Appalachian deformation is metamorphism and production of schistosity. This is developed over the whole of the area under discussion. It is distinctly regional in its development, and increases from west to east; in the west, few strata show it; in the east, all are affected. It is rare in the massive Shenandoah limestones, but even there a sharp fold is sometimes accompanied by cleavage parallel to the axial plane. In the slaty limestones of the Shenandoah it is very commonly developed, especially in the eastern part of the Shenandoah valley and in the Frederick valley. It consists of rearrangement of the feldspathic matter into quartz and mica, with a parallel arrangement. The Harpers shale is metamorphosed to the extent of a strong cleavage in its western belt and of perfect schistose rearrangement in its eastern belt. The feldspathic components of the slate have developed into quartz and the micas, and the quartz grains are often drawn out and secondarily enlarged. The schistosity is produced by the intimate parallelism of the minerals, and this arrangement is itself usually parallel to the contacts of the formation with other strata.

Owing to the rarity of the Antietam sandstones on the eastern side of the belt, their behavior under metamorphism can not be stated. If the sandy schists west of Frederick represent Antietam, it followed much the same course as the Harpers shale. The Weverton sandstone has suffered less from this type of deformation than any of the sediments. In the Blue ridge and South mountain it has undergone no greater change than a slight elongation of its particles and development of a little mica. In northern Catoctin mountain it has not changed enough to affect the cross-bedding lines. From the Potomac river south, however, increased alteration appears together with the diminution in thickness. What little feldspar there was, is reduced to quartz and mica, and the quartz pebbles are drawn out into lenses. Deposition of secondary quartz becomes prominent, amounting in the latitude of Goose creek to almost entire recrystalization of the mass. A marked schistosity accompanies this alteration, and most of the schistose planes are coated with silvery muscovite. Almost without exception these planes are parallel to the dip of the formation.

Metamorphism of the Loudoun formation is quite general. It commonly appears in the production of phyllites from the argillaceous members of the formation, but all of the fragmental varieties show some elongation and production of secondary mica. The limestone beds are often metamorphosed to marble, but only in the eastern belt. The recrystallization is not very extensive, and none of the marbles are coarse grained.

Development in igneous rocks.—The metamorphism of the igneous rocks is regional in nature and has the same increase from west to east as the sediments. The details of the alteration have been given with the description of those rocks.

In the granite it consists of various stages of change in form, attended by some chemical rearrangement. The process consisted of progressive fracture and reduction of the crystals of quartz and feldspar, and was facilitated by the frequent cleavage cracks of the large feldspars. It produced effects varying from granite with a rude gneissoid appearance, through a banded fine gneiss, into a fine quartz schist or slate. These slaty and gneissoid planes are seen to be parallel to the direction and attitude of the sediments, wherever they are near enough for comparison.

Dynamic alteration of the Catoctin diabase is pronounced and widespread. Macroscopically it is evident in the strong schistosity, which is parallel to the structural planes of the sediments when the two are in contact. In most areas this alteration is mainly chemical and has not affected the original proportions of the rock to a marked extent. Its prevalence is due to the unstable composition of the original minerals of the rock, such as olivine, hypersthene and pyroxene. Along Catoctin mountain, however, both chemical and mechanical deformation have taken place, so that the original rock structure is completely merged into pronounced schistosity. This was materially assisted by the weak lath shapes of the feldspar and the mobility of the micas. Occasionally this has gone so far as to deform even the schistose planes already produced, as in the contorted gneiss near Point of Rocks.

The average dip of the schistose planes is about 60°; from this they vary up to 90° and down to 20°. In all cases they are closely parallel to the planes on which the sediments moved in adjustment to folding, namely, the bedding planes. In regions where no sediments occur, the relation of the schistose planes to the folds can not be discovered.

Parallel with the micas that cause the schistosity, the growth of the quartz and epidote lenses took place. These, too, have been deformed by crushing and stretching along Bull Run mountain and the south part of Catoctin mountain. From this fact, taken in connection with the folding of the schistose planes at Point of Rocks, it would appear that the deformation was not a single continuous effort.

The quartz-porphyry has yielded to dynamic metamorphism less than any igneous rock. Chemical changes of great extent took place in the devitrification of the original glass, but these were consummated before Appalachian folding occurred. In fact, it may be said to have suffered no change except along occasional fault lines. Certain small areas of the rock are known on the east side of the belt where schistose partings were developed by squeezing and stretching, but these do not destroy its original character. Along fault planes, however, it is sheared and pulled out of its former shape, until nothing remains but a silky micaceous slate. This form of alteration is essentially local in its nature, but it serves to emphasize the connection in dynamic origin between schistosity and fractures.

Comparative amounts of alteration.—The ratios of schistose deformation in the igneous rocks are as follows: diabase, with unstable mineral composition and small mechanical strength, has yielded to an extreme degree; andesite, with slightly more stable composition and more compact texture, has also yielded to a great extent; granite, with stable composition and moderate mechanical strength, has yielded to the more pronounced compression; quartz-porphyry, with the simplest chemical composition and great mechanical strength, has yielded only to concentrated action along fault lines.

In the foregoing statements of the metamorphism of the different rocks four general relations appear: the schistose planes are parallel with the axial planes of the recognized folds; schistosity is most common in rocks that have no bedding planes; it is most developed in the rocks containing most feldspathic material; the schistosity is regional and most developed at the southeast.

The prominence of schistosity in the unstratified rocks, which must fracture in order to yield, and its prominence in feldspathic rocks, which readily break up into schist-producing minerals, and its visible production by deformation, indicate plainly that schistosity is merely the accompaniment of deformation. It is, in truth, an integral part of the process of deformation, the more commonly noted parts of which are folds and faults.

SUMMARY.

On summing up the facts of structure several things appear that bear upon discussions of the cause of Appalachian folding. Folds, the earliest development of deformation, appear throughout the province. Faults, the next step in deformation, are localized along the anticlines and developed among beds of greatest rigidity. Schistosity, the most extreme deformation, also appears throughout the province most prominently in feldspathic rocks. In addition to this system of deformation, another system, one of regional deformation in schistosity, is developed in the Catoctin belt, with increase toward the southeast. Distinction of these systems involves the existence of two initiative environments and consequent bipartition of the period of deformation. This idea gains strength from the evident bipartition of the period in some parts of Catoctin mountain and from the universal occurrence of the two systems in the southern Appalachians. Demonstration of this relation is, however, a matter for future work.

Among all the facts of structure herein set forth the one of perhaps the broadest application is the equal deformation of both stratified and igneous rocks. It is a condition existing throughout the Appalachians, and it must be met by any explanation of their structure. If its cause is to be considered nearest when its effects are most pronounced, then it lay to the east of the Catoctin belt, for its effects increase up to the eastern limit of the belt. If the cause lay far to the east, it must have resided in the fundamental crystallines, for the sediments were but sparingly deposited there. If the effects measure only the amount of resistance, then they merely show the location of the obstructions to deformation, and the cause may lie there or anywhere. If merely the obstruction was situated near the greatest deformation, then its cause may have resided either in sediments or in fundamental crystallines. To decide between these alternatives is beyond our knowledge at present.

GEOMORPHOLOGY.

The history of the Catoctin belt has been deduced thus far from the variations in the original character of the rocks and in the changes to which they have been subjected by deformation. The third great class of variations due to rock character are those of surface form. The rocks have been exposed to the action of erosion during many epochs and have yielded differently according to their natures. Different stages in the process of erosion can be distinguished and to some extent correlated with the time scale of the rocks in other regions. One such stage is particularly manifest in the Catoctin belt and furnishes the datum by which to place other stages. It is also best adapted for study, because it is connected directly with the usual time scale by its associated deposits. This stage is the Tertiary baselevel, and the deposit is the Lafayette formation.

TERTIARY.

LAFAYETTE FORMATION.

Composition.—The Lafayettė formation is a deposit of coarse gravel and sand lying horizontally upon the edges of the hard rocks. Over the Coastal plain and the eastern part of the Piedmont plain it is conspicuously developed and composes a large proportion of their surfaces. As the formation is followed westward it is more and more dissected by erosion and finally removed. Near the area of the Catoctin belt it occurs in several places, all of them being small in area. The most northerly is 5 miles north of Frederick, where a gravel bed caps three small hills of Newark sandstone. The boundaries are well defined and the deposit undisturbed. Another is 3 miles northeast of Aldie, Virginia. Here again a Newark sandstone hill is capped with gravel. This gravel is much disturbed by recent erosion and consists rather of scattered fragments than of a bedded deposit. The most southern consists of a series of terraces upon the east side of Bull Run mountain, which are in places covered with gravel. In some places the gravel has been removed from the rock floor; in others the terrace grades up through a planation slope into the side of the mountain. All of these outcrops have the same general height, 500 feet.

Correlation.—Correlation of these gravels as Lafayette is rendered difficult by the absence of fossils and by lack of a horizontal connection. The evidence upon which they are so defined is fourfold, and consists of (1) its identical composition with the Lafayette; (2) its similar elevation and deposition upon the same plane; (3) its position as the oldest gravel bed in the area; (4) its parallel position in the system of events. The Lafayette formation consists of gravels, sands, and sandy loams. The pebbles are quartz, quartzite, and sandstone, and many of them can be referred directly to the Weverton formation on account of their blue streaked appearance and *Scolithus* borings. This description precisely fits the gravels of this area with the exception that the loams do not appear. This, however, is the normal difference between sea and shore varieties, and perhaps even this would disappear if the sections were more complete. Similarity of composition is here of more than usual value as a guide to correlation, because the coarse gravels are confined on the Coastal plain to the Potomac, Lafayette, and Columbia formations.[1] The Potomac formation does not appear in the Catoctin belt, but its epoch was represented in a period of baseleveling. The Columbia formation is largely derived from the materials of the Lafayette, and, as will be shown, its period is represented in the Catoctin belt, so that the double correlation is more than doubly strong. Over the Coastal and Piedmont plains the Lafayette gravel was spread as a nearly horizontal deposit upon a baseleveled surface. Since its deposition it has been tilted to some extent with an elevation of the western portion. Thus the vertical element so valuable in connecting horizontal deposits has been disturbed and must be used with caution. The older baseleveled surface upon which the gravels were laid down slopes up from 40 feet on the western shore of Maryland to 300 feet east of Washington, to 350 feet west of Washington, and to 500 feet in the last westward outcrops.[2] About 12 miles west of these at the same altitude are the gravels of the Catoctin belt. That these should be Lafayette requires discontinuance of tilting in the intervening region or possibly an anticlinal arch between them. This arching tilt seems to be a fact over the same baselevel north of the Potomac in Parrs ridge, Maryland. Even without this it would seem that like horizontal formations at the like altitudes should be regarded as the same until a tilting is proved which differentiates them.

The surface upon which they are laid down, since it is proved to have been a plane surface,[3] may be used to establish connection just as if the deposit actually accompanied it. This surface can be detected at intervals of a few miles between the western outliers of the Lafayette and the Catoctin belt. The locality east of Aldie itself constitutes one such outlying link. Another is a flat ridge 500 feet high, 6 miles east of Leesburg and north of Farmwell, Virginia. North of this and running east near the Potomac are several less separated fragments of the

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[1] McGee, Am. Jour. Sci, Vol. xxxv, Feb., 1888, p 120 et seq

[2] For these elevations the author is indebted to Mr. N H. Darton.

[3] N. H. Darton, Bull. Geol Soc. America, Vol II, p. 446.

plane. Twelve miles southeast of Farmwell the most westerly outcrop of Lafayette occurs. From these scattered links, all at the same elevation, a relatively flat surface can be constructed which continues the sub-Lafayette plain across to Catoctin mountain. By this means a satisfactory connection of the deposits can be made, even if the accidents of erosion have swept off the soft gravels and left the hard rock untouched.

The third means of connecting the two series of gravel lies in the attitude of the Lafayette formation. Over the Coastal plain these gravels are deposited unconformably on all adjacent formations. The unconformity is not marked by visible difference of dip, but is shown by the general disappearance of the underlying formations westward. This culminates in the overlap of Lafayette upon the crystalline rocks, so that for the western portion of the Coastal or eastern portion of the Piedmont plain the Lafayette is the stratiform deposit in contact with the hard rocks. This fact of first deposition, together with its characteristic gravelly nature—a nature not prominent in earlier deposits—renders it easy to correlate the Lafayette with the isolated gravels near Catoctin mountain, which are also the first gravels that were laid down upon the hard rocks.

A fourth and broader means of correlating the two series lies in the sequences of time breaks evidenced by their topographic forms. In subsequent pages the sequence of events in the Catoctin region will be developed. Along the Coastal plain reduction to baselevel (1) was followed by depression and deposition of Lafayette gravels; elevation followed and erosion of minor baselevels (2); second depression followed and deposition of Columbia gravels; again comes elevation and excavation (3) of narrow valleys; then depression and deposition of low level Columbia; last, elevation (4) and channeling, which is going on at present. Along the Catoctin belt denudation to baselevel (1) was followed by depression and deposition of gravels; elevation followed and erosion of minor baselevels (2) among the softer rocks; second depression followed, with possible gravel deposits; elevation came next with excavation (3) of broad bottoms; last, elevation and channeling, at present in progress. Of these classes of events only those involving elevation would be shown in the Catoctin belt, unless, as in the Lafayette, the depression amounted to submergence. Simple depression would merely accelerate the reduction to baselevel. Emphasizing the periods of elevation, therefore, a simple count of epochs backward from the present establishes their identity, and the individual stages correspond entirely in magnitude.

The facts above set forth are summed up as follows: Both gravel series have a composition best developed in Lafayette time; they lie upon the same baselevel plain; they are the oldest stratiform deposits now lying upon the hard rocks; they followed the same orographic movement. From these facts the conclusion is sure that the isolated gravel patches along the Catoctin belt are of Lafayette age.

TERTIARY BASELEVEL HEADWATERS OF GOOSE CREEK.

Bearing of the correlation.—The importance of this correlation lies in the broader range which it gives to the history of the Lafayette formation and in the close connection which it establishes between the sedimentary deposits and the great period of erosion that carved the present valleys of the Appalachians. It enables us to say definitely that this great degradation was nearly as complete before Lafayette time as at present. The length of this period is therefore measured relatively to post-Lafayette or Pleistocene time by the comparative volumes of material eroded. This correlation also makes it possible to measure the depth and extent of Lafayette submergence, inasmuch as it indicates certain shore lines and certain areas unsubmerged.

Source of material.—The materials of the Lafayette gravel are chiefly pebbles and grains of quartz, with a considerable admixture of quartzite and sandstone. The large quartz pebbles were probably derived from the large lenses of quartz in the Catoctin schist, for no other formation above water at the time contained quartz in large enough masses to furnish such pebbles. On the hypothesis that they were of local origin and merely worked over during submergence, they might be connected with the quartz veins of the Piedmont plain. That theory, however, with difficulty accounts for their well-rounded condition, which shows either beach action or long carriage. The quartz sand may well have been derived from the granitic quartzes, but that is an uncertain matter. The sandstones and quartzites are usually massive and pure white, of the variety found along Catoctin and Bull Run mountains. Other varieties of sandstone, the blue-banded type, for instance, are derived from the Weverton sandstone on the Blue Ridge. The white sandstone pebbles in the terraces along Bull Run mountain can be traced from the ledges to the deposits. In this region, therefore, an absolute shore can be seen. In other areas along Catoctin mountain a shore can be inferred because the mountain projects above the baselevel plane and contains no gravel deposits. In fact, only a few points at the stream gaps are cut down to the baselevel.

TERTIARY BASELEVEL.

The Tertiary or pre-Lafayette baselevel is extensively developed both in and around the Catoctin belt. On the map (Pl. XXXVII) its form as restored from its remnants is given in 100-foot contours. The upper contours of the residual areas are not given. It needs but little study of this baselevel to discover considerable inequalities in its surface. Two hypotheses to account for them may be advanced. They may represent original differences, due to unequal or imperfect degradation, or they may represent later deformation of an originally flat surface. In one type of locality only can this be definitely settled, and that is along a shoreline, for there all parts were originally level. Such a line is the Bull Run-Catoctin elevation, and by its variations from level the question can be decided at least for the north and south direction.

Catoctin-Bull Run shoreline.—Most of the region south of the end of Bull Run mountain has been degraded a second time by Pleistocene erosion, and all traces of Tertiary forms are gone. The first Tertiary remnants near the Bull Run shoreline consist of scattered baselevel fragments at an elevation of 500 feet, swinging around the end of Bull Run mountain over the Catoctin schist. Immediately east of the south end of the Weverton sandstone in Bull Run mountain a baselevel remnant has an elevation of 500 feet; it is carved from Newark sandstone and much covered with subangular sandstone débris.

Two miles northeast of this, and 2 miles south of Thoroughfare gap, a baselevel fragment at an elevation of 500 feet is covered with subangular gravel. Half a mile south of Thoroughfare gap a series of quartzite knobs are reduced to an elevation of 500 feet. One mile north of Thoroughfare gap a terrace covered with angular gravel marks the horizon at 500 feet. At 2 and 3 miles north of Thoroughfare gap baselevel remnants at 500 feet are strewn with gravel. Thence northward, along Bull Run mountain to its end, benches of sandy slate appear at intervals at the same horizon.

Three miles southeast of Aldie and the end of Bull Run mountain, a ridge of Newark sandstone rises to 500 feet. The same ridge at its north end, near Goose creek, attains 500 feet and carries a gravel cap.

The eastern side of Catoctin mountain for 6 miles northeast of Aldie is baseleveled at 500 feet. Over the next 12 miles there are no features definitely connected with the Tertiary plane.

One mile south of the Potomac river a granite ridge rises from the soluble Newark rocks to a height of 500 feet. North of the Potomac a series of schist knobs flank Catoctin mountain as far as Frederick. They are strewn with quartz fragments and deeply decayed, and are 500 feet in elevation.

These knobs broaden out west of Frederick into a small baselevel, which also includes some of the Newark rocks. Four miles northwest of Frederick a sandstone covered planation slope lies a little above 500 feet. Five miles north of Frederick lie the gravel-capped knobs, previously mentioned, at a height of 450 feet.

At Catoctin Furnace, 3 miles southwest of Mechanicstown, where a stream issues from its gorge in Catoctin mountain, a gravel deposit resembling a delta cone lies a little above 500 feet. One mile east of this, the Newark rocks are well baseleveled at 500 feet, with a broad Pleistocene bottom 50 feet lower. Around Mechanicstown a broad baselevel maintains a height of 500 feet with a Pleistocene bottom about 25 feet lower. This baselevel is continued 2 miles northeast of Mechanicstown by slate knobs and Newark sandstone hills at 500 feet.

At the end of Catoctin mountain broad creek bottoms have an elevation of 500 feet, the Newark areas rising gradually above them to the east. The same bottom passes northwest through a narrow gap between hard rocks, rising gradually to 600 feet near the stream heads.

EDGE OF TERTIARY BASELEVEL, SOUTHEAST OF SNICKERS GAP, VIRGINIA.

Slightly above this a large area of Newark is baseleveled at 610 to 620 feet.

These figures show substantial uniformity, and, in fact, are identical, except in the northern part of the region. On the assumption that all represent points of an original plane surface the variations would measure subsequent deformation. The different features, however, represent different elements of the process of degradation and must be differently treated in estimating their original positions in the plane of erosion. When classed according to genesis they fall into two groups—surfaces produced by erosion, or destructional, and those produced by deposition, or constructional. The former can be further analyzed into the different stages from a perfect baselevel, through bottoms and terraces, into planation slopes. The differences in the phenomena displayed are due largely to differences in the size of the streams and the distance from baselevel. The latter can be separated into subaqueous deposits grading up through delta cones into gravelly bottoms and planation slopes. By these criteria two elements of the problems are eliminated as being below the water level, the gravels northeast of Aldie and north of Frederick representing the constructional or subaqueous category. All the other, or destructional, phenomena north to the vicinity of Mechanicstown show almost no variation. From that point north to the end of the plain on this drainage the elements of the plain rise in elevation 100 feet. Over the region of no variation the phenomena consist of baselevels with edges sloping rapidly up into unreduced mountains or residuals. The gravels which cover most of them may be either relics of subaqueous deposits or merely waste from the residuals dropped there at the decrease of grade, and are intermediate between the constructional and destructional forms. They represent but a narrow zone of transition between the baseleveled and the residual areas.

When the test of nearness to the baselevel of drainage, or sea level, is applied, it is seen that all of these phenomena have about the same relation, i. e., they are at nearly equal distances from the point where tide fixes the baselevel. The drainage is accomplished by the Potomac river, Goose creek, and Bull Run creek. All of them are near tide water and head beyond the residual range, and thus are of ample size to cut their valleys rapidly down to baselevel to and beyond the residuals, because their basins are not limited by their residuals. A baselevel plain established by them, therefore, would be in truth as nearly a level as such plains ever are. Therefore, the actual identity in level shows that the plain has now the same slope north and south that it originally had.

When the details of the variations in level north of Mechanicstown are considered the solution appears easy. The areas cited are all drained by the Monocacy river, a stream similar in size to Goose creek. Over most of its basin and where the stream retains considerable volume the baselevel is truly a level. In its northern part the stream branches and rapidly diminishes; its carrying power is less, and its proximity to the residual mountains causes its channel to be clogged with their débris. Its grade, therefore, depends less upon solution and more upon corrasion, and should be higher. The surfaces of solution dependent upon and adjacent to its grade would in the same degree have their slopes increased. In fact, the highest point of the baselevel is where the heads of Monocacy disgorge their débris from the residuals upon the Newark rocks. This small difference of 100 feet between upper and lower baselevels seems, therefore, to be the normal difference between solution grades and deposition grades. Taking the two parts of the baselevel together, the fact is clear that the north and south ends of this old baselevel and shore line have been equally raised and depressed, i. e., they have not been deformed.

Potomac zone.—In regard to the other, or east and west component of the baselevel plain, the evidence is less conclusive as to later deformation, inasmuch as the data to be compared are less directly referable to an original uniformity.

The elements of comparison consist mainly of the scattered relics of the baselevel between the Catoctin belt and the Coastal plain deposits on the baselevel. As a large part of the baseleveled area to be considered is underlain by rocks of different solubility, some indeed being hardly affected by solution, the grades due to solution and those due to corrasion should be separated. The grades of solution are limited only by the flow of water, and are very low; the grades of corrasion are limited by the size of streams and the nature of the load of sediment. Errors which might arise from comparison of different parts of the slopes may be removed by grouping the factors according to distance from the drainage lines to which they are due. In this manner such differences of elevation as exist at the head of the Monocacy river may be referred to their place in the system and not attributed to subsequent deformation.

A belt 10 miles wide north of and parallel to the Potomac includes as many points of comparison as any other, and is throughout within a few miles of its base level in the Potomac formation, thus minimizing the errors due to unequal grades. Over the western part of this belt in Shenandoah valley the limestones are reduced to a uniform height of 500 feet. In its eastern part in this valley subsequent solution has lowered the Tertiary surface over the soluble limestones. Next to the Blue Ridge the areas of Harpers shale and Antietam sandstone lie at 500 feet. The narrow valley between Blue Ridge and South mountain has an elevation near the river of 500 feet. Between South mountain and Catoctin mountain the granites and schists are uniformly degraded to 500 feet. From 2 to 5 miles on either side of the river these have been further reduced by subsequent erosion to 450 feet. On the eastern flank of Catoctin mountain lie the remnants of a plain in the schist knobs at an elevation of 500 feet. East of Point of Rocks and 4 miles east

EDGE OF TERTIARY BASELEVEL, SOUTHEAST OF BERRYVILLE, VIRGINIA.

of the Potomac there is a considerable baselevel at 500 feet. Thence, at a distance of 6 or 8 miles from the Potomac and eastward for 18 miles to a point north of Washington, occur frequent large remnants of the baselevel at 500 feet. The eastern 20 miles are eroded from a variety of rocks, including red sandstones, slates, schists, and gneissoid rocks, introducing all manner of control of grade. From this succession of elevations two things appear: the baselevel is everywhere the same in height, and it is carried to such perfection that all rocks except the very hardest have been reduced to monotony. The difference between grades of solution and corrasion is practically eliminated, therefore, and direct comparison of elevations is sufficient to show that in this, the simplest case, there has been practically no elevation at one end not shared by the other end. Possibly a small allowance must be made for the ancient grade, since the identity of the elevations would allow no slope at all for the streams. The amount of this allowance would measure the subsequent deformation; that it was small, however, is plain from the perfection of the degradation, and it would undoubtedly fall within 50 feet.

These facts, viewed as a whole, make it clear that over a north and south belt 80 miles long and an east and west belt 60 miles long, crossing at Point of Rocks, there has been no permanent deformation of any importance whatever. There has been elevation to permit excavation of the Pleistocene baselevel, submergence for deposition of the Columbia formation, and elevation to the present level, but the old slopes are scarcely changed.

This determination applies without reservation to the fields from which the facts were drawn, and they were the simplest cases that could be found. In other areas differences in elevation may appear and may seem to be due to deformation. Determination of this, however, will be subject to uncertainty, on account of the more complex features involved, and will be less satisfactory than the two areas taken as types.

Relation of grade to rocks.—Study of the accompanying map (Pl. XXXVII), on which the old Tertiary surface with its possible deformations is restored, shows considerable variation in the altitude of different parts of the baselevel.

Differences of elevation of the baselevel occur most frequently in the medial valley of the Catoctin belt, but exist also in the Shenandoah valley. Between these two unlike provinces there should theoretically be considerable difference in mode of transition from reduced to unreduced, or residual, portions. In order to determine whether they are original or subsequent differences they should first be analyzed according to genesis.

Shenandoah valley is underlain by limestones and dolomites highly susceptible to removal by solution. Débris of these rocks is small in amount, is very finely divided, and remains in suspension so readily that a grade sufficient to make water flow is nearly enough to carry off the débris. They should, therefore, be reduced to a nearly horizontal surface. That is to say, the largest streams that have constant flow should have only enough fall to carry off the water, while the intermittent drainage near the divides should have a slightly greater grade, because it operates during shorter periods and is less in volume.

Streams flowing in the medial valley, however, have different obstructions to contend with, for the underlying rocks are chiefly schists and granites. Both of these rocks are to some extent soluble, because both contain considerable feldspar. Both of them also leave a great bulk of insoluble débris after the soluble matter is removed; the granite in the form of quartz and clay, the schist in the form of quartz, mica, and clay. In the case of both, also, the débris is left for a long time with the insoluble skeleton intact and firm, and these skeletons yield only to corrasion. This is so marked in the case of the schist that the mica often remains in its original cleavage position in the most thoroughly decayed regions. Over the medial valley, therefore, the differences of elevation were determined by the grades of corrasion instead of solution, and were more abrupt than in the Shenandoah valley. Its surfaces, even when perfectly baselevcled, must have had slope enough to carry off the débris from the numerous residuals without clogging their own channels, for, in all streams that degrade by corrasion, clogging transfers the corrasion from the rock masses to the débris and stops the reduction of grade.

As a whole therefore, the Shenandoah valley should show a surface with a very slight fall in the streams and broad flat arches between the drainage lines. The medial valley should have a surface with a distinct fall in the streams and a quick rise of the divides, where solution begins to be more efficient than corrasion.

Shenandoah valley.—When the facts are determined and compared with these standards, the results attained by theory approach very closely to those of nature. The topography of the Shenandoah valley is remarkably uniform from Front Royal, Virginia, northward into Pennsylvania. Its characteristics are shown in the photograph (Pl. XXVIII) taken at Berryville, Virginia. The slight swells between drainage lines and the monotony of elevation are well marked and in many regions are even quite pronounced. In fact, the differences of general level between one district and another can only be certified by instruments. Over this, the largest part of the valley, there is perfect agreement between fact and theory.

South of Front Royal a different condition of surface obtains. The hilltops marking the dissected baselevel rise rapidly toward the south from an altitude of 600 feet at Front Royal to 1,000 feet at Luray. The course of the river is still on the Shenandoah limestone, so that a change of grade must be due to some other cause than the underlying rock. Attendant on this change is the bisection of the valley by the rise of Massanutten mountain and the westward swing of the Blue

POTOMAC GORGE IN TERTIARY BASELEVEL.

Ridge, so that from a broad open sweep of 20 miles the valley is contracted to two parts only 5 and 3 miles in width. At the same time there is some small change in character of rock by the introduction of Martinsburg shale areas.

This latter feature might at first sight be held responsible for the change. The Martinsburg shale, however, does not differ so radically from the limestone in its effect upon grades. Its calcareous nature renders it readily soluble, and the residue is in a state of fine division ready for transportation at very low grades. Moreover, the same belt of shale runs north to Pennsylvania and is everywhere perfectly reduced.

The other feature attendant on the increase of grade, the proximity of the residuals, must have produced an effect by the substitution of corrasion grades for solution grades. The evidence of this is everywhere patent in the large amount of sandstone débris scattered over the limestone hilltops, often, as at Front Royal, amounting to a distinct deposit.

The inadequacy of this as the cause of the steeper grade is brought out by its amount relative to the size of the river. On a small stream such cause would be efficient, but the Shenandoah, even after its bifurcation, was amply able by bulk alone to carry off such débris without serious clogging. Moreover, such a corrasion grade is largely in excess of those established as sufficient on the smaller streams east of the Blue Ridge, such as the Rappahannock river and Goose creek.

The discrepancy between cause and effect is best shown by the distribution of the increase of grade. The 1,000-foot elevation is reached on the north fork of Shenandoah at a point north of Luray, where the southern fork attains that elevation, and the 800-foot level is due north of the similar level on the south fork. The base level rises therefore much faster on the north fork, although the stream is of greater size and the valley wider and less dominated by the residuals. Along the south fork the increase in grade is most marked near Front Royal, being about 200 feet in a direct land distance of 7 miles. The next increase of 200 feet is distributed over 14 miles. This greatest increase occurs below the narrowest portion of the valley, or that part most influenced by débris from the residuals, while the least increase occurs where the valley is most confined.

In short, the increase in grade is beyond the scale of a solution grade; it is distributed not according to the prevalence of conditions causing corrasion grades, but according to the reverse, and it is also beyond the scale of corrasion grades established on smaller streams. The inadequacy of a substitution of corrasion for solution to explain the change leaves only one explanation, and that is subsequent deformation of the surface.

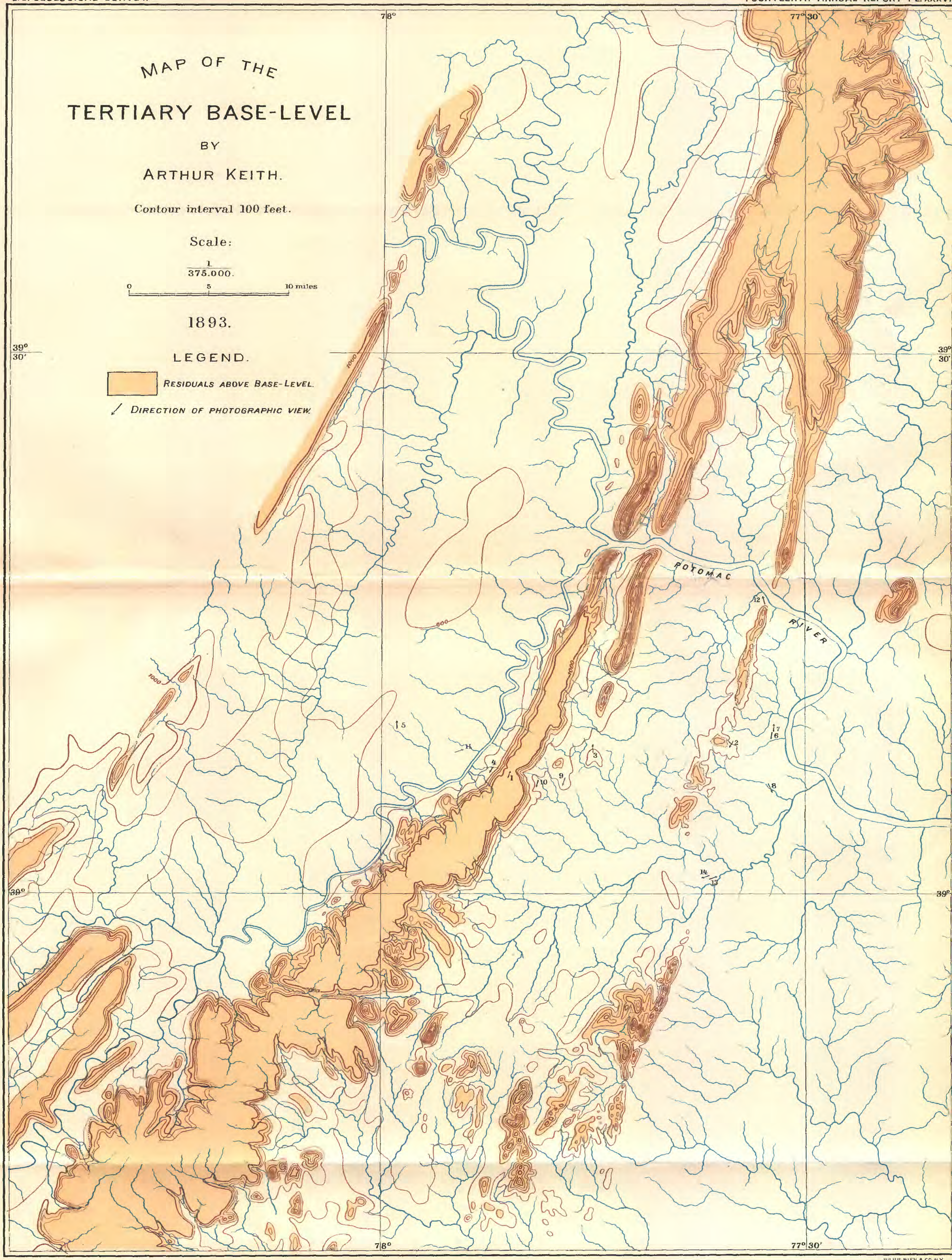
The old baselevel plain has been depressed on its eastern margin, and the lines of equal depression run nearly north and south. The eastern edge of this incline lies very near Front Royal, and the old plain is undisturbed towards the northeast. The continuation of this slope or step can be traced due north up to North mountain, west of Winchester. It causes the same marked change in the plain although the rocks underlying are limestones; it is also somewhat sharper than near Front Royal, since the 1,000-foot is closer to the 600-foot elevation. The southward extension of this incline, passes immediately into the Blue Ridge, so that its effects are complicated and masked by various conditions. The further extension of the Shenandoah valley beyond Luray shows a gradual rise to its head. It is doubtful, however, if the rise is much more than the normal rise of an undisturbed baselevel.

Medial valley.—In the medial valley of the Catoctin belt the conditions under which topographic details may be studied are more complex and more open to suspicion of error than in the Shenandoah valley. The way is made much clearer, however, by the location of the zone of disturbance in the Shenandoah valley and its limitation to that zone by the evidence of the Potomac and Catoctin-Bull Run zones. A general inspection of the medial plain shows no marked differences in the elevation of the baselevel except around the heads of drainage, where they should normally exist. Analysis of the medial plain will therefore be made on the assumption that its relative elevations are unchanged.

The natural groups into which forms of erosion most readily fall in the field are three: (1) baselevel plains, or regions of perfect reduction; (2) residuals, or regions of least reduction; and (3) intermediate types, such as concave valleys, terraces, bottoms, planation slopes, and ravines. These, of course, are all parts of a single process, and the distinctions are only for convenience in describing the stage and form of degradation. Pl. XXXIII, a photograph of the headwaters of Goose creek along the Blue Ridge, shows the wide area of degradation and the residual, along whose borders occur the intermediate types of incomplete reduction.

The drainage of the Catoctin belt and adjacent Piedmont plain can be divided into two provinces. One is the Potomac province, which is drained by a system of small tributaries of that stream. Its elevations are quite uniform and are referable to that master stream, whose grade is largely determined by its great basin beyond the Catoctin belt. The second province is the region drained by small streams, such as Goose creek and Rappahannock river. In this province the drainage lines head entirely within the Catoctin belt, and the elevations are variable according to the constitution of the rocks in the belt itself.

The surfaces of these provinces were practically the same over the Piedmont plain because the harder rocks which might have differentiated them were near tide and were speedily reduced, and because the Newark rocks on the western Piedmont plain did not offer enough resistance to cause differentiation. Westward from the margin of the Catoctin belt the rocks were at a distance from tide, the streams of the second province were more divided, and the rocks were harder.



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Thus the baselevel, which was of the same height over the entire width of the belt at the Potomac, shows in the southern province a gradual rise to the heads of drainage along the Blue Ridge.

The baselevel begins at a uniform height of 500 feet along Catoctin and extends for most of the distance to the Blue Ridge at nearly the same level along main streams. Along side branches many areas rise to 600 feet on the divides. As the streams bifurcate, carrying power decreases and their baselevels rise faster and faster in concave curves until they pass into valleys with base levels or terraces sloping visibly toward the stream. These in turn yield to U-shaped valleys with broad bottoms. Bottoms give way to planation slopes, and these to ravines and gullies. These features are possessed by nearly every stream that flows east from the Blue Ridge in the second or self-drained province. The direction of flow of the stream makes no apparent difference in the curve, and in its constant repetition is the best proof that it is normal.

The residuals rise abruptly from the reduced areas, even though themselves nearly reduced, and frequently are conical in shape. The profile of the typical residual is composed of a convex curve at the top and long concave curves at the sides. The concave curve changes rapidly where it rises from the reduced areas and continues with but slight steepening three-fourths of the way to the top; there it is replaced by the convex curve, whose greatest change occurs near the top. This profile is shown to some extent in Pl. XXXIV, drawn from a photograph, the actual curves being somewhat less definite, since the view is taken at an angle with the line of the range. The view represents the head of Goose creek against the Blue Ridge at Snickers gap.

The reason of the abrupt change at the foot of the residuals seems to be that degradation over all surfaces other than drainage lines is accomplished by solution and intermittent surface wash; the former plays a very inconspicuous part and the latter is efficient only at high angles. As the necessary high grades are attained by lowering of the draining streams, it follows that the last slopes to be increased and the last residuals to be removed are those farthest from the drainage lines. In this way, elevations between diverging streams and not on the main divides are eroded from every side into a nearly conical form; those between converging streams become short abrupt spurs; and those between parallel streams are dwindling ridges studded with occasional knobs. Examples of the isolated cones are seen in the groups of residuals northwest of Warrenton and east of Front Royal. The first steps in the separation of these peaks from the main mass are exhibited north and west of Washington, Virginia. The dwindling ridges are shown on both sides of the Blue Ridge west and southwest of Washington; intermediate forms occur at various points in the vicinity. The divides of the main drainage basins are thus perpetuated as ridges gapped at the head of every stream.

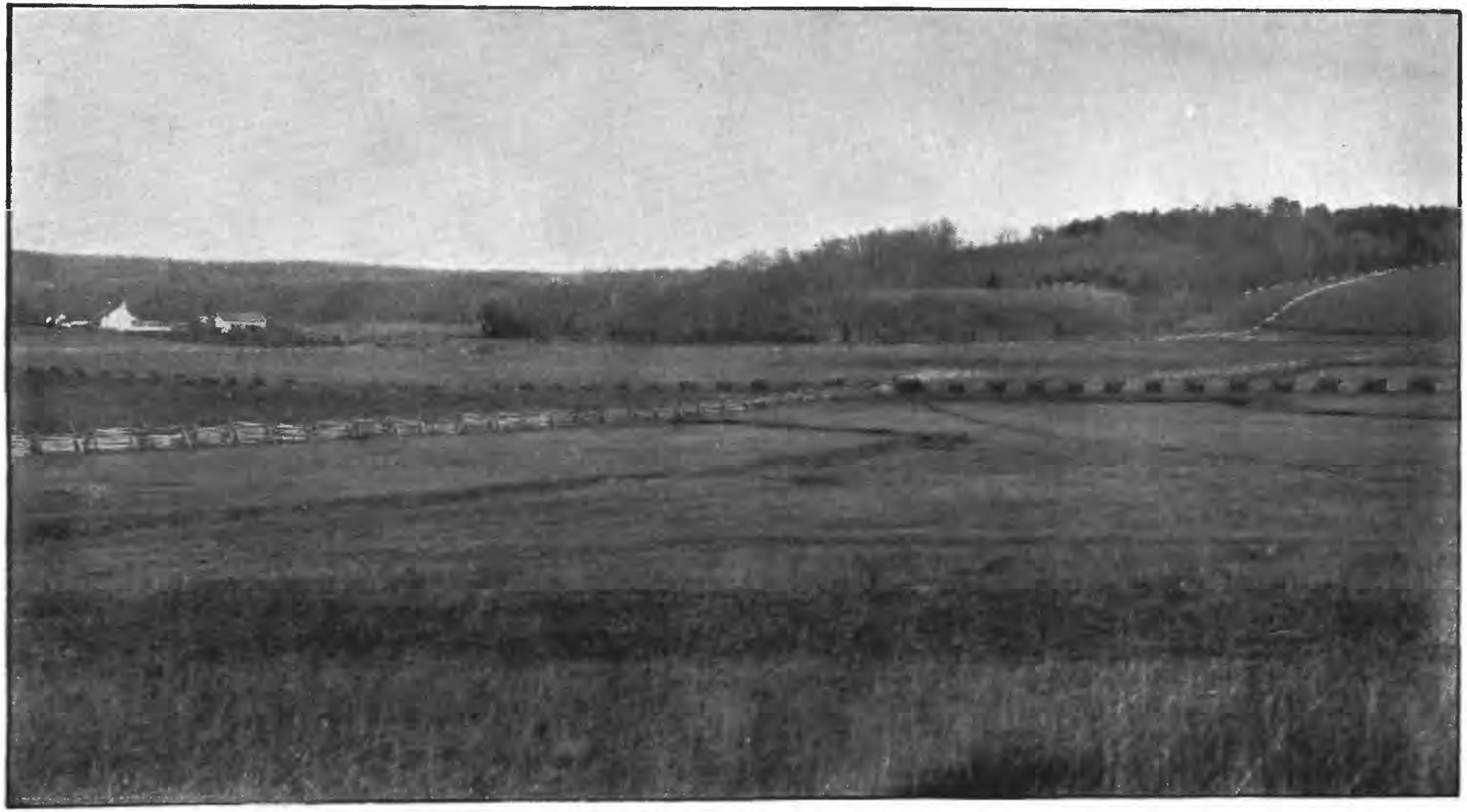
With this system the degradation of the Catoctin belt has proceeded. The efficiency of the process varied largely with the nature of the underlying rocks, so much so that the distribution of the different forms is in large measure the distribution of the formations.

Control of solubility over erosion.—Inasmuch as complete reduction of the divides is so largely a function of solubility, the close connection of the baselevel with the more soluble formations is as should be expected. In order of solubility the rocks stand as follows:

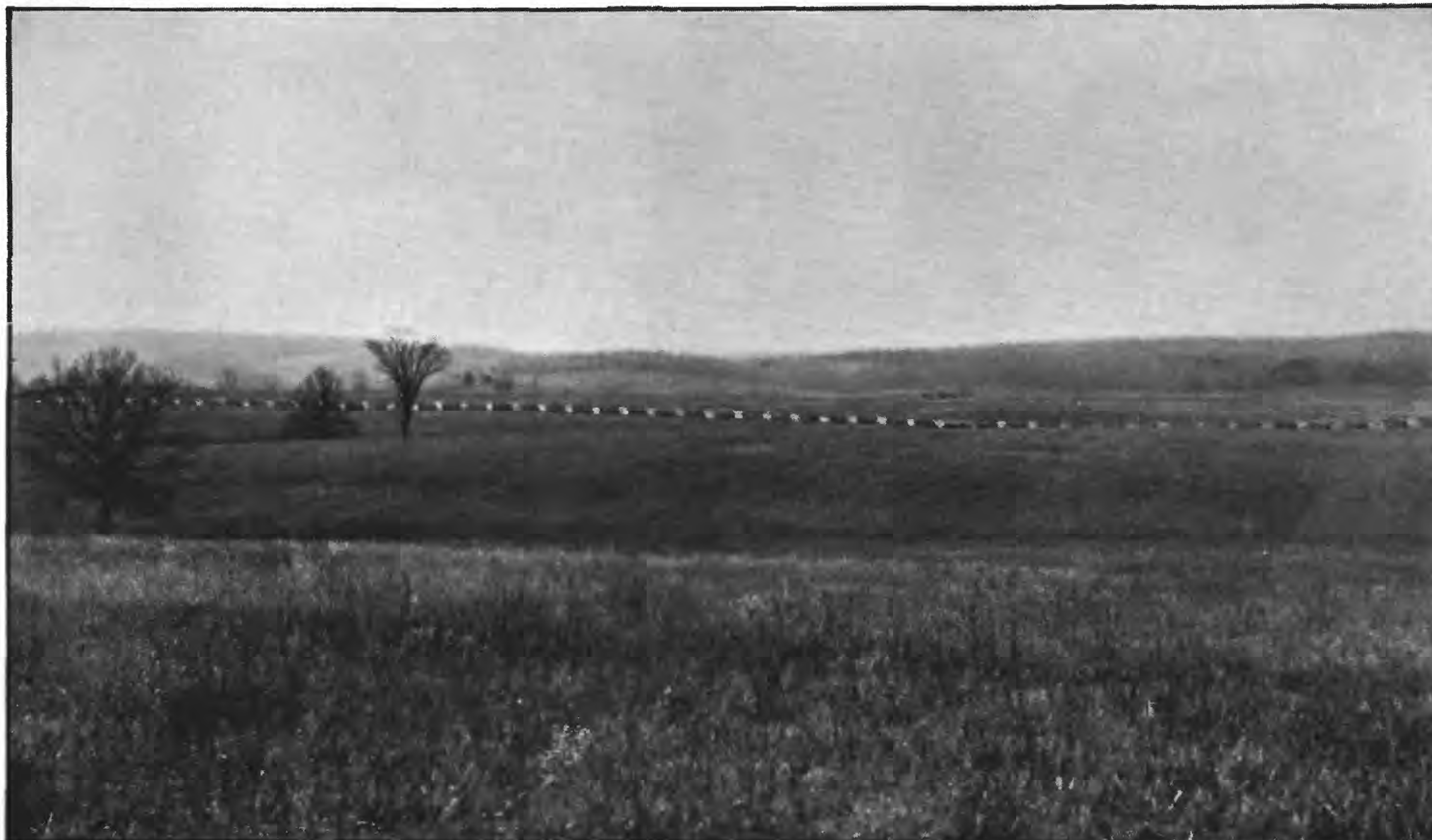
1. Shenandoah limestone; calcareous.
   Newark limestone conglomerate; calcareous.
2. Newark sandstone and shale; calcareous and feldspathic.
3. Newark diabase; feldspathic.
4. Harpers shale; feldspathic.
5. Granite; feldspathic.
6. Loudoun formation; feldspathic.
7. Granite and schist; feldspathic.
8. Antietam sandstone; calcareous.
9. Catoctin schist; epidotic and feldspathic.
10. Weverton sandstone; siliceous.

All of these formations are in places reduced to baselevel. The first four invariably are, unless protected by a harder rock; the next four usually are; the Catoctin schist only in small parts of its area; the Weverton only along a small part of Catoctin mountain. The view of Catoctin mountain west of Leesburg (Pl. XXI) shows the Catoctin schist nearly reduced. The even crests represent the old surface, the deep hollows, the degradation of Pleistocene time. The complete degradation of the granite and granite-schist areas on the headwaters of Goose creek appears in Pl. XXXIII (from photograph); the residual at the right is the Catoctin schist of the Blue Ridge. Pl. XXVII (from photograph) shows the reduced area of Harpers shale east of Berryville. In the same view are shown the main Blue Ridge residual of Weverton sandstone and Catoctin schist and one of the few Antietam sandstone residuals. Pleistocene erosion is shown in the small stream hollows. A photograph of the Potomac gorge above Point of Rocks (Pl. XXXVI) illustrates the equal altitude of baselevel remnants in the schist, even where exposed to strongest subsequent erosion. In the distance the Blue Ridge residual appears. The Newark formations are so universally degraded by Pleistocene erosion that illustrations of their Tertiary forms are not readily obtained. The baselevel over Shenandoah limestone is well illustrated in Pl. XXVIII. Pl. XXXV illustrates its partial destruction by Pleistocene and recent erosion and the rounded forms of the limestone hills under active solution.

The extent of the baseleveling of each formation bears a very close ratio to its position in the scale of solubility. Those formations that succumbed entirely to Tertiary erosion have their relative resistances



TERTIARY, PLEISTOCENE, AND PRESENT BASELEVELS, SOUTH OF LEESBURG, VIRGINIA.



PLEISTOCENE BASELEVEL, SOUTH OF LEESBURG, VIRGINIA.

brought out by Pleistocene erosion, and will be considered under that head. The most striking illustrations of the relative resistances are the Blue Ridge, South mountain, and Catoctin residuals along the Potomac, which the combined corrasion and solution of Tertiary, Pleistocene, and present times has failed to reduce. Through all of these mountains the river goes in a narrow pass hemmed in by high cliffs on either side, while the 500-foot baselevel sweeps up to the very cliffs. Almost equally striking is the protrusion of the Catoctin schist residuals above other rocks from the moment that the geologic boundary is passed. This appears in every case, whether the streams flow along or across the strike, and even where it is practically baseleveled, southwest of Leesburg, there is some difference of elevation. In most cases the broad expanses baseleveled over the coarse schist and granite contract into narrow baselevels or U-shaped valleys immediately on reaching the Catoctin schist.

Anticlinal drainage.—In adjustment to the general geological structure the streams have followed the law of anticlinal drainage so conspicuous in the Appalachians. The anticlines of the Shenandoah valley had developed the Shenandoah river long before it eroded its course down to the soft limestones; discovery of them strengthened and extended its grip. The medial valley or main anticlinorium is reduced and drained by anticlinal streams in its northern half; its southern half is drained by lateral streams, but is equally reduced along the anticlinal portions. Wherever the synclines contain hard rocks they constitute mountains, and every mountain except the larger residual groups is a syncline; even the synclines of softer rocks retain some eminence. The main river of the region, the Potomac, is entirely antecedent, and no theory of its location can be formed from the facts of the Tertiary baselevel. Streams such as Goose creek and Rappahannock river represent subsequent drainage dependent on the syncline of the Blue Ridge and dating back at least as far as Cretaceous time.

In short, the Tertiary baselevel is a complete display of erosion under all conditions of structure, rock composition, and drainage. If it were necessary, precise determinations of grades could be worked out for each environment, but they would scarcely be of service in other regions on account of the difficulty of certifying the similarity of conditions.

The Lafayette gravels associated with the Tertiary baselevel are the latest sedimentary record in the Catoctin belt. Steps can be taken, however, toward a completer history of the region by tracing the surface forms produced at different epochs and connecting them with recognized time divisions. Two divisions which have left their impress on topography are the Pleistocene and Cretaceous; their records are baselevel plains, that form of surface which may be detected longest in spite of subsequent vicissitudes.

PLEISTOCENE.

CORRELATION.

Of these epochs the Pleistocene is most readily studied on account of its recency and immunity from subsequent erosion. In this period two baselevels were developed, one at nearly 450 feet, and a second at about 350 feet. They are correlated with the Pleistocene period and Columbia formations on much the same evidence as the Tertiary level was correlated with the Lafayette, i. e., on the analogy of intervals or distinct periods of erosion. This correlation has, moreover, the added strength of the identification of the Tertiary level as the complement of the Lafayette formation on the evidence of a much wider field.

UPPER BASELEVEL.

Development.—The upper baselevel is chiefly developed over the Piedmont plain, but was sufficiently impressed on the Catoctin belt to be still recognizable. Over most of the Piedmont plain south of the Potomac, and especially on the Newark areas, it is quite uniform at an elevation of 450 feet, and but little of the Tertiary baselevel has escaped reduction. North of the Potomac the contraction of the Newark areas and consequent exposure of harder rocks has enabled the Tertiary level to escape to a considerable extent. A zone 4 or 5 miles wide on each side of the Potomac in the Catoctin belt has been reduced to 450 feet, with a gradual rise from the river to the Tertiary baselevel. The dissection of this plain by the Potomac in its recent cutting is shown in the photograph from Catoctin mountain (Pl. XXXVI).

Variations in level.—At the south end of Bull Run mountain this baselevel is 450 feet above tide. It extends only a mile from the residual toward the east and then gradually merges into the lower level at 350 feet. The Newark sandstone ridge, running parallel to the Catoctin line for 6 miles south from Leesburg, is in most places reduced from the 500-foot Tertiary to the 450-foot level.

In the southern Monocacy valley its plane is shown by scattered Newark sandstone hills at 450 feet. Three miles southwest of Mechanicstown, Maryland, the level is shown by broad bottoms at 450 feet. From this latitude northward the Pleistocene and Tertiary elevations approach each other too nearly to be distinguished. On many of its southern elevations near Catoctin mountain quartz and sandstone pebbles are strewn, not, however, in sufficient amount to indicate subaqueous arrangement.

The Lafayette gravels north of Frederick, at 450 feet, seem to fall into this plane. They are considered to be Lafayette, however, for the reasons that no other portions of the 450-foot level in this region carry subaqueous gravels, although they would have been equally submerged, and that the Lafayette gravels extended to this shoreline and could have been dropped on this slightly lower level, even without occurring on the 500-foot level.

LOWER BASELEVEL.

Development and altitude.—The second or lower baselevel has an elevation of 350 feet at a point 4 miles southeast of the south end of Bull Run mountain, at which altitude it spreads over a large expanse of country toward the south, east, and northeast. Eight miles south of Aldie the same plain is 400 feet high and declining eastward. Four miles southeast of Aldie it is 400 feet high. East of Aldie and for 7 miles north it has a constant elevation of 350 feet. Pl. XXXVIII (from photograph) shows the Tertiary hill covered with gravel, the lower Pleistocene terraces on its side, the lower Pleistocence baselevel in the distance, and the recent flood plain of Goose creek. It is much dissected by recent erosion, but its remnants and terraces are flat-topped and well marked. From Leesburg nearly south to Goose creek its summits are often strewn with rounded and angular quartz and sandstone pebbles from Catoctin mountain. In the next 4 miles it rises gradually to 375 feet at Leesburg. At Farmwell, 5 miles southeast of Leesburg, its elevation is 350 feet. From Leesburg north to the Potomac its elevation falls to 350 feet. In this stretch its location is well marked by many meadows and planation slopes along the flank of Catoctin mountain. Recent erosion has developed gravel-laden bottoms along the streams from 10 to 30 feet below the baselevel. In both the Pleistocene and recent wash, there are beds of clay and ocher of considerable extent.

Northward from the Potomac the baselevel is well marked as far as Frederick by Newark sandstone hills 350 feet in height near the Monocacy. Nearer Catoctin mountain the level is less developed for 5 miles from the Potomac in broad, gravelly bottoms 350 feet in altitude between low swells. North from Frederick the 350-foot level was but scantily developed and only in the vicinity of the main stream. Its effects are also masked by recent erosion on the same lines.

The contrast between the immaturity of forms around Frederick and their maturity over the southern portion of the belt is quite striking, and is the reverse of what would be expected. In the northern portion the limestone conglomerates and calcareous shaly sandstones are extensively developed and are near the largest stream. South from Leesburg the solubility due to calcareous composition rapidly diminishes and the drainage is accomplished by Goose creek and Bull Run creek, streams of relatively small size. In this region conglomerate, shale, sandstone, and harder trap are almost wholly reduced. A photograph of the level north of Aldie (Pl. XXXIX) shows its smoothness and its reduction to the very foot of Catoctin mountain. This locality also is one of the very few where the Catoctin schist and Weverton sandstone were almost reduced in Tertiary time.

Cause of variations.—This disproportion of results might be attributed to excess of load carried by the Monocacy river in the northern areas, and that this was a considerable cause is proven by the excess of load in recent streams in the same areas. Evidence in the same direction is the area of high level along the flanks of Bull Run mountain, where the sandstone again furnishes a large amount of waste. This higher area, and a similar one at Leesburg, are also the chief divides, where added height should be expected. However, excessive load is not the sole cause, for the excess is as great in the more southern areas as it is in the northern, yet the southern baselevel is nearly perfect. The contrast is not so much in the grades of streams as in the maturity of forms and the disproportion between Pleistocene and recent results on the same rocks around Frederick and around Aldie.

The only adequate explanation for the immaturity north of the Potomac is a tilting of that region which caused erosion to be earlier and thus more complete over the southern regions. That this is true can hardly be asserted from the narrow evidence of the Frederick valley. Aside from this northern portion, however, there are no inequalities in the level which can not be sufficiently explained by their relation to the drainage lines.

RECENT.

EXTENT.

In this Pleistocene baselevel recent drainage has incised itself to a considerable extent. East of Bull Run mountain the depression ranges from nothing to 40 feet. Goose creek has cut down 80 feet, as shown in Pl. XXXVIII, while 1 mile westward Little river, a tributary of Goose creek, has only cut down 30 feet. The Potomac has canyoned itself 100 feet below the base level, while its smaller tributaries between Leesburg and Point of Rocks have progressed only from 10 to 30 feet. North of the Potomac the Monocacy canyon, in the Shenandoah limestone, is 100 feet below the level nearly as far north as Frederick; its small streams on the Newark rocks are from 100 to 20 feet below.

All of these streams have a steady and rapid fall to tide water, so that they are far from the baselevel. Even the Potomac falls 250 feet in about 40 miles, and the smaller streams have still higher grades. Local baselevels are developed during the removal of some barrier of hard rock, such being the broad flood plain of Goose creek in Pl. XXXVIII. The drainage is therefore in its infancy.

COMPARISON OF PERIODS.

TERTIARY AND EARLY PLEISTOCENE.

In Tertiary time 600 square miles of hard rocks were cut down to baselevel from an average height of 1,800 feet to an average of 500. In the same area Pleistocene erosion reduced about 40 square miles from a 500-foot to a 450-foot baselevel, and partly reduced about 300 square miles. Pleistocene erosion was in its earlier stages, and was consequently more rapid than the average of Tertiary erosion; it also attained its baselevel limit sooner on account of its lesser uplift. The comparative removal of material, therefore, best represents the comparative time of the periods. These may be expressed proportionally in mile-feet of degradation as follows:

$$\left.\begin{array}{ccccc} \text{Miles.}\ \ \text{Feet.} & & \text{Miles.}\ \ \text{Feet.} & & \text{Miles.}\ \ \text{Feet.} \\ 600 \times 1{,}300 & : & 40 \times 50 & + & \frac{300 \times 50}{4} \\ 780{,}000 & : & 2{,}000 & + & 3{,}750 \\ 134- & : & 1 & & \end{array}\right\} = \text{Tertiary time to early Pleistocene time.}$$

EARLY AND LATER PLEISTOCENE.

The same unit, the Catoctin belt, can not be used to measure the earlier and the later Pleistocene periods, since they are not differentiated therein. In the Newark rocks they are both represented, because these softer rocks have yielded to their briefer attacks, and for comparison a belt is taken 6 miles wide, from the Potomac to Frederick, and 12 miles wide, from the Potomac south to the latitude of Warrenton. In this area 600 square miles were reduced from the 500-foot level to the 450-foot level in earlier Pleistocene time, and 300 square miles were reduced from the 450-foot level to the 350-foot level in later Pleistocene time. Expressed proportionally, the result in mile-feet of degradation is—

$$\left.\begin{array}{ccc} \text{Miles.}\ \ \text{Feet.} & & \text{Miles.}\ \ \text{Feet.} \\ 600 \times 50 & : & 300 \times 100 \\ 1 & : & 1 \end{array}\right\} = \text{Early to later Pleistocene.}$$

When it is considered, however, that greater elevation gave greater speed to the later Pleistocene erosion, it will be seen that the later period was shorter than the earlier, perhaps as 5 to 6.

No material for comparison of any value between Pleistocene and recent erosion exists in this region, because the stages to which they are carried and the conditions of elevation controlling them are so different. In the above comparisons no account is taken of the nature of the uplifts, whether gradual or simultaneous, because there are no means of determining it. The ratios of time can not be regarded as exact or scarcely as approximate, but are merely expressive of the scale of difference between the separate periods.

GENERAL COMPARISON.

The different periods thus rank, in point of time elapsed, somewhat as follows:

Tertiary, 134.
Early Pleistocene, 1.
Later Pleistocene $\frac{5}{6}$.
Recent, a small fraction.

In depth of degradation to baselevel, and therefore in amount of elevation above tide, they stand as follows:

Tertiary, 1,800—500 = 1,300 feet.
Pleistocene, 500—450 = 50 feet.
Later Pleistocene, 450—350 = 100 feet.
Recent, 350—50 = 250 feet.

From the above tables the Tertiary period stands out as far greater than any or all the others in actual disturbance of the earth's crust, in alteration of the surface, and in duration.

CRETACEOUS.

BASELEVELS.

Development.—The final additional step to be taken in unraveling the history of the Catoctin belt is the recognition of Cretaceous time in its baselevel records. This record is the least satisfactory of all that have appeared in this region, because it is so far obliterated by later degradation. It is very finely shown in the northern portion of Catoctin mountain and South mountain, especially the former. On Catoctin mountain, northwest of Frederick, the broad, flat summits of sandstone remain unaltered by later events, and extend alike over lightly and steeply dipping beds. At this point its shape can be surely identified as that of a baselevel remnant. Its elevation ranges between 1,700 and 1,900 feet along the north part of Catoctin mountain, and over South mountain it has the same limits. One point on South mountain, south of Monterey, rises abruptly to 2,300 feet, and probably represents a small Cretaceous residual. North of Monterey the crests soon rise to 2,000 feet and then to 2,200.

These ridges are drained by many diverse streams, including Monocacy river, Catoctin creek in the Catoctin belt, Antietam creek and Conococheague creek, in Shenandoah valley—all having independent drainage and great diversity of underlying strata. The regularity of these tops can not be attributed to the action of the present streams, therefore, least of all in view of their visible inefficiency wherever they gap the mountain rocks. The elevations comprise both Catoctin schist and Weverton sandstone, lying at such various angles that their uniformity can not be attributed to structure. No other cause remains, then, but reduction to uniformity by long erosion.

Criteria.—The baselevel is apparent in the north part of the Catoctin belt; in most other places it is far otherwise and is only realized by close study of the summits. In searching for evidence of its existence, its nature should first be considered and then the mode of its destruction.

A baselevel plain consists initially of a nearly plane surface, whose drainage basins are barely separated by low divides. Since it is developed by progressive degradation and completed chiefly by solution, it contains frequent unreduced areas. These are due (1) to structure, through the development of anticlinal drainage, and (2) to insolubility of hard rocks which eventually are situated on divides.

A baselevel is destroyed by elevation, which adds to the grades and thus to the erosive power of the streams. The steepening extends fastest up the largest streams and only reaches the divides in its final stages. The existence of divides is therefore perpetuated, as a rule, on account of their structure, their superior resistance, and their immunity due to mere distance. To the divides attention should be turned, therefore, and especially to those retained by the most insoluble rocks. The area of the Catoctin belt is scarcely extensive enough for the purpose of studying the Cretaceous level, and a broader bearing of facts must be obtained from other areas. Marked features occur, however, within this area, and from other areas they can be corroborated and their extent determined.

It is not the author's purpose to enter into a comprehensive analysis of the Cretaceous surface, but only to point out its salient features in the Catoctin belt as corroborated in other areas and to discuss their bearings upon various other questions.

Effect of Tertiary erosion.—The elevations along divides will be correlated on the assumption that the summits in most cases approximate the original elevations before Tertiary erosion began. That this assumption is well founded appears from several facts. Elevations on Catoctin mountain progressively diminish southward from Frederick to Aldie, although the rocks remain the same, and the Tertiary drainage, which might be supposed to determine their elevations, becomes less effective in that direction. Elevations along the Blue Ridge rise steadily southward, although the rocks are constant and should have been reduced equally by the Shenandoah river, which is almost absolutely parallel to their course. The insignificance of Tertiary erosion on the hard divides is perfectly shown in the gaps of the Potomac in the Blue Ridge, South mountain, and Catoctin mountain. The level, almost unvarying tops of the two former stand at 1,200 and 1,100 feet in both directions, and rise out of the river in bold bluffs and cliffs. Catoctin mountain shows precisely the same features south of the river, but is slightly reduced for a mile to the north, the difference being due to the absence of Weverton sandstone over that distance and the slightly inferior resistance of the Catoctin schist. In short, the utmost that post-Cretaceous erosion has been able to accomplish along the harder divides is shown in the abrupt baselevel trenches on the main streams and in the ravines and valleys of smaller streams rising up to the gaps in the dividing ridges. Accordingly the surfaces deduced from the altitudes of the main summits will be a fair representation of the irregularities of the surface before Tertiary degradation.

Variations of altitude.—Great irregularities of altitude are evident on examination of the summits. They are arranged in columns below, reading down from north to south, equal latitudes being roughly on the same line:

Alleghany front.	North Mt.		Blue Ridge.	South Mt.	Medial valley.		Catoctin Mt.
				2200			
				2000			
				2000			
	1500			Monterey 2000			
	1300			1700	1900	1700	1700
	1200			2300			1600
	1100			1700		1900	1900
				1700			1600
	1000 Potomac.			1800		1900	
				1900			1800
	1100			1800		2000	1800
				1700			1800
	1400			1700			1900
	1700		1300	1600			1600
2700 Potomac.	1500		1200	1800			1200
3000			1200	1500			900
3000			1200	Potomac 1100			1200
			1100				
3100			1000	1100		Potomac.	900
			1600	1100			700
3400	2500		1600	1300			700
	2700		1500	1200			700
3700	2800		1700				
	2800	Massanutten	1800				700
3700		Mt.	1900				800
			1900				
4000	2300		1800				600
4300		2100	Front Royal. 2100				Bull Run Mt.
4400		2200	2400				Goose creek. 600
4500		2000	2600				1000
		1800	3100				1300
4700		2400	3200				1200
	2200	2500 W. Luray E.	3000				900
		2500	4100				Warrenton.
	2700	2500	4100				
		2500	Stony Man. 4000				
		2800	4000				
	2700	3000	4200				
	2500	2800	3800				
		2800	3500				
	2800						Southwest Mt.
			3600				1100
			3200				1200
			3300				1200
			3300				1800
	3000		3000				1400
	2900		3100				1300
	3000		Waynesboro. 3000				Charlottesville.
	3000						

These elevations have wide range, and it seems absurd at first sight to search for a baselevel among them. That a part of the elevations represent a baselevel is beyond question in northern Catoctin and in the eastern edge of the Alleghany plateau. These elevations show a distinct system, however, which is fruitful in hypothesis, at least.

Axial system of drainage.—Six things stand out from the array of figures that are of interest. (1) A general axis of high altitudes passes a little south of Luray in direction N. 60° W. (2) A general axis of low altitudes passes through Harpers Ferry in a direction N. 40° W. (3) The Potomac, the chief stream of the region, flows closely parallel with the axis of depression. (4) Massanutten mountain, the chief residual of Shenandoah valley, lies on the axis of greater altitudes. (5) The chief group of residuals of the medial valley lie on the axis of greater altitudes. (6) The general divide of Potomac and Rapidan river drainage lies in these residuals.

These greater relations of altitude and degradation to drainage indicate a close connection between them, such as cause and effect. Either the Potomac and Rapidan were antecedent and developed these axes as valley and divide, or the axial system was produced before these rivers and determined their location. The evidence in favor of the former hypothesis is merely the present location of the main streams in the main depressions. If the character of the interstream areas is not that appropriate for such areas under the known conditions, then the hypothesis has practically no support. The evidence in favor of the latter hypothesis is that which militates against the former.

Fact of baseleveling.—One condition has been determined with which the hypothesis must comply, namely, that much of the Cretaceous surface was a baselevel. As previously stated, the Alleghany plateau and the northern Catoctin belt are undeniable instances. That the major part of the ridges between the remnants were nearly baseleveled can not be doubted by any one looking over them from a point in their plane. In that situation the eye discriminates and generalizes in a moment with a better result than can be obtained by long study of maps and elevations. Such long even-crested ridges could not attain their monotony under diverse drainage systems and varied structures except in the last stages of degradation. Moreover, the location of the two baseleveled areas on both sides of the area in question is strong presumptive evidence that all were baseleveled, since most of the points lie between the elevations of the two baselevels.

Two baselevel periods.—The possibility exists, however, that while all the ridges may be baseleveled, the reduction took place at more than one period. To the solution of this question a cross section will contribute largely. In a narrow belt at latitude 39° 30′ between the Catoctin baselevel and the Alleghany baselevel the ridges have the following altitudes:

Alleghany. Catoctin.
3,000, 2,300, 2,100, 2,100, 1,900, 2,000, 1,900, 2,500, 1,900, 1,800, 1,800, 1,800

In this series there is a marked grouping about 2,000 feet, quite distinct from the level of the Alleghany plateau. In fact, the elevations between 2,100 feet and 1,800 feet fall almost precisely into an eastward dipping plane, and comprise the essential features of a baselevel. A curious fact, possibly a coincidence, is that the only ridge much out of this plane falls exactly into a plane produced from Alleghany plateau to the Catoctin baselevel.

Other profiles of the Appalachian ridges in central Virginia show a similar separation into groups. In Tennessee the baselevels of a belt transverse to the valley near Knoxville fall into three groups—those around 1,000 feet, or Tertiary; those around 1,900 feet, or Cretaceous (?), and those from 3,000 to 3,400. In North Carolina a similar sequence obtains on the upper Little Tennessee river: Tertiary bottom at 1,800 feet, Cretaceous base level at 2,000 feet, and an upper baselevel at 3,000 to 3,200 feet. Similar series occur on the Doe river, in North Carolina: Tertiary bottom lands and terraces at 1,800 feet, Cretaceous baselevel at 2,600 feet, and upper baselevel at 3,400 feet. In more southern districts of the Appalachians, then, there are two distinct periods of reduction before the Tertiary, marked by actual baselevels. In central and northern Virginia there are two periods of reduction marked by actual baselevels and by a system of baseleveled ridges. Such extensive reductions and uplifts as appear in the southern Appalachians are of continental nature, and each must have made its mark in northern Virginia, unless, indeed, two of the periods coincide. Since, therefore, two distinct periods are manifested in northern Virginia after the Tertiary, correlation of the northern and southern series becomes easy. The lower or ridge level represents the southern Cretaceous reduction and the Alleghany level the older and earlier period.

DOUBLE LEVEL IN CATOCTIN BELT.

Reference of the Catoctin level to the Alleghany or to the Cretaceous level is doubtful at first, because it appears to lie in the plane of both. Analogous cases are known elsewhere. In portions of Georgia and Alabama the Tertiary and Cretaceous baselevels are so close together as to be indistinguishable. In Piedmont Virginia, the Pleistocene and Tertiary levels are separated with difficulty in many places. May it not be that two baselevels, which diverge towards the west, are nearly coincident in the Catoctin belt? The summits, taken as a whole, decrease toward the Potomac, but there is a sharp reduction in height of the Blue Ridge, South mountain, and Catoctin mountain at points equidistant from the Potomac, which throws the summits into two groups. The Catoctin baselevel continues at about 1,900 to 1,800 feet to latitude 39° 30′, both on South mountain and Catoctin mountain. Then there is an abrupt step down to 1,200 feet on South mountain and 900 feet on Catoctin. South mountain has an elevation of 1,100 to 1,300 feet for 6 miles north and 10 miles south of the Potomac. Blue Ridge stands from 1,300 to 1,200 feet for 5 miles north of the river, falls from 1,100 to 1,000 feet in 4 miles south of the river, and then, rising sharply to 1,600 feet, continues at the higher series of elevations. Catoctin mountain has been reduced to 900 feet on its lower bench by Tertiary erosion, where the Weverton sandstone is thinner and weaker. One knob remains at 1,300 feet, and is comparable to the Blue Ridge. Sugar Loaf, east of the Monocacy river, rises to 1,280 feet. The even crests of these ridges are distinctly those of a baselevel, and their grouping around 1,200 feet equally suggests one. The similarity in range of the reductions north of the Potomac and the abruptness of the step from Catoctin baselevel down to the lower, or Weverton, level are additional evidence of their distinctness.

The double nature of these baselevels can be better shown by the facts of a larger area. For this purpose three classes of phenomena can be utilized: (1) The low gaps of the main divides or places where the baselevel has reached the heads of the streams; (2) the summits of ridges and peaks that are not destroyed by later erosion; and (3) fragments of baselevels of sufficient size to show their original character.

Evidence in gaps.—The gaps of the main divides are relatively few in number. All gaps in Catoctin mountain have been cut down nearly to the Tertiary baselevel. South mountain contains many deep gaps of Tertiary age; one also, Turners gap, stands at 1,100 feet and has a broad arching watershed. The Blue Ridge has only two Tertiary gaps of note, the Potomac gap at 500 feet, and Manassas gap at the head of Goose creek at 900 feet, nearly reduced to baselevel. Other Blue Ridge gaps are: Snickers gap, at 1,100 feet; Ashby gap, at 1,100 feet, at heads of the main forks of Goose creek; Chester gap, at 1,300 feet, at the head of the Rappahannock; and Thornton gap, at 2,200 feet, at the head of a branch of Rappahannock. These gaps are reduced to the successive baselevels according to the size of the streams.

Evidence in summits.—The evidence of baselevel remnants in ridges and peaks is manifold. On the west face of South mountain for 5 miles south of Monterey a line of knobs and butts of Antietam sand stone stand at 1,100 to 1,200 feet. A group of Antietam sandstone knobs at 1,100 feet lie 7 miles northeast of the end of the Blue ridge. As before stated the Blue Ridge and South mountain are reduced to 1,300–1,000 feet for considerable distances. From Snickers gap nearly to Front Royal the knobs and ridges of Weverton sandstone are uniformly reduced to 1,100–1,200 feet. Along the same stretch the few Tertiary residuals of Antietam sandstone stand at 1,100 feet. East of Front Royal many summits of Catoctin schist rise to 1,200 feet. West of Browntown a granite ridge rises from the Tertiary drainage to 1,100 feet. South and west of Browntown, and near the Shenandoah river, various ridges of Antietam and Weverton sandstones are 1,100 to 1,200 feet high for 5 miles. The west side of Massanutten mountain is evenly reduced to 1,200 feet for 6 miles. Southward from this point the rise of the Tertiary baselevel to 1,000 feet brings it nearly into the plane of the Weverton level.

In the region between Snickers gap and Ashby gap the Catoctin level is marked at 1,800–1,900 feet. Between Ashby and Chester gaps it shows at 2,100 feet. South of Front Royal it is well marked in Massanutten mountain and rises from 2,100 to 2,500 and 2,800 feet. When this is reduced by 400 feet, the amount of Tertiary warping, the rise is 2,500–2,800. Dickeys hill, north of Browntown, an outlier of Catoctin schist, rises to 2,200 feet. Southeast of Browntown a series of spurs of the Blue Ridge have about the same height as the opposite parts of Massanutten mountain. Most of the Blue Ridge is considerably above the level thus defined, and constitutes a residual of the earliest period.

The medial valley shows no stage of reduction intermediate between Tertiary and Catootin baselevels except south of latitude 39°. In this region a great number of peaks and short ridges appear above the Tertiary plain. Out of 50 such outliers 40 are between 1,100 and 1,300 feet in height, while 7 are from 900 to 1,000 feet. Three knobs rise above the 1,300-foot level to 1,400 and 1,500 feet, and nowhere else is the 1,300-foot level exceeded except along the flanks of the main residual of the Blue Ridge. North of Warrenton a considerable number of residual areas are reduced to 800 to 900 feet, or nearly to baselevel; two points reach 1,200 feet, and several reach 1,000 feet.

The northern portion of Catoctin mountain stands at 1,800 to 1,900 feet, the Catoctin level. One knob near the Potomac rises to 1,300 feet, comparable to Sugar Loaf, 1,280 feet, and the remainder is nearly reduced to the Tertiary level. Bull Run mountain is largely reduced to Tertiary level, but has three summits at 1,200 and one at 1,300 feet. Thoroughfare mountain rises to 1,200 feet, and Clark mountain to 1,100. The summits of Southwestern mountain stand 1,100, 1,200, 1,200, 1,200, 1,200, 1,800, 1,300, 1,300, 1,400, 1,300, 1,300, 1,300.

Evidence in baselevel remnants.—Actual remnants of the 1,200-foot baselevel are very rare, as would be expected from the thoroughness of Tertiary reduction, but in two places they can be identified. Six miles east of Front Royal 10 or 12 square miles of broad upland are preserved from reduction at an altitude of 1,200 to 1,300 feet. The valley around Browntown, Virginia, is a well developed baselevel, consisting of broad bottoms and low rolling divides. The soft granites permitted its formation even under the shadow of the Blue Ridge, and a rib of hard garnetiferous granite has prevented the small stream from doing more than cut a canyon in the hard rock and sloping bottoms in the soft rock. The older level has a height of 1,200 to 1,300 feet.

Summary comparison.—These facts can be generalized into four statements: (1) Actual baseleveled areas exist in two places at 1,200 to 1,300 feet, 800 to 900 feet below the upper level in Massanutten; (2) baseleveled ridges exist at 1,000 to 1,300 feet, 700 to 800 feet below the Catoctin base level; (3) areas above 1,300 exist only along the chief residuals, Catoctin mountain, South mountain, Blue ridge, and three solitary peaks on principal divides; (4) all other elevations above the Tertiary baselevel range between 1,100 and 1,300, except the few which are nearly reduced. In short, only the main divides stand above the 1,100–1,300 foot plane; the junction of the residuals with this plane is marked by baselevel remnants; elsewhere no peaks stand above this plane, and four out of five lie in it. The conclusion is inevitable that the region was generally baseleveled at about 1,200 feet or about 800 feet below the Catoctin level.

There were, then, two periods of baseleveling in the Catoctin belt before the Tertiary. Two periods are also shown in the valley ridges and Alleghany plateau before the Tertiary. As no other periods are shown the correlation of the two groups is natural and probable. If the Catoctin level were identified with the Alleghany level some warping of the surface must be supposed to explain the difference of elevation. If it were identified with the 1,900-foot level of the intermediate ridges no warping need be assumed. Warping of the surface has taken place and is shown in the steady northward fall of the Alleghany baselevel. Warping is evident also in the steady fall of Catoctin mountain and the rise of North mountain. Its introduction is thus within the probabilities. On the whole, it seems very probable that the Catoctin and Alleghany baselevel periods are the same. They are of similar magnitude, for they reduced the main divides to baselevel over greater areas than any other period. These baselevels have been subsequently deformed more than any other, and the deformation occurred largely between their time and that of the next succeeding periods. They occupy analogous positions with reference to the Tertiary datum plane. In fact, the burden of proof is with the hypothesis that separates them. Still, their identity can hardly be considered established, and must await the development of facts in a larger field.

Residual nature of Blue Ridge.—One feature of the ancient surface can scarcely be explained by any warping of a baselevel, and that is the high land immediately east of Luray. The altitudes show a progressive decrease in all directions from this region, thereby having the character of a warped surface, but the decrease is rather irregular. The baselevel characteristics, however, are manifested in Massanutten mountain immediately to the west, at a height much lower and better comparable with the other portions of the baselevel. The points on Massanutten mountain vary considerably in height, but when the amount of Tertiary warping near Luray is subtracted from the altitudes west of Luray, their increase is much more uniform toward the south, and accords in degree with the tilting observed in the Alleghany plateau.

The peaks of the Blue Ridge east of Luray rise more than 1,000 feet above the Massanutten plane and are deeply dissected. They are clearly a much less mature form of divide than Massanutten mountain and belong to a different period, for if the peaks represent base-level remnants coeval with Massanutten, why has not Massanutten shared in their dissection, since it is formed by much weaker beds? If they represent not the Massanutten plane, but an older surface partially reduced to the Massanutten plane, they may possibly be referred to the Alleghany plane. If the Massanutten plane itself corresponds to the Alleghany plane, then these peaks may represent, not a baselevel surface at all, but a residual area. Moreover the Massanutten level itself is paralleled in the spurs on the west face of the Blue Ridge, so that the Blue Ridge is a residual on the oldest baselevel surface.

Location of Potomac.—Summing up the record of pre-Tertiary topography, we find two baselevels represented, one by the high ridges of the valley and the Alleghany plateau, and the other by the lower valley ridges. Along the Catoctin belt these two appear perhaps in the upper Catoctin level and the Weverton level at the Potomac. Whatever may be the exact connection from area to area, two periods of reduction can be differentiated. The elements of these were warped in pre-Tertiary time, and now the Potomac, the main stream, occupies the lower portions of the old level.

How much readjustment of drainage was necessary to secure this relation of drainage and relief, and what was the means which made easy the location of great streams like these in the most appropriate places? A certain amount of rise in the surface away from the drainage line was essential, but that later warping should so closely follow the lines of the river system seems decidedly improbable. If the Potomac had been readjusted from a different location, so as to fit the new surface, why did not the hard beds control the process and send the Potomac through the space between the ends of the South mountain and Blue ridge. The present arrangement of streams and barriers near Harpers Ferry is clear proof that the course of the Potomac was determined independently of the barriers. Either, then, it cut down its original channel with location reenforced by later warping, or its channel was adjusted to the warped surface, and developed under some condition which fixed its location before the influence of the barrier was felt.

The former is clearly not the sole cause, for it is a priori improbable in such detail, and it can not account for the position of the upper Potomac on the warped Alleghany baselevel, which slopes continuously north past the Potomac.

The second alternative could only be effective under some such condition as was suggested by Davis,[1] to account for similar features of New Jersey drainage, i. e., the location of the streams on the surface of a nearly flat formation, which covered up older barriers and determined drainage by the inequalities of its own surface. Immediately after emergence from the sea these inequalities would be most pronounced, the drainage would be in search of a new location, and the rivers would speedily cut canyons in the depressions of the new formation, which would fix the courses in spite of underlying barriers. Beyond the extent of this deposit no such adjustment of drainage to warped surface would be seen.

Such a deposit would be situated in the depressions of the older surface, hence they would be along the axis of depression passing near Harpers Ferry and would coincide with the course of the Potomac. The deposit would have a shore beyond which it could not affect the drainage; this shore would probably lie to the east of the high or Alleghany baselevel, since in that region the Potomac is uninfluenced by the tilting of the plateau. The Potomac, then, would represent an older stream, developed at least as soon as the Alleghany baselevel. A brief his-

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[1] Nat. Geographic Magazine, Vol. II, 1890, p. 91.

tory of these events would picture coincident development of the Potomac river and Alleghany baselevel, tilting of the surface with submergence and deposition on the east, elevation and warping with location of the Potomac in the depressions of the newly made surface, reduction to baselevel, followed at some later period by Tertiary elevation and reduction.

CORRELATION.

On the theory that the Potomac was located by warping of the surface, the deformation occurred between the Alleghany-Catoctin and the Weverton periods, because the former baselevel is warped to a considerable degree, while the latter scarcely varies. On the second theory, that the lower Potomac was located by a newly deposited formation, the deposition must have preceded the second baselevel period in order to have shared in the warping. Therefore the formation which caused the location of the Potomac was deposited between two periods of baseleveling and between two continental movements—depression first, then differential uplift. Such orogenic movements are of the grade that define time divisions, such as Tertiary and Cretaceous,and to such a division before the Tertiary these periosd must be referred.

The next division before the Tertiary is the Cretaceous, and with that these periods of erosion and deposition naturally are correlated. No direct connection of deposit and erosion can be made in this area, but various analogies can be seen between them. The Cretaceous formations were, as a whole, deposited on a baseleveled surface[1] of crystalline rock and consist chiefly of sands, gravels, and clays.[2] The two lower members, Potomac and Magothy, are highly siliceous, rather coarse and variable, and are separated by an unconformity. A greater unconformity intervened between these formations and the next succeeding, the Severn. The texture of the Severn, also, being "mainly black argillaceous sands,"[3] shows greater stability of environment. These formations were followed by a period of uplift and erosion.

Two hypotheses of connection occur between the formations of this time and the baselevels. The first baselevel, of course, preceded the first deposition. The second baselevel may either represent one of the unconformities before the Severn or that following the Severn. The first intermediate unconformity is of small rank and such as might have resulted from transient emergence during deposition without general deformation. The second intermediate unconformity was associated with change of environment and deposit, and may have resulted from deformation. The erosion period closing this deposition was of great extent and importance. Until the nature of the disappearance of the Magothy formation in southern areas is explained, whether by

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[1] W J McGee, Am. Jour. Sci., Vol. xxxv, 1888, pp. 135, 141.

[2] W J McGee, op. cit., pp. 126-134. N. H. Darton, Am. Jour. Sci., Vol. XLV, May, 1893, p. 407.

[3] Darton, loc. cit.

erosion or by overlap, the correlation of the Weverton baselevel with any particular unconformity is a matter of great doubt. The Severn formation might, it is true, represent the débris of the second baselevel period, but the Cretaceous formations, as a whole, have the usual sequence from coarse irregular to fine regular deposits which usually accompanies reduction to baselevel. The second baselevel ensued on elevation, and it is unlikely that deposition would accompany it except farther from shore than the previous deposits. The whole magnitude of the movements differentiating the baselevels is out of keeping with the small results shown in the intermediate unconformities. On the whole it is more reasonable to suppose that the elevation which initiated the reduction to the Weverton baselevel was that which closed Cretaceous deposition.

The magnitude of the movement separating the two Cretaceous baselevels is also of the higher order, which determines time periods, and suggests that the earlier level represents a period coequal with Cretaceous and Tertiary. Whether this be a part of Cretaceous time or a part of the Newark period of reduction, or of a period between these two, it is impossible yet to say.

SUMMARY.

With the discrimination of these two periods of erosion and deformation the last page of the history of the Catoctin belt must end. The Catoctin belt has shown itself to be an epitome of the leading events of geologic history in the Appalachian region. It contains the earliest formations whose original character can be certified; it contains almost the latest known formations; and the record is unusually full, with the exception of the later Paleozoic rocks. Its structures embrace nearly every known type of deformation. It furnishes examples of every process of erosion, of topography derived from rocks of nearly every variety of composition, and of topography derived from all types of structure except the flat plateau type. In the recurrence of its main geographic features from pre-Cambrian time till the present day it furnishes a remarkable and unique example of the permanence of continental form.

With certain qualifications previously stated, a summary of the leading events that have left their impress on the region is as follows:

1. Surface eruption of diabase.
2. Injection of granite.
3. Erosion.
4. Surface eruption of quartz-porphyry, rhyolite, and andesite
5. Surface eruption of diabase.
6. Erosion.
7. Submergence, deposition of Cambrian formations; slight oscillations during their deposition; reduction of land to baselevel.

8. Eastward tilting and deposition of Martinsburg shale; oscillations during later Paleozoic time.

9. Uplift, post-Carboniferous deformation and erosion.

10. Depression and Newark deposition; diabase intrusion.

11. Uplift, Newark deformation; and erosion to Catoctin baselevel.

12. Depression and deposition of Potomac, Magothy, and Severn.

13. Uplift southwestward and erosion to baselevel.

14. Uplift, warping and degradation to Tertiary baselevel; deposition of Pamunkey and Chesapeake.

15. Depression and deposition of Lafayette.

16. Uplift and erosion to lower Tertiary baselevel.

17. Uplift, warping and erosion to Pleistocene baselevel; deposition of high-level Columbia.

18. Uplift and erosion to lower Pleistocene baselevel; deposition of low-level Columbia.

19. Uplift and present erosion.

TERTIARY REVOLUTION IN THE TOPOGRAPHY OF THE PACIFIC COAST.

BY

J. S. DILLER.

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ILLUSTRATIONS.

TERTIARY REVOLUTION IN THE TOPOGRAPHY OF THE PACIFIC COAST.

By J. S. Diller.

INTRODUCTION.

It is now generally recognized that rivers are the architects and sculptors of their own valleys. The land is everywhere shaped largely by its streams, and the forms developed are serial, beginning with the rivers' youth and changing in the progress of time until, finally, the streams attain old age and their topographic work is completed. In their early life, when rivers have their highest grade, they wash away their beds more than their banks, and cut canyons. Their beds are a succession of gentle flows, rapids, and falls over the softer and harder beds. When by deep cutting the fall of a stream is reduced, it tends to spread out and erode its banks, the canyons widen, and the divides become narrow and sharp, sometimes with rugged peaks showing the stream's maturity, but the work of the fluvial sculptor still continues, and the mountains are reduced to hills, and the hills to knolls so low that the general aspect of the country is that of a plain. The streams are powerless to erode the land below the level of this gentle plain, which has been appropriately named by Powell the "baselevel of erosion." Thus, in a complete cycle of a river's history the canyon and the broad divide, or plateau, are features of its youth; narrow, sharp, more or less rugged divides of its maturity; and the baselevel of its old age. The canyons have then disappeared, and the land has been reduced by long-continued erosion approximately to sea level.

The development of the baselevel begins upon the seashore, by which the level is determined, and gradually spreads inland toward the principal divides. Under similar conditions the shales and limestones wear away more rapidly than the coarser sediments and crystalline rocks, and local baselevels appear for a time, determined by the harder rocks. But these are all obliterated in a general baselevel when it is completely developed.

The land is so unsteady that it rarely, if ever, remains without elevation or depression long enough for the complete development of a baselevel of erosion It commonly happens, however, that the large masses of harder rocks upon the slopes of the principal divides form independent elevations in the plain, which may be more or less distinctly defined upon the softer rocks. The topography of the region is then essentially a peneplain.

It is evident that a general baselevel of erosion must have originated approximately at sea level. This is the only position in which a very extensive baselevel of erosion can originate. If we now find such a baselevel at considerable elevation above the sea, its position furnishes evidence that the country has been uplifted in the process of mountain building since the baselevel was formed.

Upon our Atlantic slope ancient baselevels of erosion are well developed in the Piedmont region and elsewhere, as shown by Davis, McGee, Willis, Hayes, and Campbell. The ancient mountains have been swept away and modern mountains are the result of later upheavals.

Similar changes have taken place on the Pacific slope. Russell found in the Saint Elias range, at an elevation of over 5,000 feet, shells of marine mollusks like those still living along the Pacific coast, showing that the great mountain range has been uplifted in very late geologic time.

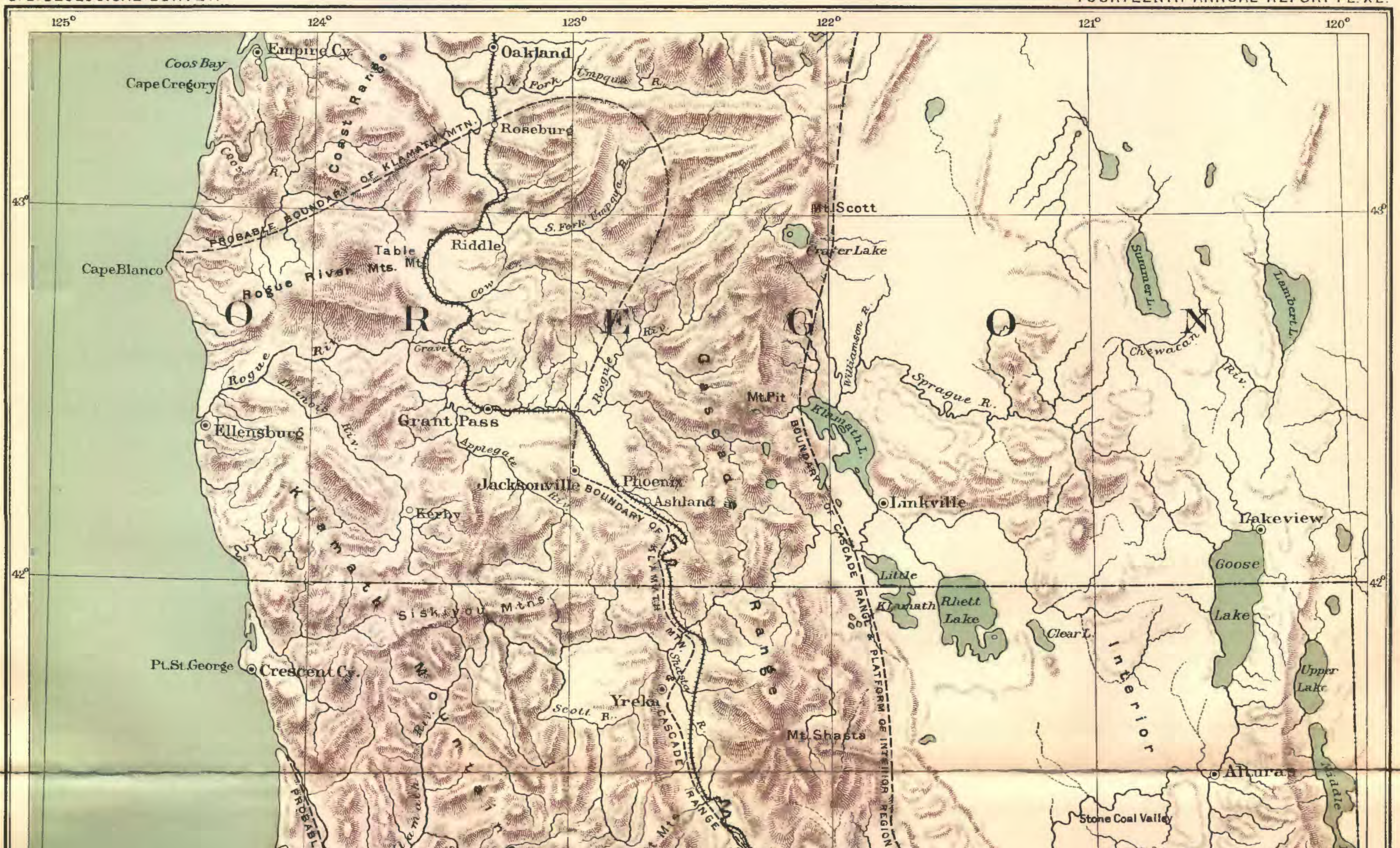
So also the Sierra Nevada and Coast ranges, and to some extent the Cascade range, now such prominent features of the Pacific coast, have been upheaved to their present great height, and the deep canyons cut upon their slopes, in the later geologic ages. At an earlier epoch the whole country was comparatively low and near sea level, or, in other words, near its baselevel of erosion. The mountain ranges were then inconspicuous and the slopes everywhere gentle.

It is the object of this paper to trace out this ancient topography and briefly to outline the great changes by which the present features were developed. Incidentally the auriferous gravels will be considered, because they originated in large part during this topographic revolution, which has on this account a most important economic interest.

TOPOGRAPHY OF THE PACIFIC SLOPE.

There are two prominent topographic belts on the Pacific slope. One is the platform of the interior basin region, and the other the mountain belt which lies upon the border of the continent. The latter embraces the Sierra Nevada, Cascade, and Coast ranges, including the Klamath mountains, where all the ranges meet. Between the ranges to the south of the Klamath mountains lies the great valley of California, and to the northward the Sound valley extends from central Oregon across the State of Washington.

The name Klamath mountains is not yet in general use, and requires explanation. In northwestern California and southwestern Oregon, where the Sierra Nevada, Cascade, and Coast ranges meet, there is an irregular group of mountains extending from the fortieth to near the



MAP OF SOUTHERN OREGON AND NORTHERN CALIFORNIA, SHOWING THE BOUNDARIES BETWEEN THE SIERRA NEVADA, CASCADE AND COAST RANGE AND THE KLAMATH MOUNTAINS.

BY

J. S. DILLER.

0 5 10 20 40 Miles.

Scale.

JULIUS BIEN & CO. N.Y.

forty-fourth parallel, for which there is in that country, so far as I am aware, no general name. The various ridges and peaks of this group, including the Yallo Bally, Bully Choop, South Fork, Trinity, McCloud, Marble, Scott, and Salmon mountains in California, as well as the Siskiyou, Rogue River, and perhaps others in Oregon, have all been specially designated. Investigations have shown that the geological history of this group has been essentially the same throughout, and that there is need of a general name for the whole group. For this purpose Maj. Powell several years ago proposed the name of Klamath mountains, using the name of the river which, in a deep canyon, cuts directly across the group from the interior platform and the Cascade range to the sea.

The area in which this study of ancient topography was made embraces the landward borders of the Klamath mountains, the northern end of the Sierra Nevada, and the interior region of northeastern California, with the adjacent portion of Oregon. This area is shown upon the accompanying map, Pl. XL, in which the limits of the Klamath mountains are approximately outlined.

The mountains are everywhere deeply canyoned by the streams, but if we take a more general view, overlooking those features which, like the canyons, are still developing, we shall discover others of much greater antiquity.

ANCIENT BASELEVEL OF EROSION.

NORTHWESTERN AND NORTHERN BORDER OF SACRAMENTO VALLEY.

Upon the northwestern border of the Sacramento valley is a well-marked plain of erosion, which extends for nearly 100 miles, from about the fortieth parallel around the northern end of the Sacramento valley to near the great bend of Pitt river. It varies from 1 to 14 miles in width, and is best marked in the region of the Greasewood and Bald hills, where the characteristic views in different directions illustrated in Plates XLI, XLII, and XLIII may be obtained. Especially good views of this old plain may be had from the Red Bluff and Hay Fork stage road, 5 miles northwest of Hunter's post-office, and from the mountain roads and trails leading westward from Stephenson's, Miller's, Lowrey's, and Paskenta, in Tehama county. The larger portion of the plain has been carved upon the upturned edges of the Cretaceous strata, and the denudation has reduced the thick, hard conglomerates and sandstones to the same level as the soft shales. At a number of places the plain extends for several miles into the area of the harder and more durable metamorphic rocks of the Klamath mountains. The production of such a broad uniform plain by the erosion of rocks varying greatly in hardness could only be accomplished on a very gentle slope, near the level of the controlling water body, and we may therefore properly consider this plain a baselevel of erosion. Elder creek, Red Bank, and the numerous branches of Cottonwood creek, on their way from the Coast range and Klamath mountains to the Sacramento river, have cut canyons across this plain, but in studying this ancient feature the canyons must be overlooked. As we shall see later, they are closely related to the deep canyons of the streams flowing down the western slope of the Sierra Nevada. Both originated in the same way and at the same time, but after the development of the baselevel plain upon the northwestern border of the valley.

The features of this plain may be illustrated by a series of sections across it from the foot of the mountain to the newer deposits of the Sacramento valley. The first, Pl. XLIV, *a*, is the most southern, just south of the fortieth parallel, near Elder creek. At this point the baselevel has a width of about 10 miles, and is cut upon the Shasta-Chico series of Cretaceous strata.[1] The composition of this series varies greatly, from thin limestone and fine, more or less calcareons shales to heavy beds of coarse conglomerate, but the soft and hard beds alike have been cut to the same level.

The western edge of the plain reaches the foot of the mountain at an altitude of 1,900 feet, where the unaltered Cretaceous rocks abut against the metamorphics, which form the eastern base of the Yallo Bally and Bully Choop mountains of the Klamath group. The eastern border, where the Chico beds pass beneath the newer deposits of the Sacramento valley, has an altitude of 600 feet. The slope of the plain from 1,900 to 600 feet in 10 miles is at the rate of about 130 feet per mile.

Originally the upper surface of the plain was even and regular, and it still remains so upon the hard rocks in the divides. Where slates predominate, however, it is less uniform and shows the rounded mammillated topography of the Bald hills.

Eight miles to the north, near Red Bank creek, the plain has the profile represented in Pl. XLIV, *b*. It is well marked at this point upon the divides. The trail from Miller's to South Yallo Bally (Mount Lynn) ascends one of these and affords an excellent view. Here the western edge of the baselevel, where it enters the mountains, has an altitude of 2,600 feet, and occasionally ends so abruptly against the serpentine as to suggest a sea cliff. It has a width of nearly 14 miles, with an easterly slope of 114 feet to the mile. In this section, as in the other just noted, the general slope of the plain is apparently somewhat greater than the average western slope of the Sierra Nevada.

To the east the Cretaceous strata run rather abruptly beneath the newer formations of the Sacramento valley, and where they disappear there is no topographic change to mark the limit of the baselevel plain.

The third section, Pl. XLIV, *c*, represents the baselevel 10 miles farther northward, in the region of the Cold fork of Cottonwood creek. The

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[1] Am. Jour. Sci., Vol. XL, Dec., 1890, p. 477; Bul. Geol. Soc. of Am., Vol. II, p. 207, also Vol. IV, p. 211.

VIEW OF BASELEVEL FROM DIVIDE BETWEEN DRY AND MIDDLE FORKS OF COTTONWOOD, LOOKING SOUTH.

Humboldt trail from Pettijohn's westward leads directly across it, and affords fine views. Its western edge grades into the mountain slope at an altitude of 2,350 feet, and the transition is less abrupt than at some other points. Its eastern edge, where marked by the overlapping valley deposits, has an altitude of about 1,300 feet, so that the slope of the plain toward the Sacramento is nearly 90 feet per mile.

The Cold fork section is of special interest in showing that the baselevel is cut not only upon the tilted Cretaceous rocks, but also upon the older crystalline rocks which form the Klamath mountains and the Sierra Nevada. The western border of the plain, to the extent of nearly 3 miles, is cut upon the metamorphic rocks, and the remaining 8 miles is cut upon the Cretaceous, as in the sections already noted.

North of Cold fork, about Middle fork, the baselevel sweeps far westward toward the pass between Yallo Bally and Bully Choop mountains. At this point its western limit is not so well defined, but farther northeastward beyond the Bald hills, which reach to the base of Bully Choop, its limit is again distinct.

The section in Pl. XLIV *d* represents the features of the baselevel in the region along the north fork of Cottonwood creek east of Ono. At this point it has a width of about 8 miles and is carved upon the tilted strata of the Shasta-Chico series. Its western limit, where it meets the steeper slopes of the metamorphic rocks, has an elevation of 1,100 feet, while the eastern limit, near Gas point, is only 700 feet above the sea. The slope of the plain toward the Sacramento is only 50 feet per mile.

At its eastern limit it is overlapped by the newer deposits of the Sacramento valley, which sweep from the north fork of Cottonwood creek northwest to Igo, completely covering the baselevel of erosion. This fact is readily understood when we remember that at Igo a stream over 30 miles in length, Clear creek, issues from the mountains and spreads its load of detritus as a broad alluvial cone upon the old baselevel. That acute observer, Prof. J. D. Whitney, who has done so much to elucidate the geology of the Pacific coast, was the first to discover the baselevel in the neighborhood of Horsetown. He says that the Cretaceous strata, having a southeasterly dip, form a table-land: "They have evidently been denuded by the action of the waves and worn down to a level surface, which has since been eroded by streams of water and is now intersected by numerons canyons and gulches."[1]

Beyond Clear creek the baselevel swings around the northern end of the Sacramento valley, with well marked levels carved upon the metamorphic and Cretaceous rocks at many points. The road from Horsetown by way of Centerville to Reading lies upon this level much of the way. The metamorphic rocks are exposed upon the platform, but in the neighborhood of streams they are generally coated with gravel.

Northeast of Reading the baselevel may be seen below Churntown and also along the Stillwater, where the platform is cut chiefly upon the

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[1] Geological Survey of California, Vol. I, p. 320.

metamorphic rocks, but occasionally upon Cretaceous sandstone of the Chico beds. This is the case at Sandstone flat, southeast of Buckeye, where the horizontal Chico sandstone, rich in fossils, is eroded to the baselevel, which is now at an altitude of about 800 feet above the sea.

From the neighborhood of Furnaceville a spur of metamorphic rocks extends southeast toward the Sierra Nevada range as far as Clover creek, and exhibits a plain of erosion at an altitude of 1,700 feet. Farther northward the same feature may be recognized along the Backbone road from near Woodman's to Montgomery creek. The plain 4 miles northeast of Woodman's has an altitude of 1,300 feet. From this point the road gradually ascends along a flat-topped ridge, which forms the southern wall of the Pitt River canyon, for a distance of 12 miles, to an altitude of 2,500 feet. The baselevel, although sometimes capped by lava, is represented by this broad ridge of metamorphic rocks. Immediately on the opposite side of Pitt river the topography changes, and in the mountains loses the evenness which marks the baselevel.

The transition from the plain to the mountain slopes takes place within a short distance, and occasionally it is abrupt, but generally it is gradual and very suggestive.

KLAMATH MOUNTAINS.

The plain already noted lies at the southeastern base of the Klamath mountains and passes by gradual but rapid transition into the steeper slopes of the mountain. The steepest average slope of the plain observed is less than 2°. As the base of the Klamath mountains is approached it increases to 5°, and then in some cases increases rapidly to 10°, 12°, and in one case 17°, which is the steepest eastern mountain slope observed. The eastern slope of the Klamath mountains is generally not greater than 10°. The transition from the plain to the mountain slope indicates that the plain once extended across the region now occupied by the Klamath mountains. Within that group the plain has been recognized 30 miles southeast of Humboldt bay, about Showers pass, at an altitude of nearly 4,000 feet, and a little further east, in the even crest of South Fork mountain, at an altitude of 6,000 feet. Maj. J. W. Powell informs me that he observed a deformed baselevel in the Coast range north of San Francisco. It will doubtless yet be found at many points, but on account of the great deformation which has taken place in the Klamath mountains and Coast range since the baselevel was formed, it is difficult to trace.

WESTERN SLOPE OF THE SIERRA NEVADA.

The baselevel we have followed from Elder creek to Pitt river was evidently determined by a body of water occupying the Sacramento valley, and traces of a corresponding level might be expected along the opposite shore about the Sierra Nevada.

VIEW OF BASELEVEL FROM DIVIDE BETWEEN DRY AND MIDDLE FORKS OF COTTONWOOD, LOOKING WEST.

The western slope of that range has been tersely described as an inclined plain, interrupted only by the narrow canyons of the modern streams. Prof. Whitney graphically portrays the region as follows:

> To one standing on some point not too elevated, but from which a good view of the surface of the country along the flanks of the Sierra may be had, its slope will appear to be quite uniform and unbroken, to one looking along a line parallel with the general trend of the range. It will seem, provided the point of view is favorably selected, as if the whole region was a gently descending plain, sloping down to the Great valley at an angle of not more than 2° or 3°. And the slope of the Sierra is—in the mining region, at least—quite moderate, for if we allow a rise of 7,000 feet from the lower edge of the foothills to the crest of the range, the distance between the two points being about 70 miles, the average rise is only 100 feet to the mile, which gives an angle of slope of less than 2°. And if one ascends the Sierra, keeping on the divide between any two rivers in the mining districts, he will find himself, for most of the time at least, on what seems to be a plain with a very gentle rise. Let the traveler, however, turn and attempt to make his way across the country in a line parallel with the crest of the range, and he will discover that this apparent plain is cut into by the gorges or canyons in which the present rivers run, in a most extraordinary manner; he will find it several hours' work to descend into one of these and rise again to the general level on the other side, even assisted by a well-beaten trail. All along the western slope of the Sierra the streams have worn for themselves deep canyons, and it is these tremendous gorges which form the leading feature of the topography of the region. If the streams ran nearly on a level with the general elevation of the surface, the whole character of the mountain slope would be changed. This was formerly the condition of the drainage of the Sierra slope.[1]

Concerning the topography of the same region Mr. Ross E. Browne remarks that "at certain favorably located points an extended view is obtained of the Forest hill and neighboring divides. Upon losing the effect of the detail, one receives the impression of a general uniformity of the summit lines. These summit lines appear as the remaining traces of a gently undulating plain sloping regularly from the bases of the massive peaks of the Sierra to the Sacramento valley.[2] Extended views of the western slope of the Sierra Nevada may be obtained at many points from the Central Pacific railroad between Colfax and the summit, and they fully illustrate the feature referred to.

The uniformity of gentle slope is enhanced in some cases, especially in the region of the American and Yuba rivers, by the broad, flat-topped lava flows which occupy the divides between the canyons. Sometimes it appears that these flows are thin, while at other places, according to Whitney, their thickness is very great, quite often reaching 400 or 500 feet and occasionally much exceeding that. Concerning the rhyolitic and andesitic flows of this region. Mr. Lindgren[3] states that the maximum thickness of the former near the summit is 1,000 feet, but it rapidly diminishes westward, and of the latter that it ranges from over 1,000 feet on the heights to 50 or 100 feet down toward the plains. The plain, however, is not limited to areas occupied by volcanic rocks, but has a

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[1] Auriferous Gravels of the Sierra Nevada of California, pp. 63-64.

[2] The ancient river beds of the Forest hill divide. Tenth Annual Report of the State Mineralogist, 1890, p. 435.

[3] Bul. Geol. Soc. Am., Vol. IV, pp. 466, 467.

wide distribution over areas of closely folded auriferous slates and can not be attributed to the constructive effects of volcanic eruptions.

Mr. Gilbert was the first to call attention to the fact that this uniform surface is due to erosion upon a system of plicated strata, and "could only have been accomplished by streams flowing at a low angle."[1] In other words, the plain must have originated essentially as a baselevel of erosion.

Judging from my own observations and the critical descriptions of that region by Mr. Lindgren,[2] as well as from those of Messrs. Whitney,[3] Pettee,[3] Goodyear,[3] and Turner, it appears that the inclined plateau which now forms the western slope of the Sierra Nevada was originally not worn down to so complete a plain as that already described upon the western side of the valley.

Mr. Lindgren (loc. cit.) says that "the Sierra, before the accumulation of gravels began, was a mountain range greatly worn down by erosion, but not reduced to baselevel. It can not, even on the whole, be regarded as a peneplain, above which isolated and more resistant hills projected. The declivities and irregularities of the old surface are too considerable for that, nor are the projecting hills invariably composed of the hardest rock masses."

Mr. Turner informs me that "some of the groups of hills in the old peneplain of the Sierra Nevada seem certainly to have existed there during the Neocene period. They deflected the old Neocene rivers. There are no Neocene sediments or volcanic rocks on these hills, and the evidence is good that there never were any. These groups of hills, for example the Bear mountains in Calaveras county, plainly stand out because of being made of harder rocks which have resisted erosion."

While some of the irregularities now recognized in the old plain upon the western slope of the Sierra Nevada are due to protruding hard rocks, yet it is possible that a considerable portion resulted from deformation when the Sierra Nevada was upheaved, for it will be shown later that since the peneplain of its western slope was formed by erosion the Sierra Nevada has been greatly uplifted, and it would be very remarkable indeed if in the upheaval of such an enormous mass as the Sierra Nevada the original plain of its western slope were not warped and broken to an appreciable extent.

PLATFORM OF THE INTERIOR REGION.

The fact that the baselevel plain passes to the east from the northern end of the Sacramento valley beneath the lavas of the Lassen Peak district suggests that it may reach the platform of the interior region, which is now covered chiefly by volcanic material. Within north-

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[1] Science, Vol. I, p. 195; March 23, 1883.

[2] Two Neocene rivers of California, Bull. Geol. Soc. of Am., Vol. IV, pp. 257–298.

[3] Auriferous Gravels; Memoirs of the Museum of Comparative Zoology at Harvard College, Vol. I, No. 1.

VIEW OF BASELEVEL FROM DIVIDE BETWEEN DRY AND MIDDLE FORKS OF COTTONWOOD, LOOKING NORTH.

eastern California and the adjacent portion of Oregon there are vast stretches of level plains which are not far from the same altitude above the sea. As far as known, all the surrounding hills and mountains are of lava. There are no projecting peaks of older rocks, and their absence from wide stretches of plateau country tends to show a general level of the subjacent surface,[1] even though the lavas are thick.[2]

The erosion plains that we have traced upon the borders of the Sacramento valley, in the Klamath mountains, upon the western slope of the Sierra Nevada, and probably also in the interior region of northeastern California, join one another in such a way as to show that they are parts of one extensive erosion plain which formerly spread over the most if not the whole of middle and northern California and southern Oregon. What is the geological age of this plain?

DEPOSITS UPON THE BORDER OF THE ANCIENT BASELEVEL.

GENERAL STATEMENT.

In order to determine the conditions under which the baselevel was developed and its age it is necessary to study the formations deposited upon its borders during its development. At the eastern edge of the level in the Sacramento valley, as shown in the sections Pl. XLIV, *a–d*, there are three formations, all of which were influenced by it in their distribution. Only two of these, the middle and lower, need here be considered, but for convenience of reference it is necessary to name the upper one also. The middle formation is a tuff, which has already been called the Tuscan tuff. Below the Tuscan tuff and above the Chico are gravels, sands, and clays, which apparently occupy the exact taxonomic position of the Ione formation of Becker, Lindgren,[3] and Turner, and may therefore be appropriately designated by the same name. The upper formation, best exposed on Red Bank creek and at Red Bluff, on the Sacramento, may be called the Red Bluff formation. The Tuscan tuff and the Ione formation have nearly the same distribution, and upon the accompanying geological map, Pl. XLV, they are not separated. The Tuscan tuff, which is composed wholly of volcanic material, will be considered first, for the reason that it can be most easily identified in different localities, and can be used to great advantage as a reference plane in considering the other formations.

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[1] Dr. Geo. M. Dawson (Transactions Royal Soc. of Canada, Vol. VIII, sec. 4, 1890, pp. 12–14) calls attention to an interior plateau in British Columbia, about 100 miles broad by 500 miles long, ranging in height from 3,000 to 6,000 feet. He regards this plateau as an Eocene baselevel of erosion.

[2] Russell regards the Warner range as faulted on the eastern side. J. Stanley-Brown, who examined the eastern base, found no older rocks beneath the lavas; so it is probable that the lavas are at least 2,000 feet thick in that region.

[3] Geologic Atlas of the United States, U. S. Geol. Survey. Text accompanying Sacramento sheet.

TUSCAN FORMATION.

On the western border of the Sacramento valley the most southern exposure yet observed is on Thomes creek, 4 miles east of Paskenta. Its best exposures, however, in that district are 6 miles northeast of Paskenta, on Mill creek, near the old headquarters of the Nomlaki Indian reservation. At this point the tuff is 35 feet in thickness. It weathers reddish above, but is white below, and, although usually fine, the material contains small fragments of pumice. It is quarried and extensively sold for chimneys, water coolers, etc., for which purpose, being soft, porous, and a nonconductor of heat, it is well adapted.

Farther westward, but still south of Elder creek, the tuff may be seen in the Bald hills, having a thickness of 12 feet. This exposure is represented with both underlying and overlying formations in Fig. 45, and is of special interest, as it is one of the most western outcrops of the tuff found in that region. The three newer formations are conformable among themselves, but they are very clearly unconformable upon the shales of the Shasta-Chico series beneath them.

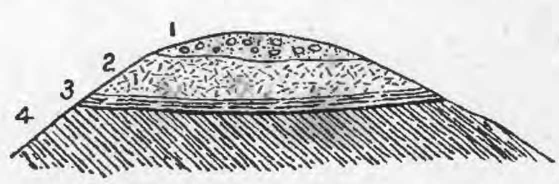


Fig. 45.—Section of Bald hill, between Lowrey's and Paskenta, Tehama county, California: 1, gravel of Red Bluff formation; 2, Tuscan tuff, 12 feet; 3, clay, 4 feet—Ione formation; 4, Cretaceous shales.

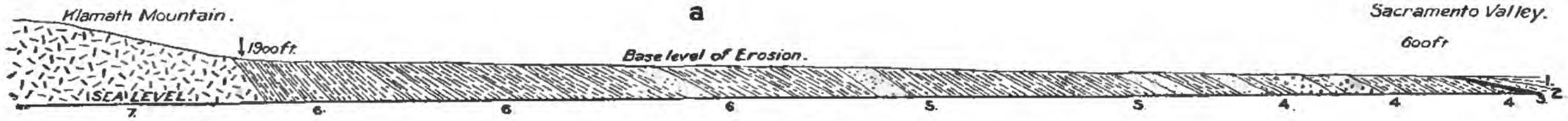
On Elder creek, 4 miles east of Lowrey's and about 6 miles northeast of the locality last noted, the tuff, as shown in Fig. 46, is well exposed in a bluff. It is of fine material and about 50 feet in thickness. A little farther down the stream only a thin layer of clay separates it from the tilted beds, but at this point it rests directly on the Cretaceous rocks. The tuff dips eastward very gently, but the Chico beds, composed of thin sandstones and shales, are much tilted, and at one place very sharply folded. They dip steeply to the east, so that the unconformity is conspicuous.

The three exposures last noted hold such a relation to one another as to show that the tuff is thinning out rapidly to the west upon the baselevel of erosion, and less rapidly to the south. It thickens toward the northeast, indicating that the source of its material was in the volcanoes of the Lassen peak region.

Beds of fine light colored tuff, composed of volcanic dust like that thrown out from Lassen peak, have been found west of the Bully Choop mountains in Redding creek basin and at Hyampome in Trinity county. It is not certain, however, that the material at the last two places came from Lassen peak. Similar material is reported by Mr. Fairbanks[1] at points in the Coast range. Prof. A. C. Lawson called

[1] Eleventh Annual Report of the State Mineralogist of California, pp. 64, 65.

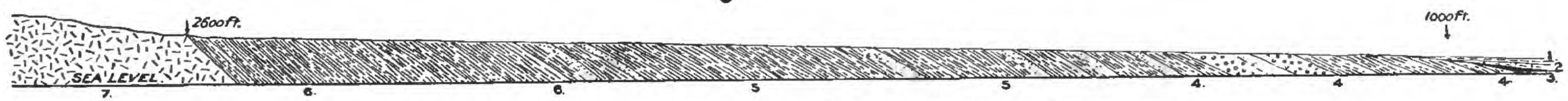
a



Section near Elder Creek, Tehama Co.

Fall = 130 feet per mile.

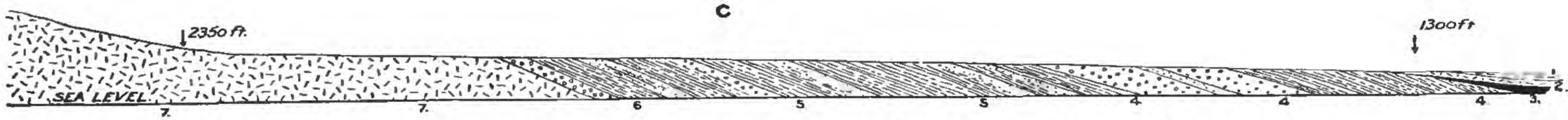
b



Section near Red Bank Creek, Tehama Co.

Fall = 114 feet per mile

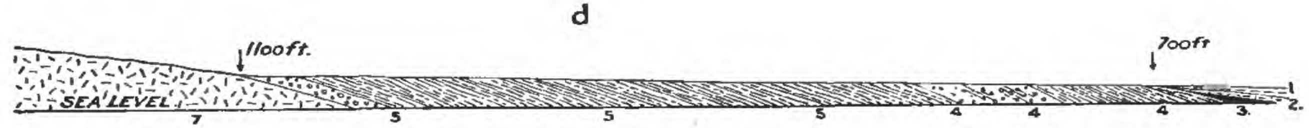
c



Section near Cold Fork of Cottonwood Creek, Tehama Co.

Fall = 90 feet per mile

d



Section near North Fork of Cottonwood Creek, Ono to Gas Pt.

Fall = 50 feet per mile.

1. Red Bluff formation – Pleistocene.
2. Tuscan } Neocene.
3. Ione }
4. Chico Beds. } Shasta-Chico Series. Cretaceous
5. Horsetown Beds. } Shasta Beds.
6. Knoxville " }
7. Metamorphic Rocks, Eruptive and Sedimentary.

SECTIONS ACROSS BASELEVEL IN TEHAMA AND SHASTA COUNTIES, CALIFORNIA.

my attention to some on the coast a short distance south of San Francisco.

With varying thickness the Tuscan tuff appears for a distance of 50 miles upon all the streams cutting the eastern margin of the baselevel from Elder creek to Reading, where the Sacramento river enters the

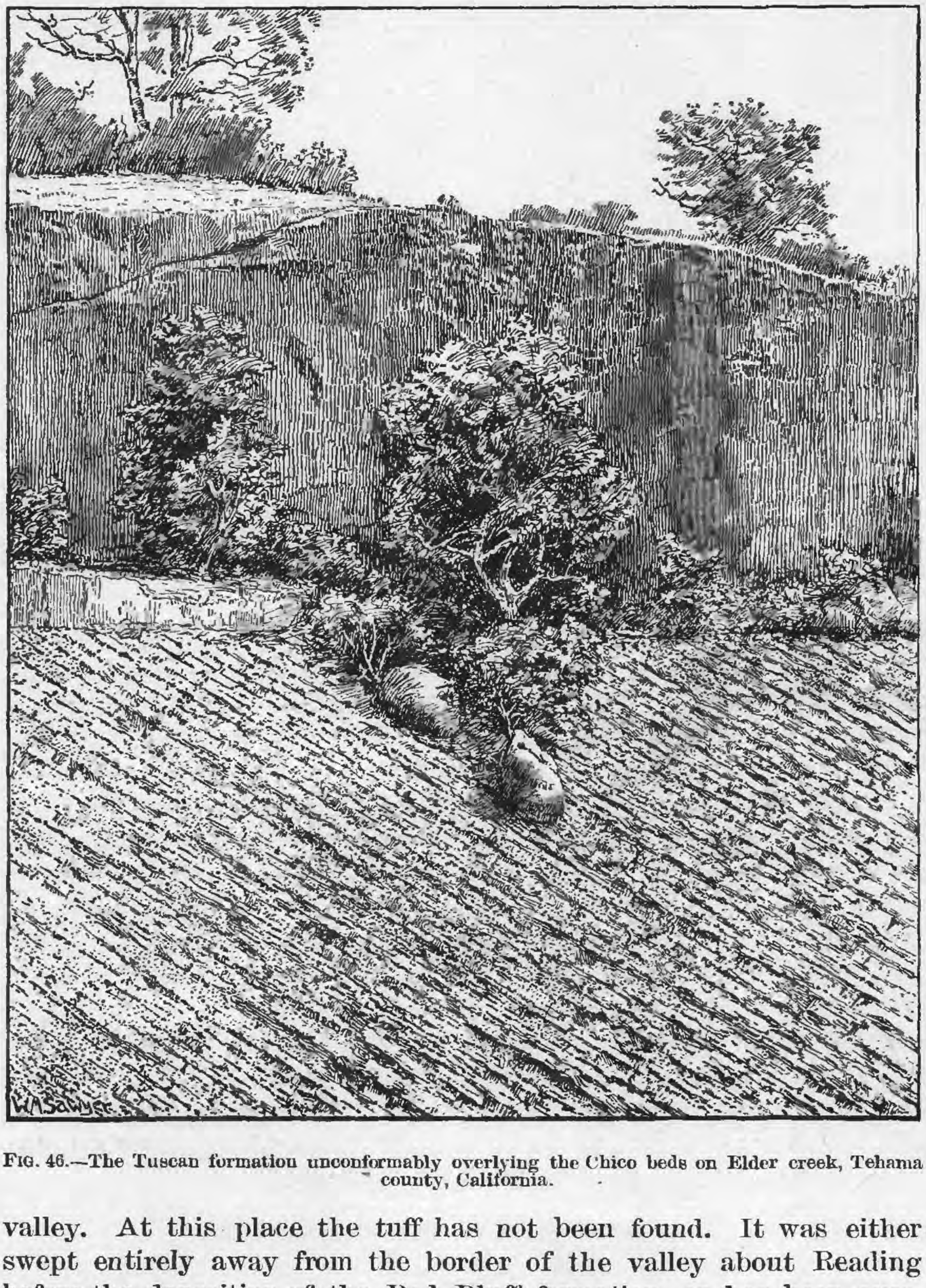


FIG. 46.—The Tuscan formation unconformably overlying the Chico beds on Elder creek, Tehama county, California.

valley. At this place the tuff has not been found. It was either swept entirely away from the border of the valley about Reading before the deposition of the Red Bluff formation, or has been overlapped by that formation. A short distance to the east, however, along Stillwater, the tuff again appears and extends as the great mass of tuff along the eastern side of the Sacramento valley from Pitt river to Pentz. The great development of the Tuscan formation along the eastern side of the northern portion of the Sacramento valley opposite Lassen peak has already been mapped and described.[1] Being near the seat of volcanic action, the tuff is very thick, sometimes nearly 1,000 feet, and contains much coarse as well as fine material.

Along a bluff which forms the boundary between the sterile volcanic plain and the eastern edge of the Red Bluff formation, about 5 miles east of the Sacramento river at Red Bluff, the Tuscan tuff bends abruptly downward toward the west, and dips beneath the newer formations of the Sacramento valley.[2] The connection between the tuff on the east and that on the west of the Sacramento valley may safely be assumed, as the material throughout is similar in kind, and connection may be traced, with interruptions, as already noted, about the northern end of the Sacramento valley.

From the Lassen peak region the stratified tuff, including layers of coarse as well as of fine material, to which the latter term is generally restricted, may be traced northward by way of the great bend of Pitt river, the upper valley of the McCloud, Shasta valley, Willow and Cottonwood creeks, into Rogue river valley in Oregon. These fragmental volcanic rocks are covered by the younger lava flows about Mount Shasta, but otherwise they appear to be for the most part continuous for over 150 miles and to have been laid down apparently in the same water body.

Northeast of Lassen peak in Stonecoal valley and at Hayden hill there are extensive deposits of stratified tuff exposed. These strata, as also those already noted throughout the whole region here described, are tilted, showing that they have been disturbed since their original deposition. Their thickness and distribution tend to show that at the time these tuffs were deposited, northeastern California and the adjacent portion of Oregon east of the Klamath mountains, as well as the Sacramento valley, were occupied by a large estuary, or a series of lakes, which covered the greater portion if not the whole of that country.

The Tuscan tuff marks an epoch of vigorous volcanic activity in the Lassen peak region. Although the period of eruption in that district was long, yet the epoch of most vigorous action, which furnished most of the material for the tuff, appears to have been comparatively brief. The Tuscan tuff thus affords a rather sharply defined time horizon of wide distribution, perhaps reaching even the western slope of the Klamath mountains, and may be regarded as showing essentially the synchronism of the surfaces upon which it rests.

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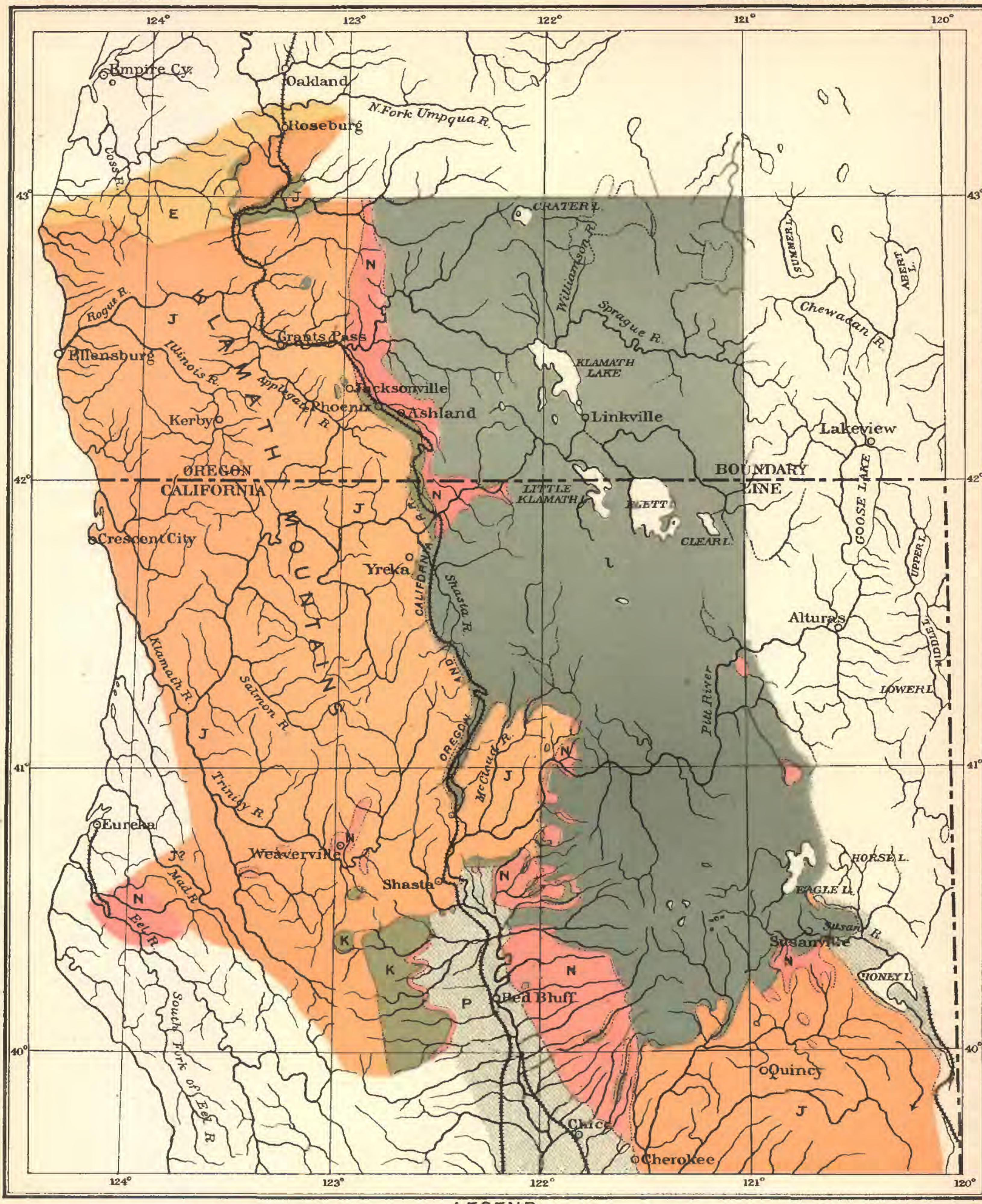
[1] Eighth Annual Report, U. S. Geol. Survey, 1886-'87, pp. 422-424.

[2] Ibid., p. 425.



LEGEND

PLEISTOCENE	NEOCENE	EOCENE	CRETACEOUS	INCLUDE JURA-TRIAS & CARB. PERHAPS OLDER ROCKS	NEOCENE ERUPTIVES
P	N	E	K	J	L
BLUFF FORMATION GRAVELS SAND & CLAY.	TUSCAN & IONE FORMATIONS TUFF UNDERLAID BY GRAVELS SANDS AND CLAYS.	CONGLOMERATE SANDSTONE AND SHALE.	SHASTA CHICO FORMATION KNOXVILLE HORSETOWN & CHICO BEDS CONGLOMERATES SANDSTONES SHALES & SOME LIMESTONE	AURIFEROUS SERIES INCLUDING A GREAT VARIETY OF METAMORPHIC ROCKS BOTH SEDIMENTARY AND ERUPTIVE.	LAVA

PRELIMINARY GENERAL GEOLOGICAL MAP

OF THE

KLAMATH MTS. & ADJACENT REGION IN CALIFORNIA & OREGON.

APPROXIMATELY 40 MILES TO 1 INCH.

25 0 25 50 75 100 MILES

NOTE. THE OUTLINES IN OREGON WERE LARGELY DETERMINED BY W. Q. BROWN.

JULIUS BIEN & CO. N.Y.

IONE FORMATION.

Between Thomes and Elder creek on the western side of the Sacramento valley the Ione formation is well developed. On a branch of Mill creek, near the headquarters of the Nomlaki Indian reservation, where the section in Fig. 47 is exposed, it is over 50 feet in thickness.

Further westward, in the Bald hills, near the road from Paskenta to Lowrey's, it appears as a thin bed of clay only, between the tuff and the Cretaceous shales (see Fig. 45). The same is true also on Elder creek, at a point a short distance east of that represented in Fig. 46.

On a fork of Red Bank creek, 6 miles to the northward, the Ione formation underlying the tuff has a thickness of 20 feet. It is composed chiefly of gravel, separated near the middle by 10 feet of clay. Its base is not exposed at this point, but it can not be far beneath the gravels noted, for the Cretaceous sandstones and shales rise to the surface a short distance westward.

In Guier valley, which lies between South and Cold forks of Cottonwood creek, the tuff is exposed further westward than at any other point, and appears to rest directly upon the Cretaceous rocks, indicating the absence of the Ione formation.

On Cold fork, however, only a few miles farther north, the exposures are good, and 30 feet of the Ione formation was seen. It is composed chiefly of yellow gravel, but is separated from the overlying tuff by a stratum of clay about a foot in thickness. Here the Ione formation ends abruptly against a steep slope of the Cretaceous strata upon the edge of the baselevel of erosion, but the overlying tuff and Red Bluff formation lap over upon the baselevel, showing that they are of later origin.

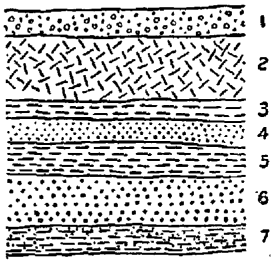


Fig. 47.—Section on branch of Mill creek, Tehama county, Cal.: 1, gravel of Red Bluff formation; 2, Tuscan tuff, 35 feet; 3, clay, 5 feet; 4, fine gravel, 7 feet; 5 clay, 10 feet; 6, gravel, 20 feet; 7, sand and clay, 8 feet. 3 to 7 inclusive = Ione formation.

On Salt creek, about 6 miles north of Cold fork, the Ione formation has the largest exposure seen on the western side of the Sacramento valley. Immediately beneath the tuff there is 16 feet of clay, which is underlain by 48 feet of sand and gravel beds, making a total thickness of 64 feet exposed. The gravel predominates and the pebbles increase in size toward the base. Similar sections are seen on Dry creek, Roaring river, and the North fork of Cottonwood creek. In every case the bed lying immediately beneath the tuff is a layer of clay. This top bed of clay extends further westward upon the edge of the baselevel than any of the other beds, and the whole formation rapidly increases in thickness toward the Sacramento valley. In some cases the tuff and gravels of the Red Bluff formation lap over upon the baselevel plain for several miles, but the Ione formation stops at its edge.

Near Gas point, on the south side of the North fork of Cottonwood creek, a carbonized log, 18 inches in diameter, was observed lying between the Ione clay and the Tuscan tuff. In the gravel mines upon the north side of the creek a number of carbonized trees were found standing and lying in the tuff.[1] They had evidently grown upon the clay soil beneath, and the region was forested at the time of the great volcanic eruption. This fact calls to mind the similar observations of Mr. Ross E. Browne on the ancient river beds of the Forest hill divide, upon the western slope of the Sierra Nevada.[2]

About the northern border of the Sacramento valley the Ione formation is not exposed. It was either eroded before the deposition of the Red Bluff formation or else it was overlapped by the Red Bluff formation so as to be completely concealed.

To the east, on Little Cow creek, there is exposed a great thickness of clays, sands, and gravels, which are sufficiently indurated in places to be called shales, sandstones, and conglomerates. They contain considerable deposits of coal, lie immediately beneath the Tuscan tuff, and rest upon the Chico sandstone, so that stratigraphically they occupy exactly the same position as the Ione formation, just described as occurring upon the western side of the Sacramento valley. Furthermore, both were evidently deposited at the same time in the body of water which then filled the Sacramento valley. They may therefore be regarded as being the same formation and may receive the same name.

This Ione formation on Little Cow creek has a thickness much over 500 feet. This is very much greater than its thickness along the western side of the Sacramento valley, but we must remember that only the western edge of the formation was there exposed, and that it was rapidly thickening toward the valley. If we had its thickness in the middle portion of the Sacramento valley we would in all probability find it much greater than upon the borders.

The lower half of the Ione formation on Little Cow creek is composed chiefly of sandstones and shales, with a bed of coal and carbonaceous material 12 feet thick, while the upper half is of coarse sandstones, occasionally containing fine gravel of the auriferous slates. Continuing upward, conglomerate appears, and the character of the pebbles changes, those of metamorphic rocks giving way to those derived from lavas, and we finally pass into the Tuscan tuff.

The shales in the lower portion of the formation contain fossil leaves and a fresh-water mussel. According to Profs. Lesquereux and Ward, the leaves indicate that the deposits belong to the Miocene, most likely upper Miocene.[3]

North of Little Cow creek the Ione formation is next exposed on Montgomery creek, in the cove of Hatchet creek, and along Kosk creek,

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[1] These were noted also by Mr. H. W. Fairbanks: Eleventh Ann. Rept. State Mineralogist of Cal., p. 53.

[2] Tenth Ann. Rep. State Mineralogist, California, 1890, p. 441.

[3] Eighth Annual Report of the U. S. Geological Survey, 1886–'87, p. 419.

near the great bend of Pitt river. At the last two places there are extensive outcrops of soft massive sandstones, conglomerates, and shales, with local traces of coal, sometimes resting directly upon the folded and partially metamorphosed older Mesozoic rocks. In this formation, at the cove, Mr. T. W. Stanton has recently found a lot of imperfect fossil leaves. According to Prof. L. F. Ward they appear to be Cretaceous forms, but in his opinion "no safe conclusion can be drawn from such imperfect material." The continuity of the beds with those of Little Cow creek can not be doubted.

Beyond Kosk creek the distribution of this formation is not positively known, because it has been covered by the floods of lava from Mount Shasta and other volcanoes in the Cascade range. In the Klamath river region, however, upon the same general strike, shales and sandstones again crop out between the tuff and the Chico beds, and they extend northward into Oregon, where Mr. Will Q. Brown, who has mapped them, is of the opinion that they are unconformable on the Cretaceous. Fossil wood and leaves have been found in them, and they are believed to be of Miocene age.

We have thus traced the Ione formation from Thomes creek in Tehama county, California, northward along the western border of the Sacramento valley, and by way of the great bend of Pit river, more or less continuously to the Klamath river and Ashland in Oregon, a total distance of over 250 miles.

To the east, upon the platform of the interior region, similar strata occur beneath the tuffs at Stonecoal valley and Hayden hill. At the first of these localities, as its name indicates, the shales contain traces of coal like that on Little Cow creek.

South of Little Cow creek, in the Lassen peak region, the Ione formation is well exposed along Old Cow creek and Bear creek, where the gravel of the conglomerate has been mined for gold. At this point it was eroded so that its upper surface was irregular before the tuff was deposited. Gravels of the Ione formation appear on Lack creek, Ash creek, the south slope of Shingletown ridge, Tuscan springs,[1] Mill creek, Deer creek, and Chico creek, but owing to the extensive development of the Tuscan tuff between Bear creek and Pentz, there are perhaps fewer good exposures of the Ione formation. At several points within that area it is not certain that the Ione occurs where it might be expected to outcrop. If absent, its disappearance may be most satisfactorily explained, apparently, by supposing that it was eroded before the deposition of the tuff. It is well exposed and has been extensively mined on Butte creek at Helltown, and at Mineral Slide and elsewhere on Little Butte. From this point the shore line can be traced south and southeast to Cherokee, near the southern end of the extensive tableland formed by the tuff. Here the Ione appears well developed and

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[1] See section by Prof. Whitney, Geol. Survey of California, Vol. i, Geology, p. 207.

contains numerous leaf impressions[1] similar to and perhaps in some cases identical with those on Little Cow creek and elsewhere in the same formation. At this point it has a thickness of over 300 feet and is composed of soft sandstones and shales, with much quartz gravel in the upper portion. It is well exposed in the Spring valley mine at Cherokee, where its lower portion, of coarse gravel with bowlders, is the rich auriferous deposit so extensively and profitably mined at that place (Pl. XLVI). The auriferous gravel is said to be in the form of a distinct stream bed several hundred yards or more in width and 50 feet in thickness. The blue gravel, consisting of large bowlders as well as pebbles and sand, is so firmly cemented that it has to be blasted before it can be worked by the hydraulic process, and the overlying 300 feet of quartz, sand, and gravel, also of the Ione formation, with a capping of volcanic material, must be removed before the best pay gravel can be reached. At the mine the Ione formation rests directly upon the auriferous slates, but a short distance westward it lies upon the Chico formation. In strata supposed to be Ione, near Pentz, Mr. Turner found some small shells, among which *Corbicula*, a fresh or brackish water form, has been identified. The relations of the strata at this place are shown by Prof. Whitney.[2]

Mr. Lindgren regards the Ione formation as contemporaneous with the auriferous gravels of the Sierra Nevada. Of this view there is corroborative evidence about the northern end of the range, where their contained plant remains as well as their coalition show that the two formations must have originated at the same time.

About the higher parts of the northern portion of the range, at least east of the Hough peak crest, the gravels are deposits of streams having northerly courses. In the vicinity of Diamond peak, Light's canyon, and Mountain meadows the deposits spread out, and before reaching the lavas of the Lassen peak region, by which they are covered, they occupy an area about 10 by 16 miles in extent, and are essentially of lacustral or estuarine origin. These deposits now range in altitude from 5,000 to over 7,000 feet, and dip from the eastern crest, opposite Susanville, toward Lassen peak and the Ione formation, which lies buried beneath its lavas. The same gravels overlap the northern end of the eastern crest to Susan river, where pebbles with fossils and substance identical with those in a Jurassic sandstone of Taylorville have been found. The drainage of that portion of the range was there northerly into the estuary which occupied the Lassen peak region. The gravels deposited there furnish very important evidence concerning a displacement along the eastern face of the northern end of the range and will be referred to again when considering the deformation of the baselevel.

At Rio Dell, on Eel river, in Humboldt county, and lapping eastward up over the ridges of metamorphic rocks to an altitude of several thou-

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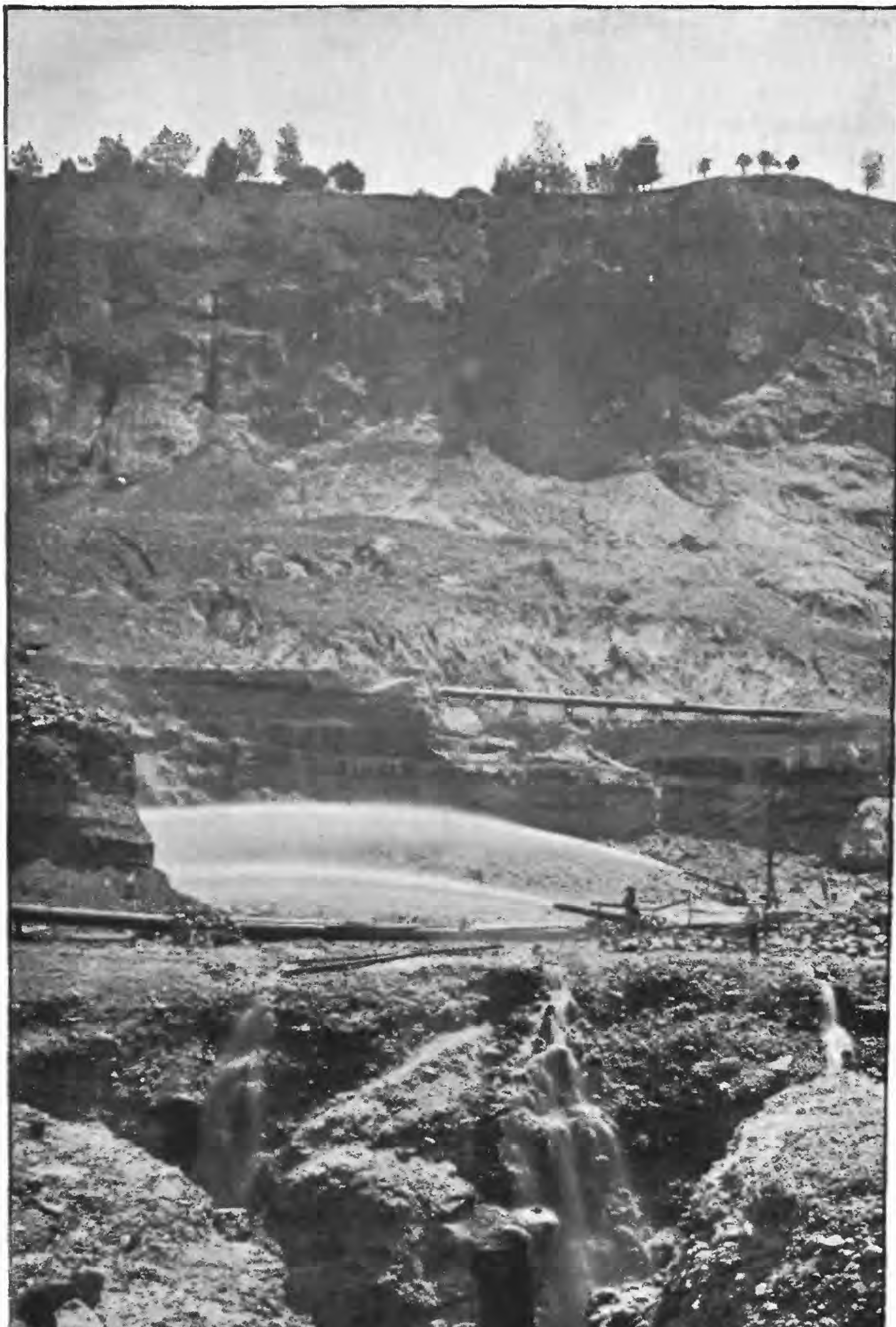
[1] Eighth Annual Report, U. S. Geol. Survey, p. 418, and Bulletin 38, p. 16.

[2] Geological Survey of California, Vol. I, Geology, p. 211.



SPRING VALLEY HYDRAULIC MINE AT CHEROKEE FLAT, CALIFORNIA.

sand feet, is a thick mass of soft sandstone containing an abundance of marine shells of Miocene age. It is probable[1] that the strata are of essentially the same epoch as the Ione formation. They extend apparently up to the edge of the baselevel noticed at Showers pass. To the southward these strata appear to be extensively developed and swing across the Coast range to the Sacramento valley.

North of the fortieth parallel, in the Klamath mountains, at Weaverville, Lowden's ranch, Redding creek, Cox's bar, and Hyampome, there are conspicuous remnants of a formation composed of conglomerate, soft sandstone, and shales, associated, in at least two localities, with a light colored tuff which closely resembles that of the Tuscan formation upon the western border of the Sacramento valley. On this account there is reason for regarding these beds as belonging to the Ione formation, and this reference is strengthened by the fact that at three localities, Hyampome, Cox's bar, and Redding creek, they contain traces of coal like the Ione of the Sacramento valley.

The only fossils yet discovered in these beds are leaves, among which Prof. Ward recognizes, with some doubt, owing to imperfect specimens, *Taxodium distichum miocenum*, Heer, and a peculiar ficus. The first of these is of wide geographical and geological range. Mr. F. H. Knowlton informs me that it has not been found in the auriferous gravels, and suggests that it appears to indicate an age older than the Miocene, but thinks the evidence is too meager to be conclusive. Prof. Whitney reports the coal-bearing Tejon as far north in the Coast range as Round valley,[2] in Mendocino county, and it is possible that the coal-bearing strata at Hyampome, Cox's bar, and Redding creek may be of the same age.

AGE OF THE BASELEVEL.

The age of the base level must be determined by reference to the formations with which it is associated. It is evidently of more recent origin than the Cretaceous, since it truncates the upturned edges of the Shasta-Chico series, and these are the youngest strata upon which it has yet been seen. It was already developed at the time the earlier auriferous gravels were deposited, for they lie in the broad shallow valleys which belong to the baselevel plain. The erosion by which it was developed therefore occupied a part or the whole of the time interval between the upheaval of the land at the close of the Chico epoch and the deposition of the auriferous gravels.

The age of the earlier auriferous gravels has not yet been fully determined, although they have been the subject of much investigation. That of the later gravels will not be considered here. Prof. J. D.

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[1] Bulletin 84, U. S. Geol. Survey, map, p. 178.

[2] Geol. Survey of California. Paleontology, Vol. I, p. XIII.

Whitney, in his Auriferous Gravels of the Sierra Nevada of California, page 283, says:

> It appears probable on stratigraphical grounds that the detrital beds overlying the bed rock of the Sierra Nevada represent the whole Tertiary period; that is, that they have been forming since the beginning of that epoch.[1] It also seems likely that there has been no break in the series of events; none, at least, of sufficient magnitude to justify the drawing of a sharp line anywhere, so as to say, above this is Pliocene, and below it is Miocene, or Eocene. The evidence as to the geological age of the gravel deposits afforded by the plants found in the sedimentary beds underlying the latest eruptive masses in the mining region of the Sierra has already been discussed by Mr. Lesquereux. He distinctly recognizes the presence in this flora of forms identical with or closely allied to those of the Miocene, but still calls the age of the group Pliocene. Something of the same kind seems to be legitimately inferred from the animal remains of the same deposits. There are certain fossils which have been found only in deep-lying gravels like those of Douglass flat and Chili gulch. No traces of the rhinoceros, the elotherium, or the small equine animal referred with doubt by Leidy to Merychippus have there been found in deposits which could by any possibility be proved to be more recent than the basaltic overflow. It is true that the evidence thus far collected is but fragmentary. Still, taking it for what it is worth, it may be said that the affinities of the animals found in these lower deposits would indicate a Miocene rather than a Pliocene age. There are also, it is believed, stratigraphical reasons for admitting that some, at least, of the deposits containing these older fossils may be proved by other than paleontological evidence to belong to an older series than those strata which, though anterior to the basalts, yet contain a fauna decidedly more Pliocene than Miocene in character.

A collection of plants made from the older auriferous gravels upon the northern end of the Sierra Nevada was examined by Prof. Lesquereux, who reported that their relation is evidently to the Miocene.[2] Prof. L. F. Ward, who examined the same collection, agreed that they were Miocene, most likely upper Miocene.

Recently the evidence afforded by the plant remains has been ably reviewed by Prof. F. H. Knowlton, who studied extensive collections from the auriferous gravels of Independence hill, Placer county, California. He concludes that the gravels are probably upper Miocene in age.[3]

On stratigraphic grounds the auriferous gravels are regarded as contemporaneous with the Ione formation of the Sacramento valley, but here, too, as in the earlier auriferous gravels, the fossil plants and shells appear to indicate that they belong to the Miocene.

That the approximate baselevel reached its greatest development about the time the earlier auriferous gravels were deposited is indicated by the fact that they lie in the broad shallow valleys of that plain. The present tendency of the organic evidence contained in these gravels is to indicate that their deposition took place during the Miocene, most likely later Miocene. The erosion necessary to develop the

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[1] By the Geological Survey of California the Tejon was regarded as Cretaceous. Paleontology, Vol. II, p. XIII. It is now regarded as Eocene, and in Oregon lies unconformably on the Shasta-Chico series.

[2] Eighth Annual Report, U. S. Geological Survey, p. 419.

[3] Bulletin 108, U. S. Geological Survey, page 104.

baselevel out of the topography resulting from the uplift at the close of the Shasta-Chico period must have occupied a long interval of time, possibly beginning in the later part of the Cretaceous and continuing through the Eocene and earlier portion of the Miocene, but as the plain appears to have attained its maximum extent during the Miocene, it may be referred to as the *Miocene baselevel.*

ALTITUDE INDICATED BY FLORA OF THE AURIFEROUS GRAVELS.

The flora of the region indicated by the remains found in the earlier gravels is of special interest on account of its bearing upon the topography. Numerous fossil leaves have been collected in the early auriferous gravels about the northern end of the Sierra Nevada, at the Mountain meadows, near the summit of Spanish peak, and elsewhere on the very crest of the Sierra at altitudes now ranging from 2,900 to 6,350 feet above sea level. These plants were studied by Professors Lesquereux and Ward,[1] who report among other forms three kinds of figs and a large number of lauraceous plants, with other forms of similar significance. Not a single species of pine or fir, such as constitute the prevailing arboreal vegetation of that region to-day, was recognized in the collections.[2]

In answer to a question concerning the climatic condition of that region during the Miocene, as indicated by its flora, Prof. Lesquereux stated that "by the presence of a large number of Laurineæ the flora becomes related in its general characters to that of a region analogous in atmospheric circumstances to Florida." With this view Prof. Lester F. Ward fully agrees, and also Mr. F. H. Knowlton, who has furnished me the following notes:

> Lesquereux, as you have already stated, argued that the presence of a large number of lauraceous plants indicated a region analogous in atmospheric conditions to Florida. From my own studies, which embrace a much larger amount of material than Lesquereux had, I am not only prepared to accept this statement, but to show that it now has stronger support than he could have given it.
>
> Lesquereux knew only about 50 species of plants in the auriferous gravels, whereas the present known flora embraces nearer twice that number. Of this number the following genera are distinctly tropical or subtropical in their distribution: Laurus (4 species), Persea (3 species), Cinnamomum (2 species), and Arcodaphne (2 species), all belonging to the Lauraceæ. In addition to these there is Artocarpus and Zizyphus each with 2 species, Ficus with 6 species, and Sabalites with 1 species, or 22 species in all, representing at least 20 of the entire present flora. The present flora of Florida has only 5 genera and 8 species belonging to the Lauraceae, which represents less than 1 per cent of the whole flora, while, as stated above, there are 4 genera and 10 species in the auriferous gravels, representing fully 10 per cent of that flora.
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> Following is a list of genera, with the number of species in each, having living representatives confined in the main to temperate regions, some of them growing at elevations at or but little above sea level: Aralia (4), Platanus (2), Cornus (4),

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[1] Eighth Annual Report, U. S. Geological Survey, pp. 419-421.

[2] Mr. H. W. Turner has since found a bunch of pine leaves, with maple, oak, and other leaves in the Mohawk lake beds. Bull. Phil. Soc. of Wash., Vol. XI, p. 391.

Juglans (5), Liquidambar (1), Magnolia (4), Quercus (15), Viburnum (3), Rhus (6), Alnus (3). Of course it is quite impossible to say that all of these species actually grew at the above altitude, but simply that, from what we know of the living species, some or perhaps all of them may have done so. That is, there are none of these genera confined to high elevations. On the other hand there are a number of genera, as Alnus, Betula, Populus, Salix, etc., that we would hardly expect to find in great abundance at a very low altitude, but like the last mentioned genera, they are not exclusively confined to high altitudes. They might well have grown on land in close proximity to a body of water connected with the sea, such as the area under discussion appears to have been during their deposition.

There are also several genera of conifers, as Pinus, Araucarioxylon, Cupressinoxylon, and Pityoxylon, which alone would appear to argue a greater elevation than appears to have prevailed. If these genera were in great abundance, it would still further strengthen that view, but on the contrary they are very rare, the genus Pinus being represented by a single somewhat doubtful example. From their lightness and well known power of long resisting the processes of decay, they might well have been transported from long distances, for with the exception of the pine-needles there is no evidence to show that any of them grew where they were fossilized.

Florida is a comparatively low country, rising nowhere more than a few hundred feet above the sea, and it is reasonable to infer that during the early gravel period northern California, which was then analogons in atmospheric circumstances to Florida, could not have been a region of high snow-tipped mountains as it is to-day.

It is well known that during the Miocene period tropical conditions extended much farther north than now, and under such circumstances it is possible that certain forms of plants may have had considerably greater range in altitude than their relatives in California to-day.

No doubt the Sierra Nevada existed at that time, but its height was very low, at least in the northern portion, as compared with its present altitude. Yet it was high enough for alder, birch, poplar, and willows, as well as pines, a few leaves of which were found by Mr. Turner.

The evidence afforded by the flora is in complete harmony with the inference drawn from the topographic relation, viz : That during the Miocene the country was a series of plains and peneplains with low mountain ranges; or, in other words, the country was but little above its baselevel of erosion.

Under essentially these conditions the earliest auriferous gravels were deposited. To fully appreciate the circumstances that led to the accumulation of these deposits, which are of so great economic value, it is necessary briefly to review the geography of northern California during the Miocene, and consider the earlier geological history of the same region in the Cretaceous and early Tertiary.

GEOGRAPHY OF NORTHERN CALIFORNIA DURING THE MIOCENE.

The Ione formation being well stratified was evidently laid down in a body of water having a distribution at least as extensive as the formation itself. In the Sacramento valley, as far north as Marysville buttes, the water of the bay was salt, as shown by the marine shells found at that point by Mr. Lindgren.[1] Upon the borders of this bay, at Ione, where the conditions were favorable for the accumulation of the vegetable matter to form lignite, the water was either fresh or brackish. Farther northward only Unios have been found, and the water in which the Ione formation originated was fresh. Beyond the Lassen peak region, in northern California, the water was undoubtedly fresh, but whether it was in one large lake or a series of lakes, or a water body connected directly with that of the Sacramento valley as an estuary from the sea, is a matter concerning which there may be different opinions.

From the great valley the sea swept across the region of the Coast range, perhaps near the latitude of Sacramento, and extended northward over the area of the broad belt of sandstones upon the western slope to beyond Humboldt bay. The borders of the land must have been low and swampy to make the conditions favorable for the accumulation and preservation of vegetable matter to form coal. The Sierra Nevada and Klamath mountains themselves were low, with gentle slopes as compared with those of the present ranges, and the streams flowed down their flanks in broad, shallow valleys instead of in deep canyons as they do now.

CONDITIONS DURING THE CRETACEOUS.

Between the close of the Taylorville Jurassic and the deposition of the Shasta-Chico beds, the rocks of the Sierra Nevada were greatly compressed, folded, faulted, and raised above sea, giving birth to the Sierra Nevada and Klamath mountains. The land at that time in northwestern California and southwestern Oregon extended westward to the continental border, 10 to 30 miles beyond the present coast line, into the Pacific. It remained exposed to atmospheric agents for some time under conditions which allowed local accumulations of a considerable amount of residuary material upon the surface.

During the Cretaceous period, especially during that portion represented by the Shasta-Chico beds, the northern part of California and Oregon gradually subsided and the sea transgressed, sweeping around the northern end of the Sierra Nevada through Lassen strait, the gap where Lassen peak now stands, between the Sierra Nevada and Klamath mountains, into northeastern California and Oregon. The Klamath mountains, during the early part of this period, at least, formed an island. The sea entered northern Oregon directly from the west as well as from California on the south.

The sea floor upon which the Cretaceous deposits were laid down was rather rough and irregular, and even mountainous, indicating that the

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[1] Geologic atlas of the United States, text accompanying the Sacramento sheet. See also U. S. Geological Survey Bulletin No. 84, p. 197, where W. H. Dall and G. D. Harris remark that "This valley in later Mesozoic time was occupied by an arm of the sea, and this condition was maintained to some extent at least as long as the latter part of the Miocene."

country before the Cretaceous invasion of the sea was not reduced to a well-defined baselevel of erosion.

During the Cretaceous, however, there was a vast amount of erosion, and the Sierra Nevada, as well as the Great Basin region, must have been greatly reduced, for at that time over 29,000 feet of sediments (Shasta-Chico series) accumulated in the Sacramento valley. At the close of the Chico epoch, perhaps a little later than the middle of the upper Cretaceous, northern California and southern Oregon were again raised above the sea. The deformation of the rocks appears to have been less intense, at least in the northern end of the Sierra Nevada and a portion of the Klamath mountains, than that which took place at the close of the Jurassic. Nevertheless, it was considerable, for at that time the Shasta-Chico series in part of Tehama and Shasta counties was cut by a group of remarkable sandstone dikes (Pl. XLVII and Fig. 48), which are with good reason considered to represent one or more ancient earthquakes.[1]

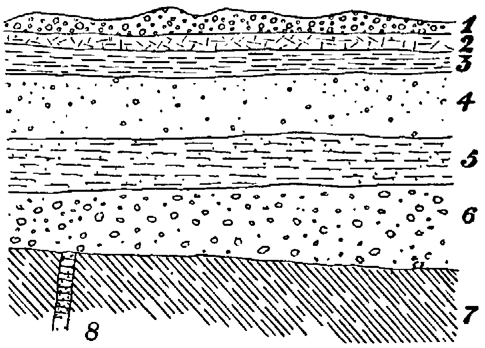

FIG. 48.—Section at Gas point, Shasta county, California: 1, gravel of Red Bluff formation; 2, Tuscan tuff, 4 feet; 3, clay, 4 feet; 4, irregular fine gravel; 5, reddish clay and sand; 6, gravel; 7, shales of Chico group; 8, sandstone dike. 3 to 6 inclusive = Ione formation.

CONDITIONS DURING THE EOCENE.

During the Eocene period northern California and a large part of Oregon were above the sea and subject to degradation. The marine Eocene deposits of Oregon, as far as yet known, lying only west of the Cascade range, are several thousand feet in thickness. They are conglomerates below, passing upward into sandstones, and finally into shales. If the relative position of the land and sea remained unchanged during the Eocene, the change of sediments indicates progressive erosion of a cycle begun with the young topography and steep slopes of the land just raised above the sea at the close of the Chico, and continued through mature topography to topographic old age, when the streams carried only the fine silts of approximate baselevel conditions. It is probable, however, that with this degradation there was a gradual subsidence, as indicated by the fact that the Tejon of southern California is largely developed and thins out northward. As far as yet known, not only the Tejon (marine) but also fresh-water Eocene deposits are absent in northern California beyond the fortieth parallel, and in Oregon east of the Cascade range. As suggested by King,[2]

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[1] Bull. Geol. Soc. of Am., Vol. I, p. 411-422.

[2] Fortieth Par. Systematic Geology, p. 434.

SANDSTONE DIKE, ROARING RIVER, SHASTA COUNTY, CALIFORNIA.

the region was a land area having free outward drainage. It had long passed the lacustrine stage and reached topographic old age.

During the closing episode of the Tejon, approaching baselevel, the rate of disintegration began to be greater than that of transportation, and the residuary material accumulated upon the weathered slopes. Of the material resulting from the decay of the auriferous slates and associated rocks, quartz is by far the most durable, both chemically and physically. The chemical agents which change the feldspar and ferromagnesian silicates in the process of weathering tend to reduce them to fine particles and favor transportation. Quartz is but little affected in this process, and thus it happens that, notwithstanding its low specific gravity, quartz, remaining in large particles, forms a greater proportion of the rearranged residuary material than it does of the auriferous slates from which it was derived.

CONDITIONS DURING THE MIOCENE—ORIGIN OF THE EARLIER AURIFEROUS GRAVELS.

The Tejon epoch appears to have been brought to a close and the Miocene initiated in northern California without any marked change of level, unless a general subsidence,[1] so that the influences in operation during the Tejon continued into the Miocene. The old streams still carried on their enfeebled erosion, and in some places the land was reduced approximately to baselevel. The removal of material was chiefly by solution, and the insoluble residuary material thus set free by the disintegration of the rocks accumulated to considerable depths upon the land.

The long period during which the land of northern California remained comparatively stationary, and which enabled the streams in many parts of that region to practically complete their cycles of erosion from youth to old age, was brought to a close by the initiation of an orogenic movement which generally increased the grade of the streams upon the western slope of the Sierra Nevada. At first the differential change of level was very moderate and increased the declivity of the streams very little, but being long continued it became in time revolutionary in its effects, and finally, accompanied by extensive volcanic eruptions, gave birth to the High Sierra of to-day, with the deep canyons upon its western slope.

The first result of this change of slope was to rejuvenate the streams and invigorate erosion. On account of surface deformation, which must have accompanied the upheaval of such a large mass as the Sierra, the stream grade would be differently affected even along the same channel, and in fact, as Mr. Lindgren has pointed out, in at least one case, owing to direction of flow, the stream grade has been not only diminished but reversed.[2]

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[1] Dall and Harris, Bull. 84, U. S. Geol. Survey, p. 278.

[2] Bull. Geol. Soc. of Am., Vol. IV, p. 281.

The country being covered by a thick coating of soft residuary material of which the great mass was fine particles, erosion was easy. There were coarser fragments of quartz, largely vein matter, as well as bowlders of disintegration which had withstood the chemical changes. The streams readily became not only loaded to their full capacity, but overloaded with the mass of fine material, and were thus forced to deposit the coarser particles. The grains and fragments not quite suspendable under the conditions of load were rolled along the bottom and rounded by attrition.

In this way the old channels of the baselevel period became filled with gravel, of which by far the larger part is quartz. In the same way the gold, being heavy and associated with the quartz, accumulated in the same channels, while the fine light detritus was carried directly to the Sacramento valley.

In his paper on the ancient river beds of the Forest hill divide,[1] Mr. Ross E. Browne classifies the auriferous gravel channel systems into three periods. The first period was prior to the first important flow of volcanic cement, the second was contemporaneous with the series of volcanic cement flows, and the third, following immediately after the last important flow of volcanic cement, extends to the present time. He calls attention to the predominance of quartz gravel[2] and sand in the ancient channels of the first period and remarks that quartz is the only important material contained in the belts (of slates) which is hard and permanent enough to resist the destructive action of the current. This is especially true when the auriferous slates are disintegrated. It is possible, therefore, that the predominance of quartz in the earlier gravels may indicate an earlier period, in which the slopes had less declivity, and disintegration exceeded transportation.[3] The fact that in the Light's canyon region of Plumas county the gravel is underlain by a sheet of residuary material which was formed before the deposition of the gravel is evidence in the same direction. Furthermore, the sand deposited with the gravel is rough, angular, and unassorted, such as is derived from residuary material near at hand, and records a period of gentler declivity during the next earlier epoch.

The old channels of auriferous gravel of the first period are in a measure characterized by the large size of the deposits. Ross E. Browne states:[4] "In a general way, it may be said that the channels of the second period differ from those of the first as follows: Their beds are narrower, rims steeper, and accumulations of bed-rock gravel incomparably smaller." In these large accumulations of older gravels Prof. Whitney saw evidence of larger streams and heavier precipitation

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[1] Tenth Annual Report, State Mineralogist of Cal., 1890, p. 457.

[2] See also J. D. Whitney's Auriferous Gravels of the Sierra Nevada, p. 323, who says "that in some localities the gravel is almost entirely made up of quartz bowlders, and pebbles."

[3] Mr. Bailey Willis sometime ago, in his study of the Appalachian region, came to a similar conclusion, yet unpublished, to account for the predominance of quartz pebbles in the conglomerate at the base of the Coal-measures.

[4] Tenth Annual Report, State University of California, 1890, p. 439-440.

during the gravel period than now belongs to that region,[1] but, as pointed out by Mr. Gilbert,[2] deposition in stream channels is indicative of diminished instead of increased rainfall.

Prof. Le Conte regarded the gravels as "deposits made by the turbulent action of very swift, shifting, overloaded currents" supplied with both water and débris "by the rapid melting of extensive fields of ice and snow" which were then supposed to occupy the higher portion of the range.[3]

A very important contribution to the literature of the auriferous gravels has been made by Mr. W. Lindgren, whose views are expressed in the following quotation:[4]

> From the rugged country in the region of their sources the rivers pursued their course down in broad valleys separated by ridges which, even in the lowest foothills, sometimes reached an elevation of a thousand feet above the channels. The outlines of the ridges were usually comparatively gentle and flowing; still, slopes of 10 degrees from the channel to the summit were common, and slopes as high as 15 degrees occurred in the eastern part of the Sierra. The character of a region of old and continued erosion, commencing probably far back in the Cretaceous period, is everywhere plainly evident. In the center of the deep depressions is quite frequently found a deeper cut or "gutter," indicating a short period of more active erosive power just before the beginning of the gravel period. At this time, probably about the beginning of the Miocene period, the streams became charged with more detritus than they could carry, and began to deposit their load along their lower courses, especially at places favorably situated, as, for instance, along the longitudinal valley of the South Yuba. Toward the close of the Neocene, gravels had accumulated all along the rivers up to a (present) elevation of about 5,000 or 6,000 feet. Above this it is plain that erosion still continued in places with great activity and furnished some of the material deposited in the lower parts of the streams. The coarse character of much of the gravel, and the often remarkable absence of fine sediments in the beds, point clearly to a somewhat rapid stream capable of carrying off a great deal of silt, and the accumulations are probably due to rapid overloading rather than to low grade of the rivers. The deep channels were filled, and the gravels encroached on the adjoining slopes, where they were deposited in broad benches. A maximum thickness of 500 feet of deposits was attained on the South Yuba, and of from 50 to 200 feet in the other parts of the lower rivers. In the lower and middle Sierra some of the rivers then meandered over flood plains 2 or 3 miles wide, above which the divides of bed rock rise to a height of several hundred feet. In some instances low passes over divides were covered, and temporary bifurcations and diversions of rivers into adjoining watersheds occurred.

It is evident from the facts already known that at the time the early gravels were deposited the northern end of the Sierra Nevada was not less than 4,000 feet lower than at the present time, and that its climatic circumstances, as indicated by its flora, were not such as to give rise to either glaciers or extensive fields of snow.[5] For this reason it is necessary to appeal to some other cause than glaciers as the source of the great mass of débris deposited in the old auriferous gravel

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[1] Climatic Changes in Later Geological Times, p. 1. See also Auriferous Gravels, p. 335.

[2] Science, Vol. I, p. 194, Mar. 23, 1883.

[3] Am. Jour. Sci., Vol. XIX, 1880, p. 184.

[4] Bull. Geol. Soc. of Am., Vol. IV, p. 265-266.

[5] See also Whitney's Auriferous Gravels, p. 295.

channels, and in view of the facts herein cited the writer suggests that a source may be found in the large mass of residuary material upon the surface at the beginning of the gravel period. There is evidence, as already shown, that disintegration exceeded transportation at the close of the Tejon, and that residuary deposits then accumulated upon the gentle slopes of the land to considerable depths. This condition appears to have continued during the early Miocene. The depth of disintegrated rock would vary greatly with different formations. Upon the diorite and other rocks containing minerals subject to ready alteration it would be deepest, and their surfaces, at least that of the diorite, would be strewn, as to-day, with large and small bowlders of disintegration. The quartz veins which intersect these rocks and the silicious slates would be but little affected. The gold not inclosed in quartz veins[1] would be set free.

If, when thus mantled with residuary material, the Sierra Nevada region were affected by a change of level in such a way as to slightly increase the fall of the streams upon its slopes, it is believed, as already suggested, that during a comparatively brief period, owing to overloading, they would be forced to deposit and fill their channels. A portion of the process is in a measure illustrated by what has taken place along some of the present streams of the Sierra Nevada, where hydraulic mining has been extensively carried on. The streams are overloaded by the debris forced into them from the mines, and their channels are at least temporarily filled with gravel.

After the deposition of the earlier gravels the declivity of some of the streams at certain points appears to have been so decreased that they deposited finer material and covered the gravel with sand and clay. This may have resulted from differential elevation, differential subsidence, or both, and there is evidence that both occurred within the gravel period. At Cherokee Flat, upon the eastern border of the Sacramento valley, the finer, essentially estuarine deposits, over 300 feet in thickness, lap over to the eastward upon the ancient river and shore gravels mined at that place. This overlapping evidently resulted from a subsidence of that region.

By this subsidence the bay which then occupied the Sacramento valley region must have been widened. The essentially fresh-water estuary was extended beyond the gap of the Lassen peak region between the Sierra Nevada and the Klamath mountains into northeastern California. By this differential change of level the drainage of that country of gentle relief was interrupted, and a large lake or series of lakes of great extent was produced in eastern Oregon and northwestern Nevada. The Piute lake of King existed about this time and later. The wide extent of these lakes corroborates the view that the country had previously been approximately baseleveled, that

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[1] Whitney's Auriferous Gravels, p. 352.

is, reduced to a peneplain with local portions where the baselevel was well defined. The character of the flora is like that of the auriferous gravels, which is, as already shown, that of a country not far above sea level, and points in the same direction.

The outlet of the lakes of that region was at least in part by way of the depression between the Klamath and the Sierra Nevada mountains into the Sacramento valley. At that time the small streams upon the northern end of the Sierra Nevada flowed northwesterly, in general parallel to the trend of the range, and entered the estuary in the region now occupied by Lassen peak. A stream rising south of the fortieth parallel flowed northerly from the Cascade mine by the Peal and Taylor diggings across the Genesee valley and the north arm of Indian valley to the Mountain meadows,[1] where it entered a sheet of water which was either the estuary itself or a lake at nearly the same level.

Mr. J. A. Edman states[2] that the stream which deposited the gravel on Spanish peak flowed from south to north and then deflected to the northwest. This course is approximately parallel to that of the stream just noted.

The valleys of these ancient streams, especially the one east of Indian valley, like those of their contemporaries upon the western slope of the Sierra Nevada, were broad and shallow, and the slopes of the range were gentle as compared with those of to-day. They had been reduced by long continued erosion to a peneplain, across which the streams flowed from the less regular crest of the mountain to the bay that occupied the Sacramento valley.

This brings us practically to the close of the Miocene with the earliest of the auriferous gravels already formed. The Sierra Nevada region has already shown differential changes of level and the Miocene base level has been somewhat deformed. This deformation continued until it amounted to a topographic revolution of that portion of the Pacific slope. We will now endeavor to trace some of the evidences of this revolution.

DEFORMATION OF THE BASELEVEL.

Mr. W. H. Pettee[3] calls attention to "evidence of extraordinary disturbances since the deposition of the gravel," at Gopher hill and elsewhere, in the region of American valley.

The observations of Mr. Lindgren[4] in the region of the Yuba and American rivers "appear to prove that the grades of the remaining Neocene gravel channels are, to a certain extent, determined by the directions in which they flowed in such a way as to strongly suggest

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[1] Bull. Geol. Soc. Am., Vol. III, p. 372.

[2] Statistics of Mines and Mining, Eighth Ann. Rep. of R. W. Raymond, 1876, p. 118.

[3] Whitney's Auriferous Gravels, p. 473.

[4] Bull. Geol. Soc. Am., Vol. IV, p. 298.

that the slope of the Sierra Nevada has been considerably increased since the time when the Neocene ante-volcanic rivers flowed over its surface. It finally appears probable from a study of the grade curves of the remaining channels that the surface of the range has been deformed and that the most noticeable deformation has been caused by a rise of the mass of the Sierra Nevada relatively to the portion adjoining the Great valley."

The deformation of the baselevel may be studied in two ways: (1) by tracing the present variations of altitude in the originally comparatively level surface itself, and (2) by tracing the deformation of the Ione deposits, which when laid down must have been at a lower altitude than the baselevel, because deposited in the water body upon its border. Each line of evidence should corroborate the other and render the conclusions concerning the deformation more trustworthy.

It is impossible to tell, from what is known at present, the original inclination of the baselevel. It is evident, however, that it must have been considerably less than one degree, for at that angle streams generally wear away their beds more than their banks, and cut canyons.

Since the baselevel upon the western border of the Sacramento valley was completely developed upon the shores of a great bay which then occupied what is now the northern end of that valley, extending through the gap between the Sierra Nevada and Klamath mountains into northeastern California, we may assume that originally it was not far from level.

If, as suggested by Whitney,[1] the erosion was due to the action of waves, the plain must have originated as a wave-cut terrace just below the level of the sea, but if a baselevel of stream erosion upon the land, it could have attained such uniformity of erosion on both hard and soft rocks only at a low angle of slope, so that in either case we are justified in supposing that at the time of its greatest development it was near sea level. In Plate XLIV (see page 112) the elevations of the baselevel at various points are indicated. The western edge of the baselevel in the Elder creek, Red Bank, and Cold fork sections averages nearly 2,300 feet, while the eastern edge is considerably less than 1,000, giving the old plain a slope of 100 feet per mile to the eastward, which is but little if any greater than the average western slope of the Sierra Nevada in the mining region.[2] Across this plain the streams now flow in canyons from 300 to 400 feet deep, and they are still cutting. The canyons in general are deepest to the westward, and gradually run out toward the Sacramento river in the newer deposits which fill the valley. It is evident that since the baselevel was formed it has been affected by differential elevation in the uplifting of the Coast range and Klamath mountains just north of the fortieth parallel to the extent of over 2,000 feet, and if we may judge from the traces of the baselevel

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[1] Geological Survey of California, Geology, Vol. I, p. 320.

[2] Auriferous Gravels of the Sierra Nevada of California, by J. D. Whitney, p. 63.

seen at Showers pass and South Fork mountain, the upheaval in the Klamath mountains has been much greater. It has long been maintained by Whitney and others that the principal upheaval of the Coast range occured at the close of the Miocene.

At the northern end of the valley the elevation of the baselevel is 800 feet. To the east it rises gradually to 1,300, 1,700, and finally, in the neighborhood of Round mountain to 2,500 feet, showing elevation in the Lassen peak region east of the Sacramento valley.

Mr. G. K. Gilbert[1] was the first to recognize the broad plateau upon the western slope of the Sierra Nevada as a plain of erosion, and discussed the matter in such a way as to show that the height of the range has been considerably increased since the erosion plain was formed.

Prof. Le Conte advocated essentially the same view. He says:[2]

> The rivers, by long work, had finally reached their baselevels and rested. The scenery had assumed all the features of an old topography, with gentle flowing curves. At the end of the Tertiary came the great lava streams running down the river channels and displacing the rivers; the heaving up of the Sierra crust block on its eastern side, forming the great fault cliff there, and transferring the crest to the extreme eastern margin; the great increase of the western slope and the consequent rejuvenescence of the vital energy of the rivers; the consequent cutting down of these to form the present deep canyons and the resulting wild, almost savage, scenery of these mountains.

The observations of Mr. W. Lindgren[3] in the region of the Yuba and American rivers upon the western slope of the Sierra Nevada "appear to prove that the grades of the remaining Neocene gravel channels are to a certain extent determined by the directions in which they flowed, in such way as to strongly suggest that the slope of the Sierra Nevada has been considerably increased since the time when the Neocene antevolcanic rivers flowed over its surface. It finally appears probable from a study of the grade curves of the remaining channels that the surface of the Sierra Nevada has been deformed during this uplift, and that the most noticeable deformation has been caused by a subsidence of the portion adjoining the great valley relatively to the middle part of the range."

Strong evidence of the deformation is furnished by the distribution of the Ione formation. As already shown, this formation was deposited about sea level. On Little Cow creek it now occurs at an altitude of 3,400 feet, and on Bear creek about 4,000 feet above the sea, indicating conclusively that since the baselevel period the Lessen peak region has been elevated at least 4,000 feet. There are indications that the elevation was still greater to the southward, about the northern end of the Sierra Nevada, for between Mountain meadows and Diamond peak, opposite Susanville, the auriferous gravels supposed to belong to

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[1] Science, Vol. I, 1893, pp. 194, 195.

[2] Bull. Geol. Soc. of Am., Vol. II, pp. 327, 328.

[3] Bull. Geol. Soc. of Am., Vol. IV, p. 298.

the estuarine Ione formation rise from 5,000 to 7,000 feet. These high gravels upon the northeastern block of the Sierra Nevada have been displaced in a remarkable manner by the upheaval of the range. The area occupied by them is about 10 by 16 miles in extent. Although the gravels cover the larger part of this area and are connected throughout, they do not now appear over the whole of it. There were a few small islands of older rocks during at least the later portion of the gravel period, and at some other places within the area the gravels have either been washed away or covered up by later volcanic flows.

During the later part of the gravel period in that region, after the effusion of the andesitic lavas, more or less well-defined beaches were formed around a series of volcanic islands upon what is now the very crest of the range from Fredonia pass, northeast of Mountain meadows, to Diamond mountain. When developed, these beaches must have been at the same level in a body of standing water, but now they gradually rise to the southward from about 5,000 feet near the northern end of Mountain meadows to 7,000 feet opposite Diamond peak, and it is evident not only that the northern end of the range has been elevated, but that the amount of elevation increased southward. The general inclination of this body of gravels toward Lassen peak, beneath whose lavas it disappears, makes it very probable indeed that they are connected with the Ione formation that disappears under the opposite edge of the same lavas bordering the eastern side of the Sacramento valley. If this could be definitely established, it would show that the northern end of the Sierra Nevada has been elevated 7,000 feet since the gravel period of that region. It is possible that the increased elevation does not extend far southward, for beyond the fortieth parallel the eastern crest of the range retreats to the escarpment of the main block of which the Sierra Nevada is composed.

In connection with the upheaval of the northeastern portion of the range a fault was formed along the eastern base, at least beyond Honey lake. A short distance above Janesville the gravels are displaced by a fault in which the throw is about 3,000 feet. On the very crest of the range, 7 miles northwest of Janesville, the gravel rises to 7,400 feet, while at the foot of the steep slope which it caps the same gravel occurs in Mr. Weisenberger's mine at an elevation of about 4,500 feet. To the northwest the fault runs out apparently in a monoclinal arch, later than most of the volcanic eruptions on the crest of the range at that point,[1] but before the final eruptions of the Lassen peak region were completed. Mr. Lindgren[2] has shown that further south the eastern slope of the range was formed before the eruption of the andesitic lavas.

Upon the western side of the Sacramento valley the baselevel in the neighborhood of Elder creek has an average altitude of 1,250 feet. From this point it rises northward to 1,800 and finally 1,850 feet in the

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[1] See also Eighth Annual Report U. S. Geol. Survey, p. 429.

[2] Bull. Geol. Society of America, Vol. IV, pp. 257-298.

quartz is the most important, was found in the thick deposit of residuary detritus which had accumulated upon the surface of the land during the baselevel period. The large mass of disintegrated rock substance rendered the loading of the streams so easy that when rejuvenated by orogenic movements they readily became overloaded and filled their ancient channels with auriferous gravels.

THE ROCKS OF THE SIERRA NEVADA.

BY

H. W. TURNER.

CONTENTS.

ILLUSTRATIONS.

THE ROCKS OF THE SIERRA NEVADA.

BY H. W. TURNER.

FIELD OF OBSERVATION.

The following notes are based on field work in two portions of the Sierra Nevada in California.

One of these areas embraces a strip of country about 30 miles wide, extending across the range just to the south of the fortieth parallel, chiefly in Butte and Plumas counties. The other area comprises that portion of the range between the parallels of 38° 30′ and 37° 30′, chiefly in Amador, Calaveras, Alpine, Tuolumne, Mariposa, and Mono counties, and includes the Yosemite National park. The field work in neither of these areas is completed, and the notes are therefore in no sense final.

The relations of certain sets of rocks, however, have been definitely determined. These relations are best shown at widely separated localities, and to illustrate them small geologic maps are presented, the locations of which are shown on the general map (Pl. XLVIII) by parallelograms.

GENERAL REMARKS.

The Sierra Nevada may be described as a monogenetic range, composed of highly compressed schists and slates, with large areas of associated igneous rocks, chiefly granite and diabase, upon which lie unconformably a series of late Cretaceous and Tertiary sediments and volcanic rocks.

Through the labors of the State geological survey, under Prof. Whitney, it has been shown that the sierra was formed as a great mountain range after the deposition of the Mariposa slates. Later it was suggested by Mr. Gilbert—a suggestion more thoroughly elaborated by Prof. Le Conte—that during Cretaceous and Tertiary time this Jurassic mountain range had been reduced by erosion to an approximate peneplain. In the later Tertiary a large part of the western slope of the Sierra Nevada was covered with volcanic materials, extensive areas of which still remain, preserving underneath them intact the old Tertiary peneplain, the drainage system of which is represented by the auriferous river gravels.

In this old peneplain were groups of hills which rose to considerable elevations above the general level of the plain. The Bear mountains, in

Calaveras county, furnish an example. These mountains at present rise nearly 2,000 feet above the old Neocene surface. These is no evidence that any Tertiary deposits or lava flows ever covered any portion of them. The streams in Neocene time, as now, were deflected from their usual southwesterly course to the northwest by the barrier formed by the Bear mountains.

According to Mr. Waldemar Lindgren, the Slate mountains, in Eldorado county, were never degraded to the general level of the peneplain, and this is likewise true of the huge mass of quartzite known as Blue mountain, in Calaveras county.

Late in the Tertiary the Sierra Nevada as a whole experienced an elevation which was intensified by faulting, especially along the east base of the range, and which is most marked to the west of Lake Mono and Owens river valley.

The range gains in elevation going south, and the old peneplain likewise occupies successively higher levels.

West of Mono lake Mr. I. C. Russell[1] found water-worn gravel on the top of the Sierra Nevada, the largest body of which is on the plateau extending north from Mount Dana and has an altitude of about 11,500 feet, or more than 5,000 feet above Mono lake. Other bodies of gravel occur 6 or 8 miles southwest of Mount Dana, and the writer collected well rounded pebbles of pre-Tertiary rocks on the main summit of the range, a few miles northwest of Tower peak, at an elevation of over 9,000 feet. The plateaus on which these gravel patches rest undoubtedly represent portions of the old peneplain, and lying as they do immediately west of the steep eastern escarpment of the range, they indicate that this scarp has been formed since the deposition of the gravels.

These gravel patches along the crest of the range undoubtedly represent remnants of Neocene river beds, now almost entirely eroded. If, as suggested by Prof. Le Conte, the crest of the sierra was farther west in Cretaceous and Tertiary time than now, it is probable that the course of those Neocene streams was easterly, and that gravels representing their eastern continuation may be buried in the downthrown area east of the escarpment.

The fact that granite forms almost the whole of the southeastern end of the Sierra Nevada would seem in itself to indicate that here the elevation had been greatest, the overlying sediments having been eroded, leaving the underlying granitic rocks exposed.

The normal faulting along the east base of the southern part of the range may indeed have amounted to some thousands of feet, and this faulting seems to have caused an absolute elevation of the crest of the range, tilting it somewhat toward the west. It was accompanied by the subsidence of the Great Basin region, which subsidence resulted in the formation of separate drainage basins in the downthrown area,

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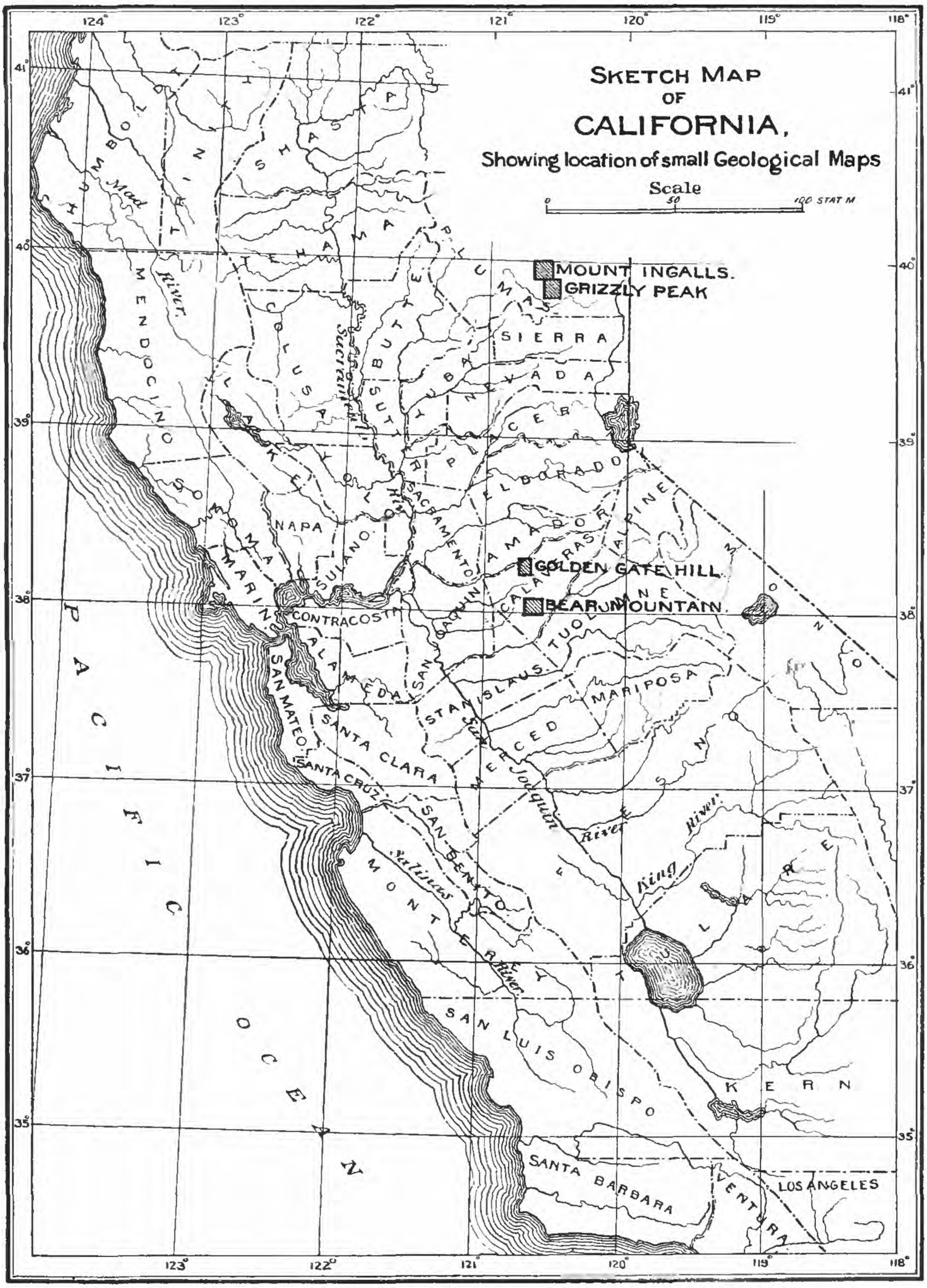
[1] Eighth Annual Report U. S. Geol. Survey, p. 322.


SKETCH MAP
OF
CALIFORNIA,
Showing location of small Geological Maps
Scale
0 50 100 STAT M
MOUNT INGALLS.
GRIZZLY PEAK
GOLDEN GATE HILL.
BEAR MOUNTAIN.
PACIFIC OCEAN
HUMBOLDT
TRINITY
SHASTA
TEHAMA
PLUMAS
BUTTE
MENDOCINO
COLUSA
SUTTER
YUBA
SIERRA
NEVADA
PLACER
LAKE
YOLO
SONOMA
NAPA
SOLANO
SACRAMENTO
EL DORADO
AMADOR
ALPINE
CALAVERAS
MARIN
CONTRACOSTA
SAN JOAQUIN
TUOLUMNE
MONO
ALAMEDA
SAN MATEO
STANISLAUS
MARIPOSA
MERCED
SANTA CLARA
SANTA CRUZ
SAN BENITO
FRESNO
TULARE
MONTEREY
SAN LUIS OBISPO
KERN
SANTA BARBARA
VENTURA
LOS ANGELES
Mad River
Sacramento R.
San Joaquin River
King River
Salinas River
124° 123° 122° 121° 120° 119° 118°
41° 40° 39° 38° 37° 36° 35°

the lowest portions of which are now occupied by lakes, of which Mono lake and Owens lake are examples.

That the Sierra Nevada has been elevated as a whole is shown by the occurrence of Neocene deposits, sandstones deposited in gulf waters, and river gravels in the lower foothills at the very west edge of the range. If the elevation has been increased only along the east crest, tilting the range westward, at the west edge of the block so tilted the Tertiary deposits would lie approximately at sea level. As may be seen by examining the Jackson geologic atlas sheet, the gulf deposits of the Ione formation attain an elevation of 1,000 feet near Valley Springs, only about 10 miles east of the edge of the San Joaquin valley, and Neocene river gravel occurs on the Gopher ridge, about 2 miles east of Jenny Lind, at an elevation of 900 feet, only about 5 miles east of the valley.

The Neocene sediments underlying the Oroville Table mountain, on the Chico geologic atlas sheet, are very near the edge of the Sacramento valley, and attain a maximum elevation of about 1,400 feet above sea level. A considerable portion of this sediment is fine white material, indicating comparatively still water, and suggesting that it is a deposit formed where a river once debouched into the gulf that then occupied the great valley. The elevation of this water was probably not much, if at all, above that of the sea.

In his admirable book, Études Synthétiques, Daubrée has shown to what a remarkable extent the drainage system of portions of France has been determined by a system of fissures that intersect the country.

If a piece of tracing paper be placed over a map of California, and the general courses of the streams drawn on it in right lines, several sets of parallel lines will be the result, suggesting strongly that the courses of the streams have been determined by systems of preexisting fissures. This is more evident in the Sierra Nevada than in the Coast ranges.

It seems most probable that such systems of fissures could not form without displacement along the fissures. Nevertheless, this conclusion does not seem substantiated by the geologic atlas sheets of the Gold Belt. In the first place, the old Tertiary peneplain shows no marked vertical displacement on opposite sides of the canyons; and in the second place, where marked vertical contacts occur in the river canyons between dissimilar rocks, such as slate and granite or slate and diabase, the general strike of which is northwesterly across the canyons, no lateral displacement has thus far been noted.

The chief displacements in the older rocks of the Sierra Nevada, except the late Tertiary faulting, appear to have taken place at the time of the intrusion of the older igneous rocks of the granite series. This is well shown on the Placerville and Jackson atlas sheets, where large masses of stratified rocks are thrown out of their normal northwesterly strike, lying in some cases nearly east and west, their strike being more or less nearly parallel to the contact line of the intrusive granite.

While the slates and schists of the Sierra Nevada dip easterly as a rule, this is by no means universal. Nearly all the bedded rocks of the Grizzly mountains in Plumas county dip to the west, and vertical and westerly dips for short distances may frequently be noted. The Sierra Nevada of to-day may thus be said to represent the base of the Jurassic range, which was again elevated about the end of the Tertiary.

It has been noted by Whitney and others that the bedded rocks of the Sierra Nevada usually dip northeasterly at a high angle—that is, they dip toward the crest of the range. This does not appear to be entirely the result of compression forming a schistosity across the original stratification of the rocks, which would perhaps satisfactorily account for the uniform dip; for although these bedded rocks are in some cases amphibolite-schists derived from diabase, etc., by dynamo-metamorphism and in other cases mica-schists, there are frequent calcareous and arenaceous layers in some of the clay-slates, which also have the same easterly dip, and fossils, when found, lie in the plane of schistosity, which may therefore be the plane of bedding.

It seems most probable that this easterly dip is due to an overthrow of the folds. The thickness of the stratified rocks with the associated diabase and amphibolite-schists is in places 40 miles or more, and it seems certain that this series represents a duplication of strata by folding, but it is by no means easy to prove this because of the lack of definite horizons, like conglomerate beds or continuous quartzite or limestone layers; and the great infrequency of fossils makes them of little avail.

Prof. Le Conte[1] writes that "40 miles of slates and schists outcropping at high angle would give an incredible thickness of sediments, if we regard them as a single unrepeated series. It is probable, therefore, that these flanking slates really consist of several closely appressed folds, afterward deeply eroded so as to simulate a single series."

Prof. Whitney[2] states that "a carefully constructed section along the line of the Central Pacific railroad, on which the inclination of the strata at every outcrop was laid down, failed to furnish proof of any regular system of folds."

Geikie, in his Manual of Geology, describes the structure indicated above, where a series of strata composed of a number of folds has a uniform dip as an isoclinal structure. Examples of it are known in the Alps and elsewhere.

The section of the Cretaceous and Tertiary strata to the southeast of Mount Diablo,[3] from Tasajero creek to Lone Tree valley, represents a simple example of this structure.

Fig. 51 represents a section across the Gold Belt on the ridge to the north of the Mokelumne river, in Amador county. Here the auriferous slate series, with its associated basic igneous rocks, attains a width of only 9 miles. The eastern belt of the Cretaceous formation is figured as

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[1] Am Jour. Sci., 3d series, Vol. XVI, p. 101.
[2] Auriferous Gravels. p. 50.
[3] Bull. Geol. Soc. Am., Vol. II, p. 400.

being an isoclinal of four folds—three anticlines and one syncline—and the western belt of the Calaveras formation as being composed of a single anticline. The two belts of Mariposa slates are presumed to constitute synclines.

This explanation of the structure of the Gold Belt, however, is presented merely as a working hypothesis.

SEDIMENTARY ROCKS.

The sedimentary rocks have been grouped in two series: (1) the auriferous slate series, embracing the older slates and schists in which the auriferous quartz veins occur, and which are usually much metamorphosed and stand nearly vertical; and (2) a later unaltered series, separated by a great unconformity from the auriferous slates and designated the Superjacent series in the descriptive text of the geologic maps of the Gold Belt now being issued.

The formations into which these rocks have been provisionally subdivided are indicated in the following table:

AURIFEROUS SLATE SERIES.

Grizzly formation	Silurian.
Calaveras formation	Carboniferous.
Robinson beds	Upper Carboniferous.
Little Grizzly creek beds	Upper Carboniferous.
Juratrias beds	
Cedar formation	Triassic.
Mineral King beds	Triassic (?)
Mariposa formation	Upper Jurassic or lowest Cretaceous.

SUPERJACENT SERIES.

Chico formation	Upper Cretaceous.
Tejon formation	Eocene.
Ocoya creek beds	Miocene.
Ione formation	Upper Miocene (?)
Auriferous river gravels	Neocene.[1]
Neocene shore gravels	Pliocene.
Shore and river gravels, lake beds, and moraines	Earlier Pleistocene.
Alluvium	Late Pleistocene.

AURIFEROUS SLATE SERIES.

GRIZZLY FORMATION.

The name Grizzly formation has been given by Mr. Diller[2] to the Silurian beds of the Grizzly mountains of Plumas county. The beds comprise the Grizzly quartzite and the Taylorville slates of Diller, with a few limestone lenses, in which the following fossils were found:

Crinoid stems.
Stromatopora sp. (?)
Zaphrentis.
Syringopora, like S. serpens.
Heliolites.
Halysites catenulatus.
Orthis, of the type of O. flabellum.
Ormoceras.

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[1] This term includes both the Miocene and the Pliocene.

[2] See descriptive text of Lassen peak geologic atlas sheet, and Bull. Geol. Soc. Am., Vol. III, p. 376.

These rocks form a narrow strip in the northeastern portion of the Downieville sheet, but it is not known that they enter into the composition of the range farther south.

CALAVERAS FORMATION.

A large portion of the sedimentary rocks of the auriferous slate series consists of argillite, quartzite, and mica schist, with lenses of limestone. Few fossils have been found in these rocks, and these chiefly in the limestone lenses. Rounded crinoid stems, suggesting the Paleozoic era, have been collected at many points, and in addition the following more characteristic fossils:

Pleurotomaria.
Polyphemopsis.
Loxonema.
Spirifera.
Phillipsastrea.
Clisiophyllum gabbi Meek.
Lithostrotion whitneyi.
Fusilina cylindrica.

The limestone at Pence's,[1] in Butte county, containing *Productus semireticulatus* and *Spirifera lineata*, belongs to the Calaveras formation, as does also the Bass ranch locality,[2] in Shasta county, where the State Geological Survey of California obtained the following fossils:

Fusulina robusta Meek.
Fusulina gracilis Meek.
Fusulina cylindrica Fischer (?).
Lithostrotion.
Clisiophyllum gabbi Meek.
Productus semireticulatus Martin.
Rhynchonella.
Spirifera lineata Martin (?).
Spiriferina.
Retzia compressa Meek.
Euomphalus whitneyi Meek.
Orthis.

Mr. Walcott is of the opinion that the fossils in the above lists indicate the lower Carboniferous, but the exact time range of the series is yet to be determined.

The term "Calaveras formation" was first used by the writer in a review in the American Geologist, Vol. XI, p. 309, where it was defined as including all of the Paleozoic sedimentary rocks of the Sierra Nevada, but it was not intended to include in the series the Silurian beds of the Grizzly mountains nor the Little Grizzly beds, nor the Robinson beds, which appear to be of upper Carboniferous age. So far as known, the rocks of the Calaveras formation comprise the larger part of the sedimentary rocks of the auriferous slate series.

Fusulina has been found in the Gold Belt region in limestone at Hite's cove, in Mariposa county; on the north side of the Mokelumne river, 5 miles southwest of Jackson; and at a point about 1 mile west of north from the last locality. This fossil genus is not known to range above the Permian or below the Carboniferous.

Fossils were collected in limestone in the Calaveras formation at several localities in Plumas county, in 1893, by Mr. T. W. Stanton and the writer. These were examined by Mr. Charles Schuchert, who reports the following:

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[1] Geology of California, Vol. I, p. 210.

[2] Paleontology of California, Vol. I, pp. 1-16.

South side of Onion Valley creek, near western boundary of Downieville sheet, Plumas county, California:

Fusulina robusta Meek.
Lithostrotion, with small zooids.
Crinoid columns, probably Platycrinus.

Spanish creek, 1 mile east of Spanish ranch, Plumas county, California:

Fusulina robusta Meek.
Fusulina sp. undet.
Lithostrotion.
Crinoidal fragments.

One and a half miles northwest of the summit of Clermont hill, on the headwaters of the north fork of Rock creek, Plumas county, California:

Lithostrotion sublaevis Meek.
Crinoidal fragments.

The Spanish ranch locality is particularly interesting, as this limestone is one of the outcrops described by Mr. James E. Mills[1] as being of Mesozoic age. Mr. Mills says: "Thus examined and located, this long line of outcrops of fossiliferous limestones in the heart of the Sierra affords an available and definite horizon from which to measure and determine rocks upward and downward in the series."

The limestones considered by Mr. Mills as part of this "line of outcrops" to the north of the fortieth parallel do, it is true, contain pentagonal crinoid stems, showing the age of the north end of this limestone belt to be Mesozoic. Along the fortieth parallel the pre-Tertiary rocks are covered up by an area of Tertiary andesite-breccia. There is at present no evidence that these Mesozoic limestones extend to the south of the andesite area.

ROBINSON FORMATION.

The Robinson formation was first characterized by Mr. J. S. Diller,[2] who states that "the Robinson beds contain slates, conglomerate, tuff, and sandstone, of which the last two are the most important. The sandstone is a purplish rock of great variability. One-fourth of a mile south 50 degrees west of Robinson's in Genesee valley, it becomes for a short distance an arenaceous limestone. This calcareous portion was discovered by Curtice and has yielded an abundance of Carboniferous fossils. The material of which it is composed is chiefly volcanic, and close by the locality just mentioned it passes into a well marked tuff. To the naked eye the latter sometimes closely resembles the porphyritic eruptive with which it is associated."

Fossils were discovered in a calcareous portion of the tuff near Robinson's, in Genesee valley, by Dr. Cooper Curtice, who collected a considerable number of species, a partial list of which is given below,

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[1] Bull. Geol. Soc. Am., Vol. III, p. 328.
[2] Bull. Geol Soc. Am., Vol. III, p. 374.

and which are considered by Mr. Walcott to indicate an upper Carboniferous horizon:

Favosites.
Streptorhynchus crenistria.
Productus semireticulatus.
Crinoids.
Spirifera.
Aviculopecten.

LITTLE GRIZZLY CREEK BEDS.

At the southwest base of Mount Ingalls, by the road to the Cascade gravel mine and to the east of Little Grizzly creek, there occurs a highly metamorphic tuff in which are numerous fossils. Collections were made at this point by Dr. Cooper Curtice, assisted by Mr. T. W. Stanton and Mr. W. T. Turner. Through the kindness of Mr. C. D. Walcott these collections were examined by Mr. Charles Schuchert of the U. S. Geological Survey, who reports them as follows:

> The collections from Little Grizzly creek, Plumas county, California, show the fossils to be of upper Carboniferous age. The common forms are of the following species:
>
> Archeocidaris, plates and spines like those of A. ornatus Newberry, and A. trudifer White.
> Chonetes n. sp. A very common, large, subquadrate, and very convex species.
> Productus longispinus, Sowerby.
> Productus semireticulatus?
> Orthis (Schizophoria) pecosi Marcou.
> Rhynchonella (Uncinulus) n. sp.?
> Spirifer n. sp. Related to S. camerata Morton, and S. musakheylensis Davidson.
> Spirifer (Reticularia) lineatus Martin.
> Spiriferina cristata Schlotheim. The large variety.
>
> This fauna is closely related to that of the Robinson beds. The species of the latter locality are known to me only by the list published by Mr. Diller.

The Little Grizzly creek tuff contains large feldspar crystals, and throughout the groundmass an abundance of minute foils of a brownish green mica and in some thin sections minute prisms of a greenish hornblende, which appear to have formed in the rock as a result of metamorphic action. The locality is near the granite.

The porphyritic feldspars appear to be chiefly orthoclase, with some microcline.

The following is a partial analysis of a sample of this rock, by George Steiger:

No. 352 Plumas county; Metamorphic tuff.

Silica	55·29
Lime	3·08
Magnesia	1·41
Potassa	5·58
Soda	4·65

No. 352 Plumas county is not from the fossil locality but from about 3 miles southeast of Penman peak. It is, however, nearly indistinguishable under the microscope from some of the tuff at the fossil locality.

In the northeast portion of the Downieville sheet are a number of areas of metamorphic tuff that are presumed to be of the age of the Little Grizzly creek beds, but fossils have been found thus far only at the point above described. The material in which the determinable fossils occur is a fine grained tuff composed of minute grains, probably largely feldspathic, and abundant scales of the brownish-green mica and fibers of amphibole. The Little Grizzly creek beds will probably be correlated with the Robinson beds under the name of "Robinson formation" on the forthcoming sheets of the U. S. Geological Survey.

JURATRIAS BEDS.

The existence of abundant fossils at the east base of the north end of the range was first made known to the scientific world by Prof. J. D. Whitney and his assistants. Of late years this region, about Taylorville and Genessee valley, in Plumas county, has been extensively studied by Mr. Diller[1] and Prof. Hyatt,[2] and many new species added to the previously known fauna. Mr. Mills[3] and Mr. Diller[4] have also found Juratrias fossils in the Sierra Nevada to the north of the fortieth parallel at several points, and Messrs. Diller,[5] Fairbanks, and Storrs have collected Juratrias fossils in the Klamath mountains, which undoubtedly represent the continuation of the auriferous slate series of the Sierra Nevada.

South of the fortieth parallel fossils are much more rare than in the area to the north. This is doubtless mainly due to the greater metamorphism of the auriferous slates in the region comprising the main mass of the Sierra Nevada. Fossils have, however, been found indicating the presence of the Juratrias at a number of points. The most southern locality is at Mineral King, in Tulare county. This occurrence will be described later. The localities in the Mariposa slates will also be treated separately.

So far as known to the writer all of the fossil faunas of the auriferous slate series of the main mass of the Sierra Nevada are represented only by casts and impressions, often much distorted, and the original shells have in all cases disappeared.

The first locality to the south of Genessee valley where there is evidence of the Juratrias is on the southeast slope of the Sierra buttes. Some years ago I saw in the collection of Mr. C. W. Hendel, of Laporte, Plumas county, a very distinct impression of an ammonite on a piece of black slate, which Mr. Hendel informs me was obtained by a miner from the spot where the mill of the Phoenix gold quartz mine now stands. There is at this point a narrow lens of black siliceous slate included in quartz-porphyry, which forms the country rock of the mine, and the fossil presumably came from this slate lens. There are a num-

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[1] Bull. Geol. Soc. Am., Vol. III, pp. 369-394.

[2] Bull. Geol. Soc. Am., Vol. III, pp. 395-412.

[3] Bull. Geol. Soc. Am., Vol. III, p. 428.

[4] Text of the Lassen peak geological atlas sheet.

[5] Bull. Geol. Soc. Am., Vol IV, pp. 220-221.

ber of lenses of precisely similar black siliceous slate in the quartz-porphyry, etc., that forms the crest of the ridge extending north from the Sierra buttes, and it is therefore probable that all of these rocks, both the lenses and the inclosing igneous rocks, are Juratrias in age. The largest lens of this black siliceous slate noted lies on the ridge, just west of the south end of Gold lake, and is a mile or more in length, and perhaps 1,000 feet in maximum width.

Apparently overlying the igneous rocks that contain the siliceous slate lenses just described, are a series of little altered diabase tuffs with some quartzite, fine grained reddish clastic rocks, breccia, and limestone. The series is best exposed along and east of the north fork of the Yuba river in the southeast corner of the Downieville sheet, in the neighborhood of the old stage station known as Milton. The breccia contains abundant small fragments of phthanite, and other rocks of various colors, giving the breccia on weathered surfaces a variegated appearance. Pebbles of this peculiar breccia have been noted by the writer at a number of points in the northern Sierra Nevada, in the Neocene river gravels, and may be of service in tracing the course of the ancient channels.

Limestone was noted at two points only, and at both places is in contact with the granite that lies to the east of the rock here described. This limestone contains yellow and reddish garnets, probably formed in the rock as the effect of the heat of the granite, which is therefore doubtless later in age.

The same brownish green mica that occurs in the Little Grizzly beds is abundant in the sandstone or schist beds near the limestone, and is presumably also a product of contact metamorphism.

This body of tuffs and sediments shows very little evidence, either macroscopically or microscopically, of having been greatly compressed. As a rule not only has very little slaty structure been developed, but under the microscope the augite and feldspar prisms of the tuffs and quartz grains of some of the sediments show little evidence of crushing. The series as a whole has a remarkably uniform dip of from 45° to 50° to the east. At the granite contact the dip is in places much steeper. This series is considered to be Juratrias in age, although fossils have not been found in any portion of it. These beds seem to rest uncomformably on the presumably Paleozoic sediments that form the mass of the range on the Downieville sheet to the west of Milton. These Paleozoic (?) rocks consist of black slates, quartzite and magnesian limestone, with intrusive quartz-porphyry, gabbro, etc. They stand approximately vertical and are much compressed. The difference in the lithological character of the two sets of rocks, the fact of one showing much evidence of dynamo-metamorphism and the other comparatively little, and the marked difference in dip of the two bodies taken as a whole strongly suggest an unconformity.

The next locality to the south of the Sierra buttes where Juratrias fossils have been found is in Sailor canyon, which drains into the American river about 6 miles a little east of south from Cisco. Here Mr. Lindgren and Dr. Cooper Curtice collected fossils that appear to indicate both the Trias and the Jura, according to Prof. Alpheus Hyatt. The red tufaceous sandstones that cap Mount Dana, and some other patches of sedimentary rocks that occur along the crest of the Sierra Nevada, from Pyramid peak range, west of Lake Tahoe, to Mount Lyell and further south, are thought from analogy to be Juratrias in age, although none of these areas have thus far afforded any fossils.

MINERAL KING BEDS.

The old mining camp of Mineral King is situated in the heart of the southern Sierra Nevada, about 15 miles southwest of Mount Whitney, at the headwaters of the Kaweah river. The gold quartz veins occur in a lens of metamorphic sedimentary rock which is completely inclosed in the granite, of which there are two varieties, that to the east of the schist lens, forming the peak known as Sawtooth, being very coarse grained with the ferro-magnesian constituents present in small amount, and that to the west of the schist lens being the ordinary hornblendic granite or granodiorite. One of the quartz veins noted, that of the Empire mine, is in white marble, where seen at the upper workings. The quartz contains zinc blende and galena. The sediments of this lens have been converted into clay slate, mica schist, quartzite, and crystalline limestone.

The attention of the writer was first called to this locality by specimens of fossils in the State Mining Bureau, sent there by Dr. S. G. George. Later Mr. G. F. Becker and the writer made a trip through the southern Sierra Nevada, visiting, among other points, Mineral King.

The fossils collected there by the writer occur in slate between layers of bluish limestone by the trail to Lake canyon, on the steep slope near the mouth of the canyon, at an altitude of about 9,000 feet.

The fossils are represented by casts only, which are much compressed and distorted. On examining these Mr. Walcott and Dr. White considered the fossils to represent the Trias. Mr. Stanton has recently examined these fossils and reports concerning them as follows:

> Loc. 611, Nat. Mus. coll., Headwaters of Kaweah river, Mineral King district. None of the fossils from this locality have been satisfactorily determined, as they are all mere distorted impressions in a dark-blue slate. A small plicate form of *Ostrea* is quite abundant, and there are also forms that are somewhat doubtfully referred to *Pecten, Lima, Mytilus,* and *Halobia,* and a spiriferoid brachiopod. They were provisionally referred to the Trias on account of the last-named fossil and the general facies of the others.

CEDAR FORMATION.

This formation was so named by Mr. Diller,[1] who states that it includes the horizon of the Hosselkus limestone, and is characterized by pentagonal crinoid stems, *Monotis*, and so forth. A belt of slates

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[1] Text Lassen Peak sheet.

and limestones of this formation extends from Rush creek across the east branch of the north fork of the Feather river, and forms a part of the ridge north of Meadow valley, but has not thus far been recognized farther south.

MARIPOSA FORMATION.

The Mariposa slates constitute the most definite of the formations that have been recognized in the auriferous slate series. Where studied by the writer, south of the American river, this formation consists almost wholly of black clay-slates, with some layers of diabase tuff, and a little conglomerate made up of siliceous pebbles from the rocks of the Calaveras formation.

The discovery of fossils in the Mariposa estate was apparently first made by Miss Errington, and the first notice in print of this discovery appears to be that by Prof. Blake,[1] who read a statement before the California Academy of Sciences on October 3, 1864, indicating that his attention had been called to the occurrence of fossils in the clay-slates at Bear valley, Mariposa county, by Miss Errington, to whom he proposed to dedicate one of the species, if new. These fossils appear to have been sent to Mr. Meek. Dr. Gabb obtained, apparently a little later, through Miss Errington and Clarence King, more fossils from the same beds.

The first scientific description of any of these fossils was read before the California Academy of Sciences in November, 1864, by Dr. W. M. Gabb.[2] These fossils, with others, are more fully described by Mr. F. B. Meek in Appendix B, Geology of California, Vol. I. The following species are there indicated:

Amussium aurarium Meek.
Aucella erringtoni Gabb.
Aucella erringtoni var. linguiformis.
Pholadomya (?) orbiculata Gabb.
Belemnites pacificus Gabb.

One ammonite had, however, been obtained by Mr. John Conness[3] in 1861 from near Georgetown, and ammonites were reported by Blake from Oregon bar in 1864, and belemnites found by Gabb at Spanish Flat, all of these occurrences being in the northward extension of the Bear valley slates, previous to the discovery of the fossils on the Mariposa estate.

Since these first discoveries fossils have been found in the Mariposa slates at a considerable number of points.

As was first stated in the American Geologist, Vol. IX, p. 308, there are two main belts of the Mariposa slates, one lying to the east and the other to the west of the Bear mountains of Calaveras county.

The western belt appears to be continuous from just east of Folsom on the American river to Merced falls on the Merced river and farther south. Fossils have been found in this western belt at two points only, so far as known to the writer. The first discovery is that of an ammo-

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[1] Proc. Cal. Acad. Sci., Vol. III, p. 170.

[2] Proc. Cal. Acad. Sci., Vol. III, p. 172.

[3] Auriferous Fossils, p. 35.

nite on Wilkinson's ranch, near White Rock station[1] in Eldorado county, reported by Prof. Whitney,[2] and the second discovery is that of belemnites in Salt gulch, 2 miles northeast of Campo Seco in Calaveras county, made by the writer. The eastern belt of Mariposa slates is continuous from near Colfax on the Central Pacific railroad to near Mariposa, in Mariposa county. In this belt of slate occur numerous rich gold quartz veins forming the famous Mother Lode. In consequence these slates have been extensively exploited, and it is perhaps for this reason that more fossils have been obtained than from the western belt. All of the following localities are from the eastern belt.

In the northern portion of the eastern belt, as before noted, fossils were found by Conness and Gabb. The ammonites reported by Blake[3] from Oregon bar on the middle fork of the American river were several casts in an argillaceous, somewhat micaceous slate. Prof. Blake was unable to secure the specimens, but obtained a photograph of one, which was sent to F. B. Meek, who stated that it was not possible to determine whether the ammonite belonged to the genus *Ammonites* or *Ceratites*.

Another ammonite was found near Colfax in a cut of the Central Pacific railroad. I am informed that this specimen—*Ammonites (Perisphinctes) colfaxi*, Gabb—is now in Cambridge. Dr. Cooper Curtice and Mr. Waldemar Lindgren have also obtained ammonites and belemnites from the same slates in Eldorado and Placer counties.

An ammonite was obtained by the writer from Mr. J. W. Glass, given him by a miner as being found on a branch of Cherokee creek, in Calaveras county. The rock in which this ammonite was imbedded is a diabasic slate, and similar slate occurs along the branch of Cherokee creek where the fossil is said to have been found.

I saw in the collection of Mr. Smith, of Sutter Creek, Amador county the impression of an ammonite on black slate said to have come from the shaft of the Lincoln quartz mine, near by. The slate is precisely like the slate in which the Lincoln mine is situated.

In 1887 I obtained from Mr. F. F. Barrs, of Placerville, a piece of slate on which is an impression of an ammonite. It was collected by Mr. G. W. Kimble in Big canyon, north of Placerville. The specimen is now in the National Museum.

The most interesting locality discovered of late years is the Texas ranch, which lies about 2½ miles southwest of Angels, in Calaveras county, to the west of Angels creek. This was first made known to the Geological Survey by Mr. C. D. Voy. The following fossils were collected by Mr. Voy and Dr. Cooper Curtice, and determined by Dr. White and Prof. Hyatt:

Aucella erringtoni Gabb.
Belemnites pacificus Gabb.
Cardioceras.
Amaltheus.
Perisphinctes.

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[1] Prof. Hyatt says in a letter that this ammonite now in Cambridge is a species of *Perisphinctes*.

[2] Auriferous Gravels, p. 37.

[3] Proc. Cal. Acad. Sci., Vol. III, p. 167, Sept. 5, 1864.

The last three genera belong to the *Ammonitidæ*.

Perisphinctes was also found on the Stanislaus river opposite the mouth of Bear creek; by the road from Copperopolis to Sonora, on the grade west of Angels creek; and near Reynold's ferry on the Stanislaus opposite Bostwick's bar, these three localities being not far south of the Texas ranch; and also at Moffat's bridge on the Tuolumne river.

There is some difference of opinion as to the age of the Mariposa slates. They are regarded by the writer as Jurassic. Dr. C. A. White considers the age to be lower Cretaceous, holding that the Aucellæ in the Mariposa slates and those in the Knoxville beds (Neocomian) of the coast ranges belong to the same species, while recognizing that this species is an extremely variable one. Dr. White admits, however, the close resemblance of some of the ammonites to the Jurassic forms of Europe.

Prof. Hyatt[1] considers the *Aucellæ* of the Mariposa beds to be distinct species from those in the coast ranges, and regards the ammonites as closely related to Jurassic types of Europe. He therefore calls the beds Jurassic.

Prof. J. P. Smith, of Stanford University, has recently brought together the published evidence of the age of the Mariposa slates, supplemented by observations of his own. He considers[2] these slates to be of upper Jurassic age, and reached this conclusion before the publication of Prof. Hyatt's views.

Outside of the paleontological evidence there are certain facts in the physical geology of the Knoxville and Mariposa beds which lead the writer to believe the latter to be the older.

The Knoxville beds consist of sandstones and shales which are never greatly altered; at least this is true of all fossiliferous portions of these beds where alone the age is certain. The strata have nowhere been greatly compressed, so that no slaty structure has been developed. The *Aucellæ* and other fossils found in the Knoxville beds have seldom been compressed or otherwise distorted. They not only usually present their proper form, but the original shells of the fossils are generally present. The strata have nowhere, so far as known, been intruded by granite or diabase, although serpentine dikes occur in them.

The Mariposa beds, on the other hand, have been greatly compressed, in places forming a good roofing slate; the fossils in them also show compression, and the original shells of the fossils have in all cases disappeared. The strata are moreover intruded by diabase and granite. The fact of the Mariposa slates being intruded and metamorphosed by granite was first made known by Mr. W. Lindgren, who found the Mariposa slates on the American river east of Folsom to be converted into mica-schists by the heat of the adjoining granite. His results, however, were not published.

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[1] Am. Jour. Sci., Vol. XLVII, p. 143, Feb. 1894.

[2] Bull. Geol. Soc. Am., Vol. V, pp. 243–258.

Later Mr. Fairbanks[1] stated that "a great mass of eruptive granite extends down from the high sierras, cuts across all the other formations, both sedimentary rocks and dikes, and terminates 5 miles west of the town of Mariposa. The dikes as a usual thing do not extend up to the granite, but the schists and slates abut against it for a distance of 20 miles, and in the vicinity of the eruptive mass they are greatly broken and metamorphosed."

The Mariposa slates form an integral part of this 20-mile slate belt here described. In December, 1893, the writer examined the region about Mariposa and corroborated the main facts indicated by Fairbanks. The granite, however, does not cut entirely across the auriferous slate series to a point 5 miles west of Mariposa. The granite of the high sierras is separated from the area south of Mariposa by a tongue of mica-schist and greenstone-schists which extends southeast across the Chowchilla to the mining camp of Grub gulch and beyond. The width of this schist tongue is from 1 to 3 miles where crossed by the writer, and it may extend continuously southeasterly to the Kaweah river sedimentary series and beyond. Although this has not been demonstrated, it is known that schists occur at several intermediate points. There is no possible doubt, however, of the Mariposa slates being older than the large granite area south of Mariposa, which extends from Mormon bar as far south as the San Joaquin river, at the edge of the foothills. This large granite mass may be of the same age as the granodiorite mass that lies to the east of the schist belt above described, but it does not as a rule contain hornblende, while the granodiorite or granite to the east of the schist belt is, at most points seen by the writer, hornblendic.

The Mariposa slates west of Mariposa, where they terminate, abutting against the granite, have been pushed out of their normal northwesterly strike near the granite, in places striking east and west. They have, moreover, been converted into mica-schists which at some points, as in Yaqui gulch, carry small andalusite crystals, and according to Fairbanks the clay slates one-fourth of a mile from the granite contain crystals of fibrolite.

In the lower foothills in Madera and Mariposa counties is a belt of mica-schist, portions of which carry large andalusite (or more properly chiastolite) crystals in great abundance. Attention was called to this schist belt many years ago by Prof. Blake. Andalusite crystals 3 inches or more in length and half an inch or more in diameter are abundant in mica-schist at the Ne Plus Ultra copper mine on Daulton's ranch, about 10 miles northeast of Berenda. The andalusite crystals weathered out from the schist are scattered over the surface of the ground. A bed of almost horizontally bedded conglomerate, probably of Miocene age, that caps a schist hill, perhaps 2 miles northwest of Daulton's, contains numerous andalusite crystals. This

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[1] Am. Geologist, 1891, p. 211.

mica-schist belt at Daulton's is about 2 miles wide; further north, on the Chowchilla river, the width is perhaps 4 miles. Andalusite schists have been formed, as above noted, from the clay-slates of the Mariposa beds west of Mariposa, and it is considered possible that the schists above described represent the south end of the western belt of the Mariposa formation. The general strike of this belt of clay-slates would carry it into the Chowchilla mica-andalusite-schist area.

The Mariposa slates form an integral part of the auriferous slate series. The dip of the slates is usually from 70° to vertical. At Folsom, a little west of the bridge over the American river, are nearly horizontal unaltered sandstones containing Chico fossils; while not far east of the bridge are the contact mica-schists of the Mariposa formation, dipping at a high angle. No more conspicuous unconformity exists in the Sierra Nevada than that between these unaltered Chico strata and the neighboring metamorphic schists of the Mariposa formation. The possibility suggested by Mr. Diller,[1] that the upheaval of the Mariposa beds occurred after the Chico or Miocene beds were deposited, can not be entertained.

THE MARIPOSA-CALAVERAS UNCONFORMITY.

While mapping the geology of the Jackson sheet, the writer obtained proof of the unconformity of the Mariposa formation on the Calaveras formation in the neighborhood of Bear mountain, in Calaveras county. The accompanying map of the district (Pl. XLIX) shows the distribution of the formations. The evidence of the unconformity consists:

First, in the lithologic differences of the two formations, the Mariposa slates consisting uniformly of black clay-slates, which contain locally thin layers of diabase tuff and some conglomerate, while the Calaveras formation is made up of a variety of rocks, clay-slates, quartzite, and phthanite,[1] with lenses of limestone.

Second, in the occurrence in the Mariposa slates of conglomerate largely made up of phthanite pebbles precisely like the phthanite of the Calaveras formation.

Third, in the occurrence of a narrow streak of the Mariposa slates cutting across the Calaveras formation with a slight diversity in strike.

Fourth, in a paleontologic break, the Calaveras formation representing the Carboniferous, and probably the lower Carboniferous, while the Mariposa slates are of late Jurassic or early Cretaceous age.

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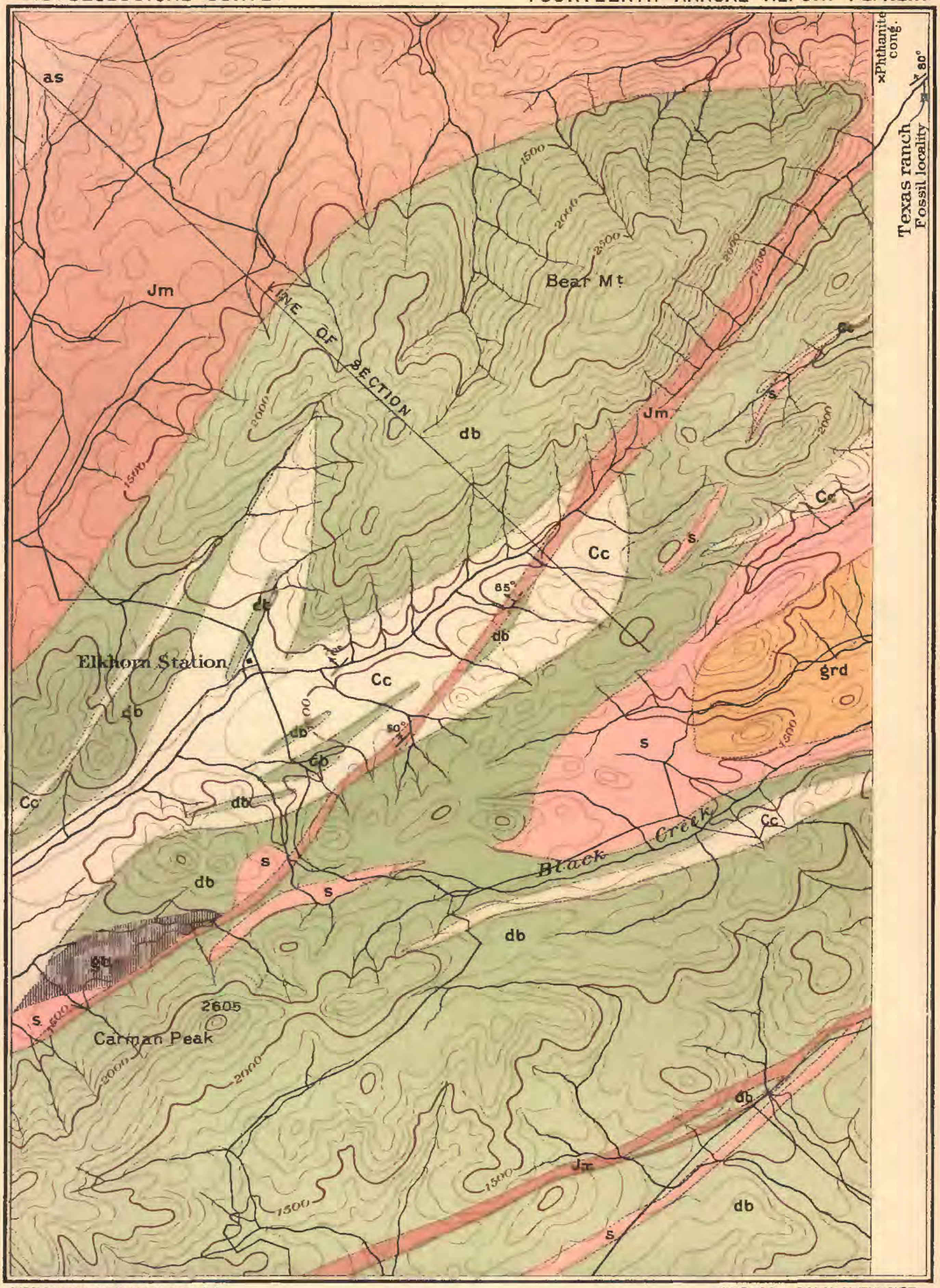
[1] Bull. Geol. Soc. Am., Vol. IV, p. 122.

[1] The term phthanite is used by the writer to include all the very fine grained siliceous rocks which have not been subjected to sufficient pressure to be rendered schistose, and in which the silica is perhaps largely secondary. As thus defined the term would include siliceous schist. The phthanites are thought by some authors to have been originally shales and limestones. The red and green jaspery rocks of the Coast ranges belong here, as also does the Lydian-stone, or Kieselschiefer of authors. Sir Archibald Geikie, in his Manual of Geology, says that as these last rocks have not been materially altered they may be present an original deposit of silica.



TOPOGRAPHY BY R.H.MCKEE. GEOLOGY BY W.H.TURNER.

JURA-TRIAS AND OLDER					JURASSIC	CARBONIFEROUS
grd	gb	s	db	as	Jm	Cc
Granodiorite	Gabbro	Serpentine	Diabase and amphibolite schist	Amphibolite schist	Mariposa beds	Calaveras formation

Scale $\frac{1}{62.500}$

0 1 2 miles

Contour interval 100 ft.

GEOLOGICAL MAP OF BEAR MOUNTAIN AND VICINITY.

CALIFORNIA

JULIUS BIEN & CO. N.Y.

The narrow streak of the Mariposa slates, referred to under the third heading, seems certainly to have been deposited in a trough between preexisting ridges of the Calaveras formation, and to have been folded up with the rocks of the Calaveras formation at the time of the post-Mariposa upheaval. Evidence similar to this may also be obtained by noting the strike of the two main belts of the slates.

The eastern belt is said to terminate to the south near Bridgeport, in Mariposa county, where it is cut off and metamorphosed by the granite, and to the north, according to Mr. Lindgren, north of Colfax, having thus a length of about 120 miles, and a width varying from one-half mile to 2 miles or more. The strike of this belt, as a whole, is northwesterly from its south end to Plymouth, in Amador county; thence nearly north to near Placerville, bending again northwesterly to the north of that town. The western area has a width about the same as that of the eastern area, and a length of about 100 miles, extending from Folsom, on the American river, where it has been altered by the intrusion of the granite, to beyond Merced Falls, on the Merced river.

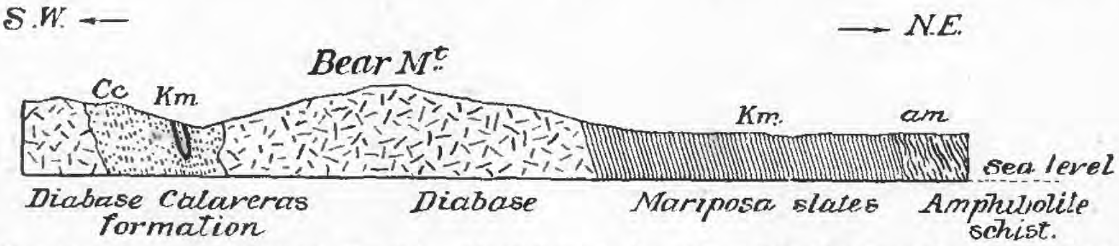


FIG. 49.—Section across Bear mountain. Cc, Calaveras formation; Km, Mariposa formation. Horizontal and vertical scales, about 7,400 feet to the inch.

The strike of this western belt is northwesterly throughout its entire course, and the strike of the slates in both belts corresponds nearly everywhere with the trend of the belts, the dip being usually to the east at an angle of 50° or more. The two belts have thus a nearly parallel trend till in the latitude of Plymouth, where the northward turn of the eastern belt causes them to diverge so that across the strike at Folsom the belts are 18 miles apart, while at Plymouth they are only about 6 miles apart.

This divergence is perhaps in part due to the intrusion of igneous rocks at the time of the post-Mariposa upheaval, but chiefly, so it appears to the writer, to the two belts having been laid down in two long troughs between preexisting ridges of the Calaveras formation.

The phthanite conglomerate occurs at the south end of Bear mountain, only about one-fourth mile north of the Texas ranch fossil locality, and in the narrow streak of slates 1 mile west of Elkhorn station, where it forms a bed a few feet in thickness and about 1 mile in length. Where the narrow strip of Mariposa slates crosses the area of the Calaveras formation, springs were noted at the contact at two or three points, suggesting a fracture or an unconformity. This narrow strip was followed on foot from the Texas ranch to the conglomerate bed west of Elkhorn station in order to make sure of its continuity.

The section across Bear mountain (Fig. 49) shows this narrow strip of Mariposa slates as a syncline folded in with the Calaveras beds. The same structure may apply as well to the larger belt of Mariposa slates to the east of Bear mountain if, as suggested, this belt was also deposited in a long trough between ridges of the Calaveras formation and was subsequently folded in with the Calaveras beds. But of this there is no proof.

The depth to which this wide belt extends is unknown. In the canyon of the Stanislaus river, five miles to the south of the line of the section, at an altitude above sea level of about 800 feet, the Mariposa slates are well exposed and still dip at an angle as steep as, or steeper than that on the ridge where the section was drawn. In the Plymouth Consolidated quartz mine, in Amador county, which has a surface altitude of 1,050 feet above the level of the sea, the lowest level of the mine in 1888 was 1,600[1] feet below the surface, or 450 feet below the level of the sea; and judging from a cursory examination, inspection of the dumps of the mine, and the descriptions in the reports of the State mineralogist, this lowest level was still in the Mariposa slates. If the mining shafts along the Mother Lode ever attain a great depth they should, if the relations of the Mariposa and Calaveras formations have been correctly interpreted by the writer, penetrate through to the underlying Calaveras formation.

However, these relations have been complicated by the intrusions and eruptions of rocks of the diabase and porphyrite series. These intrusions and eruptions appear to have commenced in Carboniferous time and to have continued up to the time of the post-Mariposa upheaval.

SUPERJACENT SERIES.

CHICO FORMATION.

The rocks of this series are yellowish sandstones and dark shales. In the area of the Gold Belt they occur only in the foothill region, lying almost horizontally on the auriferous slate series and the older igneous rocks.

The most southern locality in the Gold Belt from which it has been reported is at Folsom, where the little altered sandstones on the north side of the American river, opposite the town, afforded the State Geological Survey[1] the following:

Ammonites suciaensis Meek.
Ancyloceras ? lineatus Gabb.
Chione varians Gabb.
Trapezium carinatum Gabb.
Inoceramus whitneyi Gabb.
Exogyra parasitica Gabb.

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[1] Eighth Ann. Rep. State Mineralogist of California, p. 44.

[2] The lists of Chico fossils given here, except those determined by Mr. Stanton, are compiled from Gabb's "Synopsis of the Cretaceous Invertebrate Fossils of California." Paleont. Cal., Vol. II.

At another locality, formerly known as Texas Flat, now said to be called Rock Corral, about 2½ miles northwest of Folsom, the following fossils from strata struck in a shaft at 40 feet from the surface were collected by Dr. Trask, and determined by Dr. Gabb:

Anchura falciformis Gabb.
Lysis duplicosta Gabb.
Gyrodes expansa Gabb.
Straparollus paucivolvis Gabb.
Calliostoma radiatum Gabb.
Emarginula radiata Gabb.
Helcion dichotoma Gabb.
Cylichna costata Gabb.
Corbula traski Gabb.
Cymbophora ashburneri Gabb.
Tellina monilifera Gabb.
Meretrix longa Gabb.
Clisocolus dubius Gabb.
Lucina subcircularis Gabb.
Trigonia evansana Meek.
Axinæa veatchi Gabb.
Nucula truncata Gabb.
Pecten traski Gabb.
Exogyra parasitica Gabb.
Littorina compacta Gabb.
Sycodes cypræoides Gabb.
Discohelix leana Gabb.
Straparollus lens Gabb.
Angaria ornatissima Gabb.
Patella traski Gabb.
Cinulia obliqua Gabb.
Martesia clausa Gabb.
Asaphis undulata Gabb.
Chione varians Gabb.
Cardium placerensis Gabb.
Lucina postice-radiata Gabb.
Astarte conradiana Gabb.
Cucullæa truncata Gabb.
Nucula solitaria Gabb.
Limopsis transversa Gabb.
Anomia lineata Gabb.

A very prolific locality of Chico fossils is near Pentz post-office formerly known as Pence's ranch. The State Geological Survey reports the following from that place:

Ammonites remondi Gabb.
Helicoceras brewerii Gabb.
Ancyloceras? quadratus Gabb.
Perissolax brevirostris Gabb.
Volutilithes navarroensis Shumard?
Chemitzia planulata Gabb.
Potamides diadema Gabb.
Cylichna costata Gabb.
Corbula traskii Gabb.
Pholadomya breweri Gabb.
Lutraria truncata Gabb.
Tellina ooides Gabb.
Tellina ashburneri Gabb.
Astarte tuscana Gabb.
Trigonia evansana Meek.
Axinæa veatchi Gabb.
Anomia lineata Gabb.
Ammonites chicoensis Trask.
Helicoceras declive Gabb.
Baculites chicoensis Trask.
Haydenia impressa Gabb.
Gyrodes expansa Gabb.
Anchura falciformis Gabb.
Cinulia obliqua Gabb.
Martesia clausa Gabb.
Anatina lata Gabb.
Cymbophora ashburneri Gabb.
Tellina hoffmaniana Gabb.
Tellina decurtata Gabb.
Chione varians Gabb.
Modiola cylindrica Gabb.
Meekia navis Gabb.
Nucula truncata Gabb.

The following from near Pentz were collected chiefly by H. W. Turner and determined by T. W. Stanton. The locality is near the flume of an irrigating ditch to the south of Dry creek and about 1½ miles southeast of Pentz. Many of the fossils occur in a conglomerate made up largely of porphyrite pebbles from the older rocks of the Sierra Nevada:

Locality 405, National Museum collection; Chico fossils from Pence's ranch, Butte county.

Lutraria truncata Gabb.
Tellina ooides Gabb.
Mactra ashburneri Gabb
Mactra sp. undet.
Corbula traski Gabb.
Arca sp. undet.

Mytilus sp. undet.
Perna excavata White.
Pectunculus veatchi Gabb.
Anomia lineata Gabb.
Nucula truncata Gabb.
Trigonia leana Gabb.
Haydenia impressa Gabb.
Crassatella tuscana Gabb.
Ceratia nexilia White. Type of species.
Cominella lecontei White. Type of species.
Fulgur hilgardi White. Type of species.
Actaeon inornatus White. Type of species.
Mesalia obsuta White. Type of species.
Perissolax brevirostris Gabb.
Eripachya ponderosa Gabb.
Cinulia obliqua Gabb.
Potamides tenuis Gabb.
Gyrodes conradiana? Gabb.
Scalaria mathewsoni? Gabb.
Cylichna costata? Gabb. Young shells.
Scobinella dilleri White. Young shell.
Baculites chicoensis Trask. Small fragments.

Locality 398*a* (in part), National Museum collection; below Centerville, on Butte creek in Butte county; collected by T. W. Stanton and H. W. Turner; determined by T. W. Stanton.

Inoceramus.
Cucullæa truncata Gabb.
Pectunculus veatchi Gabb
Nucula truncata Gabb.
Trigonia evansana Meek.
Trigonia (Meekia) navis Gabb.
Trigonia leana Gabb.
Chione varians Gabb.
Cytherea nitida Gabb.
Cytherea longa Gabb.
Tellina ashburneri Gabb.
Tellina ooides Gabb.
Tellina n. sp.
Clisocolus cordatus Whiteaves.
Crassatella tuscana Gabb.
Cardium (Protocardia) placerensis Gabb.
Modiola sp. undet.
Luttaria truncata Gabb.
Pholadomya breweri Gabb.
Gyrodes expansa Gabb.
Anchura falciformis.
Turritella veatchi Gabb.
Mesalia obsuta White.
Martesia clausa Gabb.
Mactra (Cymbophora) ashburneri Gabb.
Mactra n. sp.
Dentalium cooperi Gabb.
Dentalium stramineum Gabb.
Potamides tenuis Gabb.
Ceratia nexilia White.
Faunus marcidulus White. Type of the species.
Rostellites gabbi White. Figured specimen.
Perissolax brevirostris Gabb.
Eripachya ponderosa Gabb?
Fusus averilli Gabb.
Cylichna costata? Gabb.
Actæon sp. undet.
Baculites chicoensis Trask.
Ammonites chicoensis Trask.
Ammonites n. sp.

Locality 398; National Museum collection; Chico creek, 10 miles from the town of Chico; collected by H. W. Turner (Butte county, No 4); determined by T. W. Stanton.

Pecten sp. undet. A small cast.
Inoceramus whitneyi Gabb.
Chione varians Gabb.
Crassatella tuscana Gabb.
Mactra (Cymbophora) ashburneri Gabb.
Mactra sp. undet.
Cardium (Protocardia) placerensis Gabb.
Clisocolus dubius Gabb.
Ceratia nexilia White.
Gyrodes expansa Gabb.
Perissolax brevirostris Gabb.
Cinulia obliqua Gabb.
Rostellites gabbi White.
Sycodes cypræoides Gabb.
Baculites chicoensis Trask.
Ammonites newberryanus Meek.
Ammonites sp. undet.

The following are given by Dr. Gabb in the Synopsis of Cretaceous Fossils as from Chico creek:

Callianassa stimpsoni Gabb.
Ammonites chicoensis Trask.
Baculites chicoensis Trask.
Volutilithes navarroensis? Shumard.
Anchura falciformis Gabb.
Turritella chicoensis Gabb.
Cinulia obliqua Gabb.
Cymbophora ashburneri Gabb.
Lutraria truncata Gabb.
Chione varians Gabb.
Caryatis nitida Gabb.
Dosinia inflata Gabb.
Clisocolus dubius Gabb.
Trigonia evansana Meek.
Meekia navis Gabb.
Nucula truncata Gabb.
Anomia lineata Gabb.
Trochosmilia granulifera Gabb.

TEJON FORMATION.

So far as known, strata containing shells characteristic of the Tejon formation have been found in the Gold Belt region only at the Marysville buttes, where they were discovered by Mr. Lindgren.

The Tejon formation is not known to occur in the foothills of the Sierra Nevada, between the Marysville buttes and the Tejon ranch in the Tehachapi range, where the horizon was first recognized by Conrad.

OCOYA CREEK BEDS.

As geologist to the Pacific railroad explorations, Prof. W. P. Blake[1] reported extensive deposits of Miocene age in Tulare county, extending from White river to Ocoya or Posé creek, and beyond to Kern river.

On Ocoya creek numerous casts of shells were found and drawings of these were made and sent with some specimens to Mr. Conrad, who named a number of the fossils.

As there is a probability that all of these fossils can not hereafter be recognized, the following only are given, these having been identified by Mr. Gabb. The list is compiled from Gabb's Synopsis of the Tertiary Invertebrate Fossils of California:[2]

Agasoma gravida Gabb; = undet. Conrad.
Natica reclusiana Gabb; = ocoyana Conrad.
Pecten catilliformis Conrad.

A considerable number of sharks' teeth were also found and studied and named by Prof. Louis Agassiz.

Prof. Whitney[3] says of this formation that the Tertiary sandstones form "low, rounded hills from 200 to 600 feet high, the rock being soft and chiefly made up of granitic detritus, evidently derived from the mountains to the east, and having a low dip to the west, generally less than 6°, and often horizontal. * * * The upper portions of some of the hills are, however, of a later formation and of fresh water origin, as they contain fragments of bone and wood." It is possible that these upper fresh water strata represent the Ione formation.

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[1] Pacific Railroad Reports, Vol. v, pp. 164-173.
[2] Paleontology of California, Vol. II.
[3] Geology of California, Vol. I, p. 201.

IONE FORMATION.

This term was first used by Mr. Waldemar Lindgren in the descriptive text of the Sacramento sheet for the beds of clay and sand with layers of lignite that occur along the foothills of the Sierra Nevada, especially in the Gold Belt region, and seem to have been deposited at the same time as the earlier auriferous river gravels, which are usually composed of white quartz pebbles. The series is best developed in the vicinity of Ione. The sandy layers are frequently consolidated into a firm sandstone and the clay into a friable clay rock.

The formation had, however, been previously recognized by Prof. Whitney.[1] Of the deposits about Ione he says:

> The clays are of various colors—white, red and purple; of the white a good deal has been sold and used for paint. These strata are superior in position to the sandstones immediately about Ione, which latter are divided into two portions. The lower of these is made up of a series of white, pink, and red sandstones, while the upper is a highly ferruginous rock and is about 20 feet thick. This member of the formation contains so much iron in places as to become a tolerable ore; in other localities it becomes a quartzose breccia cemented by brown oxide of iron. It is quarried to some extent for walls and fences. * * * The lower division of the sandstone is of especial interest as containing a bed of lignite, or imperfect coal, which has been worked to some extent. The locality is about 2 miles south of Ione, near the Stockton road. This coal is associated with beds of white clay. * * * The upper stratum was a white argillaceous sandstone containing a number of fossil leaves in a good state of preservation, one of which was 18 inches long; unfortunately these had not been preserved. Below this was a bed of white clay with traces of vegetable matter; under this a seam of bituminous shale 1 foot thick, succeeded by a bed of sandstone with a thin layer of coal at the bottom, then a bed of clay, under which was the coal stratum, 7 feet thick in its maximum development. Below the coal is a bed of sandstone which has not been penetrated to the bottom.

The above observations appear to have been made chiefly by Mr. Rémond. Since the publication of the above coal has been struck at many places near Ione. At coal mine No. 3, 4 miles northwest of Ione, there is a lignite stratum about 7 feet thick which has a dip from 5° to 7° to the south. Overlying the coal seam there is about 60 feet of sand and clay, in which is a layer containing imperfect fossil leaves. Some of these were collected by the writer. These are mostly very poorly preserved, but certain very numerous coniferous leaves probably belong to the cypress family.

At a point to the north of the mine the sandy clay underlying the coal was penetrated to the depth of about 800 feet without finding another coal seam. Nearly all of the valley between Ione and Carbondale is underlain by this lignite layer, as has been determined by borings and shafts. It has been mined also near the railroad west of Ione, and it is one of these mines that is referred to by Prof. Whitney. Some shafts in the hills north of Lancha Plana have struck coal, pre-

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[1] Geology of California, Vol. I, p. 269.

sumably an extension of the Ione bed. The Ione lignite does not bear transportation well. It is used on the railroad and on the Stockton steamers.

According to the Eighth Annual Report of the State Mineralogist of California, pages 110–112, there are three coal seams underlying the Ione valley, of which the lower, which is the one described, is the most valuable. This varies in thickness, according to the report, from 9 to 13 feet. This report also gives more exact data about the clay deposits. It should be noted that the white clays, so much quarried between Ione and Carbondale, and used in the manufacture of pottery, underlie the Ione sandstone series, and are not to be confused with the clay rock or feldspathic tuff that overlies the sandstones. The older white clays are of about the same age as the coal deposits.

Two miles west of Ione there is a considerable deposit of impure hematite in the Ione formation.

The Ione beds are well developed also at Lincoln, in Placer county, where there is some coal; and where the clay is used on a large scale for the manufacture of coarse pottery. The clay is also quarried extensively near Carbondale for the manufacture of pottery, and to a less extent at Valley Springs.

The rocks of the Ione formation form a poor soil, which supports a growth of brush, with scattered trees or none at all. The Ione formation has been traced north into Butte county, where it underlies the basalt of Oroville Table mountain and is said to contain seams of lignite in Coal canyon on the west side of the mountain.

In the clay of the Ione formation at the Miocene hydraulic mine, at the east end of South Table mountain, I obtained some impressions of leaves of deciduous trees, and others were obtained by Mr. Diller from the clay exposed at the north end of Table mountain by hydraulic mining. Mr. Diller's specimens were examined by Prof. Ward, who states:[1] "If it were certain that the specimen is either *Cinnamomum* or *Paliurus* I should say that it could scarcely come from a higher horizon than the Miocene, and more likely from a lower. But the specimen may possibly represent a *Populus* unlike any modern form."

At the west base of the north end of Table mountain, about 1 mile south of Pentz, the writer collected casts of a strongly concentrically ribbed shell associated with stems of fossil plants. The shells were determined by Dr. White and Mr. Stanton as belonging to *Corbicula*, a genus found only in fresh and brackish waters. The *Corbicula* bed overlies sandstones containing abundant Chico fossils, and underlies the white shales and clay of the Ione formation that is capped by the basalt of Table mountain. It is possible that the *Corbicula* bed represents the Eocene period, and possibly the Puget group of Washington.[2]

Mr. W. Lindgren has found a series of beds of clay and sandstone

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[1] Bull. No. 33, U. S. Geol. Survey, p. 16.

[2] Since the above was written Mr. Stanton has visited this locality, and is inclined to think that the age of the deposit is Miocene.

with layers of lignite at the Marysville buttes, which he considers to represent the Ione formation. From these beds he collected some marine shells, said by Dr. W. H. Dall to be of Miocene age.

Very characteristic of the sandstone of the Ione formation are pearly scales of a foliated mineral allied to kaolin. In some cases these scales are colored red by hematite, as in the red sandstone at the quarry southeast of Ione. The mineral under the microscope shows very low polarization colors and seems to extinguish parallel to the basal cleavage lines. Dr. W. F. Hillebrand separated some of this micaceous mineral by means of the heavy solution and made the following analysis:

	Per cent.		Per cent.
Silica	55.88	Potash	.42
Titanic acid	.50	Soda	.34
Alumina	30.24	Water below 100° C	.63
Ferric oxide	.42	Water above 100° C	11.72
Ferrous oxide	.16		
Lime	Trace.	Total	100.31

A microscopic examination of the material analyzed showed only a few particles of quartz in the field of view. The foliated mineral comprised all the remainder of the material. Perhaps 1 or 2 per cent might be deducted for the silica of these quartz grains.

This mineral appears to resemble rectorite[1] in composition, but does not show any strong double refraction.

Prof. S. L. Penfield has kindly examined this silicate of aluminum, and writes that, as it "is not clear and transparent, it is impossible to to be sure that it does not contain microscopic quartz or chalcedony silica deposited on it," and is inclined to consider the mineral an impure kaolinite, notwithstanding the high percentage of silica.

The writer has found it practicable to divide the Ione formation into the following beds, beginning at the lowest:

(*a*) The white clay and sand beds which contain coal seams. As before stated, this portion of the series is said to be 860 feet or more in thickness at coal mine No. 3.

(*b*) Sandstone, usually white in color, but sometimes red, and occasionally passing over into a quartz conglomerate. Along the banks of the Mokelumne river, west of Lancha Plana, this sandstone attains a thickness of more than 100 feet. This is Whitney's Upper Sandstone.

(*c*) Clay rock, or tuff, overlying the sandstone. This is light in color, but usually more or less discolored. The fracture is irregular as a rule, and it frequently contains minute tubular passages. Under the microscope it is seen to be composed of fine particles of feldspar and minute discolored fragments, with some quartz grains. The Ione clay rock is best developed to the west of Valley Springs, attaining a thickness of more than 100 feet.

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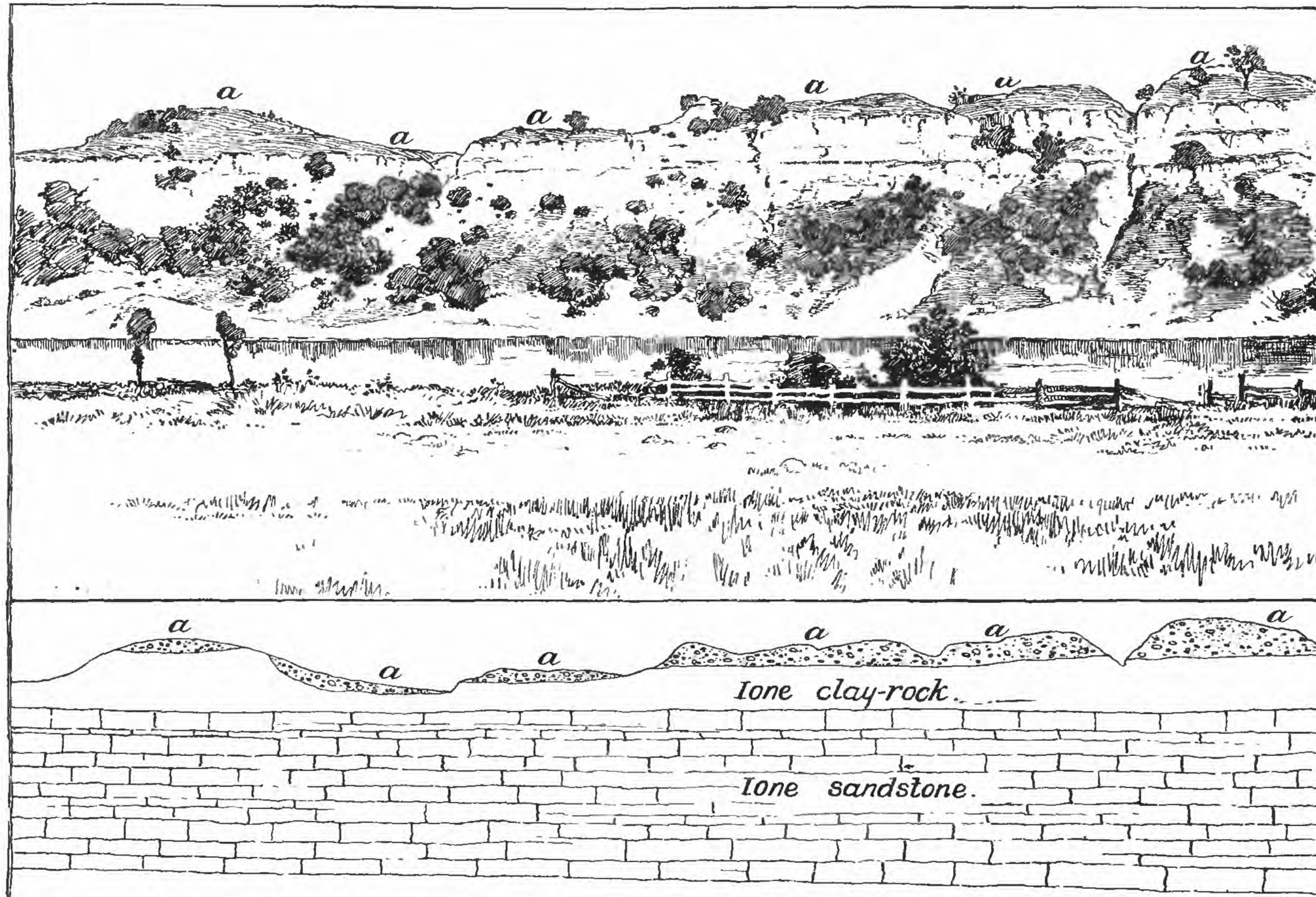
[1] Am. Jour. Sci., 3d series, Vol. XLII, p. 11.



IONE FORMATION NEAR CAMANCHE.

a. Overlying Pleistocene gravels.

The following are partial analyses of Ione clay rocks:

	Silica	Potassa	Soda
No 276, Calaveras county	52 15	1 17	1 27
No. 295, Calaveras county	59 14	2 49	2 38
No 302, Calaveras county	62 32	....	....
No 131, Amador county	72 11	1 30	32

The above determinations were made by E. A. Schneider and W. F. Hillebrand.

It will be seen from the above that the Ione formation attains a thickness of more than 1,000 feet.

The relation of the Ione sandstone and the Ione clay rock is finely seen on the south side of the Mokelumne river by the Camanche bridge (see Pl. L). Here the sandstone forms the lower part of the bank of the river. The upper surface of the sandstone has a gentle westerly dip, and a little west of the bridge reaches the level of the river, which at this point is about 175 feet above sea level. To the east of the bridge it rises at an angle of about 1 degree, reaching an altitude of 1,000 feet on the flat ridge just north of Valley Springs. Directly overlying the sandstone is the clay rock, or tuff, and forming a mantle to the irregular eroded surface of the series are Pleistocene gravels.

Sandstone quite like that of the Ione formation on the Jackson sheet was observed by the writer capping the flat-topped hills south of Merced Falls and at the edge of the Sierra Nevada foothills northeast of Madera. To the southwest of Merced Falls, along the road on the south side of the Merced river, the Ione clay-rock constitutes the lowest formation exposed. As farther north this is here capped on the plateaus by andesitic sandstone, as may be seen south of Snelling, and is covered in the eroded depressions by Pleistocene siliceous shore gravels. How much farther south the Ione formation extends is not known, but it is likely that it may be correlated later with some portion of the beds on Ocoya creek.

AURIFEROUS RIVER GRAVELS.

Under this term have been included on the maps of the Gold Belt the Neocene river gravels, which occur chiefly on the ridge tops where they were deposited, in what were then valleys, before the present deep canyons of the range were cut. These gravels are of different ages, but may be divided into two main groups:

First, the older gravels, composed chiefly of white quartz pebbles, and frequently capped by rhyolitic tuff. These may be characterized in a broad way as the gravels formed before the volcanic period.

Second, a later series, containing volcanic pebbles, chiefly of andesite, and later in age than the rhyolitic tuff. These may be called gravels of the volcanic period. Such gravels are often capped by andesite tuff.

Since there must have been rivers during the entire time of the deposition of the Neocene river gravels, it follows that gravel beds must exist which could not be referred definitely to either of these classes, but in the areas indicated in the introduction the writer has in practice found it possible to distinguish the two classes as above.

The gravels underlying the rhyolite tuff, on the geological map of Golden Gate mountain, belong to the older gravels, and the area in the southwest corner of the same map is an example of the later volcanic series. These later gravels contain, in addition to the volcanic pebbles, a great variety of pebbles of the older igneous and metamorphic rocks.

In layers of fine detritus, called by the miners pipe clay, impressions of leaves are often found in a sufficiently good state of preservation to be accurately described. Considerable collections of these have been made and studied, chiefly by Prof. Leo Lesquereux.

The following localities occur within the areas, indicated in the introduction, in which the writer is engaged in mapping the geology:

Locality, Tuolumne Table mountain; elevation of the leaf beds about 1,800 feet; collected by C. D. Voy;[1] determined by Prof. Lesquereux:[1]

Acer bendirei Lx.
Cercocarpus antiquus Lx.
Fagus antipofi Abich.
Ilex prunifolia Lx.
Persea pseudo-carolinensis Lx.
Rhus typhinoides Lx.
Rhus boweniana Lx.
Rhus metopioides Lx.
Rhus dispersa Lx.
Aralia zaddachi? Heer.
Cornus ovalis Lx.
Ficus microphylla Lx.
Platanus dissecta Lx.
Quercus elænoides Lx.
Quercus convexa Lx.
Salix californica Lx.
Ulmus californica Lx.
Ulmus affinis Lx.

Locality, No. 29, Tuolumne county. These specimens were given the writer as coming from the Buchanan tunnel, about 2 miles west of Columbia; the material is quite like the pipe clay of Tuolumne Table mountain, and doubtless forms part of the same deposit; determined by Prof. Knowlton:

Persea pseudo-carolinensis Lx.
Ulmus californica Lx.

Locality, Spanish peak, Plumas county, from the Monte Christo gravel mine; elevation about 6,300 feet; collected by J. S. Diller; determined by Prof. Lesquereux:[2]

Acer bendirei Lx.
Laurus californica Lx.
Myrica ungeri Heer.
Platanus dissecta Lx.
Pterospermites spectabilis Heer.

Locality, Mohawk lake beds, the older Neocene beds, on which the later Pleistocene lake beds rest unconformably; collected by H. W. Turner; determined by Prof. F. H. Knowlton. This lake probably represented a widening of the Neocene middle fork of the Feather river, and hence these leaves may serve as a criterion of the age of the river gravels. The occurrence of fossil leaves from Mohawk valley was noted sometime since.[3] The leaves occur at two localities, which are therefore distinguished:

Locality 115, Plumas county; elevation, 4,500 feet. These leaves are from fine grained shales, overlain by andesitic breccia, on the ranch of Abel Jackson, on the

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[1] Memoirs Mus Comp. Zool., vol. 6, No. 2.
[2] Eighth Ann. Rept. Director U. S. Geol. Survey, p. 420.
[3] Bull. Phil. Soc. of Washington, Vol. XI, p. 391.

east side of Mohawk valley. The locality is on the south bank of the middle fork of the Feather river, and just west of a little meadow from which issue sulphur springs:

Juglans egregia Lx.
Juglans californica? Lx.
Ulmus californica Lx.
Ulmus pseudo-fulva Lx.
Quercus distincta Lx.
Quercus nevadensis? Lx.
Persea punctulata Lx.
Persea pseudo-carolinensis Lx.

Magnolia lanceolata Lx.
Populus zaddachi Heer.
Laurus californica Lx.
Alnus cf. A. kefersteinii.
Rhus metopioides Lx.
Pinus sp.
Ficus?
Carya sp.

Oak leaves are very abundant in this collection, according to Prof. Knowlton, who considers that two new species are represented.

Locality 114, Plumas county; altitude, 4,500 feet. From beds that are probably of the same horizon as No. 115. They occur on the east bank of the middle fork of the Feather river, about 1,000 feet upstream from locality No. 115. The beds are overlaid by andesitic breccia. Only one species was recognized:

Platanus dissecta? Lx.

The following fossil woods were collected by the writer at various points in the Sierra Nevada, and determined by Prof. Knowlton. Some of the specimens are not from the gravel, but from the andesitic breccia. These are included here for convenience:

Locality No. 15, Sierra Nevada collection; this is called Gravel range on the Bidwell Bar sheet of the topographical atlas. It lies on a level ridge about 6½ miles south of Buck's ranch in Plumas county, at an elevation of 5,500 feet, or 3,000 feet above the adjacent middle fork of the Feather river. This specimen of silicified wood was given the writer by the owner of the Gravel range hydraulic gravel mine, as coming from the gravel deposit, which consists of thoroughly rounded gravel. Prof. Knowlton considers the wood to be that of a coniferous tree.

Locality, Dodson's gravel mine, Butte county. This is on the south side of the Mooreville ridge and about 3 miles northwesterly from Strawberry valley. The gravel is capped by the older basalt hereafter described, but contains pebbles and bowlders of volcanic rocks; elevation, 3,800 feet. This silicified wood represents a conifer, *Araucarioxylon*.

Locality 109, Alpine county; Red Lake peak; elevation, 9,500 feet. This wood is perforated by numerous passages, evidently excavated by insects or other small creatures before the silicification took place. The wood belongs to *Cupressinoxylon*, which, as Prof. Knowlton states, is allied to *Sequoia*. This specimen came from the andesite-breccia.

Locality No. 85, Alpine county; from the andesite-breccia north of Charity valley. The wood was determined by Prof. Knowlton as *Pityoxylon*, or pine wood. Some of these specimens likewise show the borings of insects (?).

Locality, Bald hill, Calaveras county. This hill lies one-half mile northeast of Altaville. It is composed of rhyolitic and andesitic tuff, and is the locality of the famous Calaveras skull, described by Prof Whitney.[1] Two specimens of wood from this place were given the writer by Mr. Demorest, of Altaville; one of these is a piece of a trunk of an endogenous tree, perhaps a palm, and the other has been identified by Prof. Knowlton as *Araucarioxylon*.

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[1] Auriferous Gravels, p. 269. The writer has noted lately in two scientific journals the statement that the Calaveras skull came from the Tuolumne Table mountain. As may be seen by referring to Prof. Whitney's description, this is an error.

NEOCENE SHORE GRAVELS.

Overlying the Ione formation, and forming level tops to the ridges in the foothill region in Amador and Calaveras counties, are conglomerate and gravel beds, best seen to the west and southwest of Valley Springs. This conglomerate consists of a variety of pebbles—quartzite, mica-schist, quartz-porphyrite, granitoid rocks, andesite, and rhyolite being represented. Rhyolitic pebbles are in places so abundant as to be characteristic of the material.

The Neocene shore gravels are of the same age (that is, Pliocene) as the latter auriferous river gravels; as, for example, the river gravels shown in the southwest corner of the Golden Gate hill map, near Cottage Springs. They appear, however, to have been deposited in the waters of the gulf that formerly filled the great valley of California, and may represent in part a delta formation. This is probably the case with a portion of the gravels about Valley Springs, which connect directly with the great Neocene river gravels of Cottage Springs and Central Hill.

In a cut of the San Joaquin and Sierra Nevada railroad, 1 mile southwest of Valley Springs, the gravels are well exposed and attain a thickness of 200 feet. At the bottom of the cut may be seen irregular blocks of the gray clay-rock or tuff of the Ione formation included in the gravel beds. The gravel here also contains one or two thin layers of white sandstone, which can not be distinguished from the sandstone at the Late quarry at Valley Springs. The unconformity of the late Neocene or Pliocene gravels on the Ione formation suggested by the above facts is more clearly shown at the red sandstone quarry 3 miles southeasterly from Buena Vista. A photograph of the exposure was taken, which is reproduced in Pl. LI. The upper surface of the sandstone is undulating, and has been worn smooth by water action. Water-worn bowlders of white Ione sandstone, such as is in place just to the north of the red-sandstone quarry, occur here in the gravel.

The Neocene shore gravels occur on the slopes of Buena Vista and Valley Springs peaks, resting unconformably on the rhyolite, which forms the main mass of the peaks. These heavy bodies of coarse gravel in Pliocene time suggest that to have been a period of rapid erosion.

EARLY PLEISTOCENE SHORE AND RIVER GRAVELS AND MORAINES.

The early Pleistocene shore gravels are somewhat remarkable in consisting almost entirely of quartzite and other highly siliceous pebbles. They appear to have been formed largely by the washing of older gravels by gulf waters, the softer volcanic pebbles being mostly completely used up in the process. Extensive areas of these gravels occur on the east side of the San Joaquin and Sacramento valleys. On the Jackson sheet they occur on low, broad plateaus and in depressions between the

UNCONFORMITY OF NEOCENE SHORE GRAVELS ON THE IONE SANDSTONE.

Neocene and older hills, up to an elevation of about 450 feet. Since these gravels usually rest on the Ione formation or on the andesitic tuff it is plain that the quartzite pebbles so abundant in them could not have been derived from quartzite croppings directly. In fact there is little or no quartzite in the lower foothills in reach of the waters of the gulf at the level at which they stood when these gravels were formed. The formation of these siliceous gravels illustrates the law of the survival of the fittest. The heavy beds of gravel that formed at the time of the enormous andesite eruptions seem clearly to have afforded the material from which, during early Pleistocene time, these shore gravels were sorted out.

The Pleistocene shore gravels have proved auriferous at many points. They have been extensively washed for gold at Irish Hill, 4 miles northwest of Ione; about Camanche, Calaveras county; at the North Hill hydraulic mine, south of Jenny Lind, Calaveras county; and at numerous other points. At places these gravels have been consolidated into a conglomerate. Associated with the early Pleistocene shore gravels are layers of hardpan, a more or less friable sandstone, generally discolored with iron.

The river deposits of early Pleistocene age consist of gravels along the present rivers, lying usually less than 100 feet above the present river level. The pebbles are largely siliceous, but there is much more variety than with the Pleistocene shore gravel, since the rivers have cut down through the older hard rocks, which have thus largely formed the material from which these gravels are derived. These early Pleistocene river gravels have proved auriferous as a rule. Occasionally a stream has entirely changed its course for a short distance, it having cut through some barrier. This is the case with the Mokelumne river, 1 mile west of Lancha Plana. The former river bed is followed by the road from Lancha Plana to Camanche. Most of the gravel of this former channel has been removed by hydraulic mining.

Another similar case occurs at the mouth of Slate creek on the Bidwell Bar sheet. The creek has cut a new bed for about one-fourth of a mile, a hill intervening between the old and the present river bed, as is also the case with the Mokelumne.

Some of the valleys of the Sierra Nevada were formerly occupied by lakes. This was the case with Meadow valley and Mohawk valley,[1] in Plumas county. Sierra valley was probably at one time covered with a shallow sheet of water, and portions of it are still swampy.

Moraines are very abundant and finely preserved in all that portion of the range where the higher points attain an altitude of 8,000 feet or more. They have been studied by Prof. I. C. Russell[2] about Mono lake and elsewhere and by Prof. Joseph Le Conte[3] at Lake Tahoe and elsewhere.

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[1] Bull. Phil. Soc. of Washington, Vol. XI, pp. 385-410.

[2] Eighth Annual Report, U. S. Geol. Surv., Part I, pp. 269-395.

[3] Am. Jour. Sci., 3d ser., Vol. X, pp. 126-139.

ALLUVIUM.

As in other portions of the world, the gravels and fine sediments formed by rivers, etc., in comparatively recent times occupy most of the valleys and river bottoms.

IGNEOUS ROCKS.

The igneous rocks may be classified as intrusive and effusive, but some of the fragmental diabases and porphyrites that are included under intrusives were undoubtedly surface rocks, and correspond to basalts and andesites. The time classification of Rosenbusch is retained for convenience:

INTRUSIVE (OLDER THAN THE CHICO FORMATION).

Amphibolite.	Basic series.
Diabase and porphyrite.[1]	
Hornblende-porphyrite.[1]	
Gabbro and norite.	
Peridotite and pyroxenite.	
Diorite.	
Granodiorite.	Acid series.
Granite-porphyry.	
Biotite-hornblende-granite.	
Quartz-porphyrite.	
Quartz-porphyry.	

EFFUSIVE (TERTIARY IN AGE).

Rhyolite.	Acid series.
Hornblende-mica-andesite.	
Hornblende-pyroxene-andesite.	
Pyroxene-andesite.	
Older basalt.	Basic series.
Dolerite.	
Other basalts.	

INTRUSIVE IGNEOUS ROCKS.

AMPHIBOLITE.

The rocks here designated as amphibolite all appear to have been derived by metamorphism from igneous rocks. The amphibolites may be classified under three headings: Massive amphibolite, amphibolite-schist, and amphibole-talc rocks.

Massive amphibolites.—Under this head are placed certain granular amphibolites which are known in some cases to have resulted from the alteration of pyroxenites. No. 240, Amador county, and No. 76, Calaveras county, are examples.

Amphibolite-schist.—The majority of the green schists so abundant in the Gold Belt are amphibolites, derived very largely from rocks of

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[1] Some of the porphyrites contain over sixty per cent of silica, and therefore extend into the acid series.

the diabase series by dynamo-metamorphism, as has been shown by the microscope and by field observations. The augite of the original diabase may frequently be seen altering into fibrous green hornblende. These schists usually contain secondary feldspar and quartz, with a good deal of epidote in small grains, and sometimes zoisite. These rocks resemble to a marked extent the greenstone-schists of Michigan, so admirably described by Prof. G. H. Williams.[1] Large areas of amphibolite-schist are shown on the Sacramento, Placerville, and Jackson atlas sheets.

Copper.—Copper is found in a belt of amphibolite-schist that lies just west of the Bear mountains in Calaveras county, and in the extension of this belt to the northwest into Eldorado county are frequent deposits of copper and iron sulphurets, which have been the source of a considerable copper industry. The ore is said to carry several dollars in gold to the ton at Copperopolis and at Campo Seco.

Amphibole-talc rocks.—Rocks of this series occur as narrow streaks in the Paleozoic schists. They have been studied by the writer chiefly in the area of the Jackson sheet, where they appear to occur only in the Calaveras formation, evidently representing original basic dikes, for, in places, they contain cores of pyroxene altering to amphibole. This is usually colorless in thin section, and is probably tremolite, but some of the amphibole corresponds more nearly to actinolite. Portions of the dikes are now altered to talc. Sometimes serpentine is associated with the amphibole and talc. In a dike three-fourths of a mile northeast of Oleta (No. 348, Amador county) the pyroxene is plainly altering to serpentine. The largest body of talc rock noted lies 2½ miles northeast of Angels, in Calaveras county. In this case the area is rounded in shape, and about one-third of a mile in diameter. Large areas of these magnesian rocks occur on the Bidwell Bar sheet.

DIABASE AND PORPHYRITE.

Rocks of the diabase series are very abundant in the Sierra Nevada. They occur, as a rule, associated with the auriferous slate series, and in minor amount associated with granite. Much of the material classed as diabase has been shown on careful examination to be fragmental, and may be designated diabase-tuff. Some such areas were undoubtedly formed by eruptions which occurred at the time the sedimentary rocks now inclosing the tuff were being deposited, but many of the fragmental diabase areas, or areas which are in part fragmental, that separate the slate belts into wedge-shaped portions, appear to have been intruded sheets, or dikes. Such is the Bear mountain area, that begins at the south end of the Jackson sheet, and extends thence across Calaveras and Amador counties into Eldorado county, a distance of about 50 miles.

This dike or intruded sheet separates for this entire distance, so far

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[1] Bull. U. S. Geol. Survey, No. 62.

as known, the Calaveras and the Mariposa formations, and might be considered as a dike at their contact. At various points, particularly about Golden Gate hill, the diabase of this area extends in long dike-like tongues into the slates of both the Calaveras and the Mariposa formations. An inspection of the geological map of the area (Jackson atlas sheet) seems to leave no doubt that these intrusions cut across the sedimentary strata in places. No careful study has yet been made of these diabase areas. The dike-like tongues noted above may prove in all cases to be massive diabase or augite-porphyrite.

There are also large areas in which the diabase is unquestionably massive, as the area southwest of Latrobe, on the Placerville sheet, portions of which form an augite-porphyrite. In other portions of this area there are scarcely any bisilicates in the rock. No. 510, Eldorado county collection, is a sample of such a rock.

In the northeastern part of the Downieville sheet, in Plumas county, is an extensive area of porphyrite. It forms a large part of the western slope of the Grizzly mountains. The same area, apparently uninterrupted, though in places covered by Pleistocene deposits, extends south to Mount Elwell, Gold lake, and beyond, having in places a width of 6 miles. A good deal of this material is a breccia, and most of it is more or less roughly schistose, portions of it being converted into a thoroughly schistose amphibolite by pressure. A very pretty example of this dynamometamorphism may be seen just east of Long lake. Here a narrow strip of the diabase has, by pressure and movement, been converted into an amphibolite-chlorite-schist (No. 110, Plumas county), and that this strip of schist is an integral part of the diabase, and not included in the diabase, is very evident, the rocks having been cleaned off most beautifully by the glacier that formerly occupied the area. Even better evidence of the dynamic origin of some of the amphibolite-schist may be seen in the vicinity of Wades lake, in Plumas county. On the slope to the south of the lake, and at other points about the lake, there are numerous diabase dikes in the white quartz-porphyry-schist. Some of these dikes are 15 feet through; others are smaller. In places the dikes have assumed a schistose structure coincident in direction with the schistosity of the inclosing quartz-porphyry-schist, but bearing no relation to the course of the dikes.

The rocks in the table of analyses will now be briefly described:

No. 510, Eldorado county, is a rather fine grained, light greenish gray rock showing porphyritic feldspars and grains of pyrite. Under the microscope, in addition to the feldspars, are seen a few augites. The analysis shows too high a percentage of silica and too little lime and magnesia for a normal augite-porphyrite.

No. 364, Plumas county, is a dark green, rather fine grained rock with large squarish darker green porphyritic crystals, which are seen under the microscope to be hornblende paramorphic after augite. This rock is presumed to have been originally an augite-porphyrite.

No. 159, Amador county, is a dark green heavy rock from the diabase dike (?) west of Jackson. It is an augite-porphyrite with very abundant augite phenocrysts. As would be expected, the silica percentage is low and the lime and magnesia high.

No. 417, Plumas county, is also an augite-porphyrite.

No. 76, Butte county, is an average sample of a diabase tuff. It is a dark green medium grained rock and is composed of plagioclase, remnants of augite, and fragments made up of feldspar microlites, with a good deal of epidote, chlorite, and green fibrous hornblende as secondary products.

No. 560, Calaveras county, is a porphyritic rock with abundant plagioclase phenocrysts and scattered quartzes in a greenish groundmass which is decomposed, but which appears under the microscope to be ophitic in structure, the original augite now being altered to epidote and chlorite. A specimen from the same magma as No. 560 (part of the Gopher ridge porphyrite area), and taken only two feet away, is a typical quartz-porphyrite.

The Gopher ridge, Calaveras county, magma is an extremely variable one. Portions of the area are quartz-porphyrite with sharp contacts with more basic porphyrites, and grading off at other points into a simple porphyrite with only plagioclase phenocrysts. Other portions of what appears to be the same magma contain plenty of augite, making an augite-porphyrite.

All of the analyses of the diabases were made by Prof. Hillebrand and Mr. Steiger.

Analyses of diabases and porphyrites.

	No. 364, Plumas.	No. 159, Amador.	No. 417, Plumas.	No. 76, Butte.	No. 560, Calaveras.	No. 510, Eldorado.	Gabbro No. 158, Plumas.	Norite, No. 343, Plumas.
SiO_2	48·86	49·24	53·33	54·66	61·37	68·58	53·14	45·92
TiO_2	....	·96	....	·67	·60	·37	....	....
Al_2O_3	....	14·79	....	15·85	15·41	13·04	....	....
Fe_2O_3	....	1·52	....	1·82	3·15	·26	....	....
FeO	....	8·00	....	5·12	3·89	3·40	....	....
MnO	....	·18	....	·18	·47	·15	....	....
CaO	7·65	10·74	9·39	8·75	4·42	3·22	9·56	9·61
SrO	....	Trace.	....	Trace.	Strong trace.	Strong trace.	....	....
BaO	....	·04	....	·04	·08	·10	....	....
MgO	9·88	6·89	7·08	5·64	3·48	1·01	4·97	13·85
K_2O	1·36	·88	·86	·47	·34	1·90	1·54	·10
N_2O	3·46	2·76	1·95	3·46	3·76	4·94	1·75	·71
Li_2O	....	Trace.	....	None.	None.	None.	....	....
H_2O below 100° C	....	·20	....	·25	·29	·16	....	....
H_2O above 100° C	....	2·97	....	2·48	2·70	1·00	....	....
P_2O_5	....	·17	....	·15	·08	·20	....	....
CO_2	....	·90	....	·39	....	1·31	....	....
FeS_2	....	....	....	·09	....	·15	....	....
	....	100·08	....	100·02	100·04	99·99	....	....

HORNBLENDE-PORPHYRITE.

Hornblende-porphyrite occurs abundantly in the southern part of Eldorado county, and to a limited extent in Amador county as fragmental areas and dikes in the western belt of the Calaveras formation (see Placerville atlas sheet). Big Sugar Loaf, in Eldorado county, is a massif of hornblende-porphyrite. As noted in the text of the Placerville atlas sheet, the hornblende-porphyrite in Eldorado county grades into rocks of the augite-porphyrite series. It is probable that these hornblende-porphyrites are of the age of the inclosing slates, that is, Carboniferous, and some of the areas may have been surface rocks.

As is noted under diorite there are dikes of a rock allied to camptonite which cut the granite, the schists, and the quartz-porphyrite, and in which are developed porphyritic hornblendes. These rocks are sometimes designated hornblende-porphyrite, but they may be observed to pass over into undoubted diorites of the camptonite series, with a holocrystalline groundmass.

GABBRO AND NORITE.

Rocks of the gabbro series occur not infrequently in the Sierra Nevada, but seldom in large areas. In general they seem genetically related to the granite series on the one hand and the peridotite-pyroxenite series on the other.

A mica-gabbro forms a considerable hill, more than a mile in greatest diameter, in Amador county, about 2 miles west of Plymouth. At other points gabbro occurs associated with serpentine dikes.

The area of gabbro about Whitmore's, in the northeast corner of the Jackson sheet, is a very variable one. While the larger part of the area is a gabbro, portions contain olivine, forming an olivine-gabbro; other portions contain only pyroxene, forming pyroxenite, some of which is entirely altered to hornblende, forming a massive amphibolite. Brown mica occurs locally, forming a mica-gabbro. At one point a specimen contains primary quartz, brown mica, plagioclase, and pyroxene, with secondary hornblende, forming kersantite; and on the south slope of Mount Crossman is a mass of rock composed chiefly of primary brown hornblende that seemed to be genetically a part of the gabbro area.

In Plumas county gabbro forms the east slope of Eureka peak below the 6,800-foot contour. It there may be seen in sharp contact with the quartz-porphyry that forms the crest of the peak, and, as fragments of the gabbro are inclosed in the quartz-porphyry, it would appear that the gabbro is here the older rock.

A partial analysis of this gabbro (No. 158, Plumas county) is given in the table of analyses of diabases. The area shown on the Grizzly peak map, and lying 4 miles southwest of that point, is in part a typical gabbro (No. 341, Plumas county) of plagioclase and diallage, and in part is composed of hypersthene and plagioclase, forming a norite. At one point in the area are developed large black hornblende crystals, some of them more than an inch long. There are also curious orbicular structures in the norite (No. 343, Plumas county). These concretions consist of a central portion that appears to be largely the same as the general mass of the norite, that is, hypersthene and plagioclase, surrounded in the particular specimen examined by three or more concentric layers, which in thin section are seen to be composed largely of olivine and magnetite, with intervening layers of plagioclase. Not many of the nodules are strictly orbicular. One of the finest collected is kidney-shaped. This has a length of 4½ inches and a width of 1¾ inches. A section through this specimen shows that in the center are several curved superimposed dark layers, probably of olivine and magnetite, with intervening thinner and lighter colored layers of plagioclase, and that this central series of layers is cut off on the sides and completely inclosed in another similar set of concentric layers, which are not spheroidal but flattened, giving the nodule a kidney shape.

A partial analysis by Mr. Steiger of the orbicular norite is given in the table of diabase analyses. This concentric structure appears to be a result of cooling in the original magma. It is very similar apparently to the orbicular diorite (kugeldiorit or napoleonite) of Corsica.

The following explanation of the orbicular or spheroidal structure in eruptive rocks by Vogelsang is taken from Hatch:[1]

> When a molten magma consolidates, an irregular cooling may produce greater contraction of the mass at certain points; and this may lead later on to a spheroidal separation.
>
> If this condition is arrived at after the point of consolidation of the several minerals has been passed, and therefore after their separation is complete, we get, indeed, a concentrically laminated body, but are without a definite arrangement of the constituents; this is the well known spheroidal structure of many eruptive rocks. If, on the other hand, the tendency to form spheroids is developed during the period in which a differentiation of the magma into various minerals takes place, the latter will naturally undergo a definite arrangement in regard to a central point.

B. Frosterus, of the Geological Commission of Finland, has lately published an interesting pamphlet[2] on an orbicular granite which forms a little eminence having a length of about 85 meters and a breadth of 75 meters.

In general appearance, as figured, this orbicular granite presents a great similarity to the rock above described. There are two kinds of orbicular nodules represented. One kind, with a diameter of from 2 to 5 centimeters, has a bright colored nucleus and a dark outer zone, which consists of two or three concentric layers of biotite, separated by layers of the same material that forms the nucleus. The latter is composed of oligoclase with less microcline and biotite. The other kind of nodule is larger, from 20 to 30 centimeters in diameter, and is characterized by a greater number of biotite zones. The author states that most of the nodules lie, not in a completely normal granite, but in a rock of a more basic character than the prevailing granitite of the country, and he regards the entire nodule occurrence as a basic "schliere" in which the nodules have formed as still more basic segregations.

Mr. Frosterus states that orbicular gabbro is known from only a single locality, Romsas in Askim, Norway, referring to a paper by L. Meinich.[3] These nodules, which are composed of hypersthene, labradorite, oligoclase, and foils of a brown mica, possess a thick-shelled concentric structure. A radial structure exists in only a few of the nodules.

Prof. G. vom Rath[4] states that he was shown by Mr. Henry Hanks, of San Francisco, an orbicular diorite (kugeldiorit) from Rattlesnake

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[1] Quart. Jour. Geol Soc. London, Vol. XLIV, p. 558.

[2] Ueber ein neues Vorkommniss von Kugelgranit unfern Wirwike bei Borgå in Finland Helsingfors, 1893. My attention was kindly called to this pamphlet by Mr Becker.

[3] Nyt. Mag. f. Naturvid., bd. 24, pp. 125–137.

[4] Sitzungsberichte der niederrheinischen Gesellschaft zu Bonn, 1884, p. 205.

bar, Eldorado county, California, which exceeds in beauty the orbicular diorite of Corsica. In the Rattlesnake bar rock the flattened nodules attain a diameter of 10 centimeters. They consist of a nucleus of dark green hornblende which is surrounded by a zone of almost pure plagioclase, and this by concentric layers of radially placed hornblende prisms and plagioclase.

Prof. G. H. Williams stated in a letter that a remarkable orbicular diorite occurs on the Yadkin river, in North Carolina; and also called my attention to a notice of an orbicular diorite from Placer county, California, by E. S. Reinhold.[1]

PERIDOTITE AND PYROXENITE.

Fresh peridotite has been found, so far as known to the writer, at very few points in the areas studied, it having as a rule been altered to serpentine. Still traces of the original olivine, together with pyroxene, have been found in many of the serpentine areas, and at a number of points beautifully fresh pyroxenite.

The largest single dike of serpentine which is known to have been originally a peridotite or pyroxenite occurs in the northern end of the range in Sierra and Plumas counties. It follows very closely the strike of the strata, and when they bend very perceptibly to the northwest, as is the case from Clermont hill, in Plumas county, to Meadow valley and beyond, this dike likewise has the same northwesterly course. The serpentine at Red hill, in Plumas county, north of the fortieth parallel, is a part of this dike, which extends south from that point at least 50 miles, crossing the north fork of the Yuba at Goodyear's bar, in Sierra county. This serpentine dike has a width, where it is crossed by the middle fork of the Feather river, of more than 3 miles. Associated with the serpentine are large amounts of amphibolite-schist. This is especially abundant to the south of Onion valley, in Plumas county. It seems at some points to replace the serpentine, which occurs sometimes to the east and sometimes to the west of the amphibolite, and sometimes, as 2 miles south of Onion valley, the serpentine is bordered on both sides by a belt of amphibolite-schist. To the north of the middle fork of the Feather river the amphibolite-schist is coarsely fibrous and forms a very definite belt one-half mile or more wide to the east of the broad serpentine dike, and a much broader belt is cut by Slate creek, in Sierra county. The relations of the two rocks are beautifully exposed on the south and west slopes of Clermont hill, and there the contact of the two is everywhere sharp.

It is presumed that there is a genetic relation between the serpentine and the amphibolite-schist, but exactly what the relation is has not yet been determined. It was first shown by Mr. J. S. Diller[2] that the original rock of this serpentine dike was a peridotite or allied rock,

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[1] Proceedings Phil. Acad. Sci. 1882, p. 59. Exact locality not given.

[2] Eighth Ann. Rep., U. S. Geol. Survey, p. 406.

and the writer found some pyroxenite in the middle of the dike on the ridge to the south of the middle fork of Feather river, and also in Sierra county near Goodyear's creek.

In this serpentine belt to the southeast of Meadow valley, at various points, are small dikes of a very white rock. The microscope shows these to be made up almost wholly of large grains of feldspar with marked cleavage, and showing occasionly a twin lamella.

From the following partial analysis by Dr. Hillebrand of a specimen from a dike between the junction of Rock and Deer creeks it seems unquestionable that the feldspar is albite:

No. 455, Plumas county.

SiO_2	66·54
MgO	·77
CaO	·43
K_2O	·89
N_2O	10·28

On the Jackson atlas sheet pyroxenite was found altering into massive amphibolite. Some of the hornblende grains contain cores of pyroxene undergoing alteration to hornblende.

DIORITE.

At numerous points in the range are dikes and small areas of fine to medium grained rocks, usually showing to the naked eye abundant hornblende needles. Under the microscope these rocks are seen to be composed of a holocrystalline groundmass of feldspar and minute brown hornblende needles, through which are scattered larger brown hornblende needles. Occasionally the rock is more nearly granular, the hornblende being in short prisms. In two instances noted, the rock contains augite phenocrysts in addition to the hornblende. One of these (No. 155, Amador county) is from a dike-like extension of a hornblende-gabbro area, and presumably a modification of the same magma as the gabbro (No. 181, Amador county).

Some of these fine grained diorites are nearly or quite identical with a diorite described by Hawes, and which is now called camptonite. They appear to be among the latest of the older intrusive rocks.

Near West Point, in Calaveras county, at Spanish peak, in Plumas county, near Merrimac and Swede's flat, in Butte county, the camptonite occurs as dikes in the granodiorite; near Railroad flat, in Calaveras county, dikes of the same rock cut the schists of the Calaveras formation; in the bed of the Cosumnes river, to the west of Lamb's bridge, (see Placerville sheet) the quartz-porphyrite is cut by dikes of this rock.

Some of the camptonites with a fine grained groundmass have been designated hornblende-porphyrite.

GRANODIORITE (QUARTZ-MICA-DIORITE.)

This name was introduced by Mr. Becker for the potash-poor granite of the Sierra Nevada in the general text descriptive of the Gold Belt geological atlas sheets. The rock strongly resembles, and is usually called, granite. It is a holocrystalline rock of hypidiomorphic structure, and is composed of plagioclase, quartz, hornblende, and brown mica, with a varying amount of potash-feldspar, which is in almost all cases exceeded in amount by the soda-lime feldspar. There are also various accessory minerals. The granodiorite was called quartz-diorite by Adolf Schmidt.[1] It closely resembles in composition the tonalite of Vom Rath. The rock might be properly called a quartz-mica-diorite.

The granodiorite occurs in very large areas in the range and is the rock of the Yosemite valley. According to Mr. W. Lindgren, the granodiorite at Folsom, on the American river, has metamorphosed the Mariposa slates into mica-schists, and Mr. H. W. Fairbanks[2] states that the slates and schists near Bridgeport, in Mariposa county (this includes the Mariposa slates), are cut off and metamorphosed by the granite, an observation which the writer verified. It therefore appears that much of the granodiorite is later in age than the Mariposa slates.

In the table of analyses of the granites, the following are considered granodiorite: Nos. 345, 81, 359, 95, and 330.

No. 345, Plumas county, is from the area just north of the gabbro-norite area of Grizzly peak.

No. 81, Butte county, is from 2 miles northeast of Bangor, in the Swede's flat granodiorite area, on the Smartsville sheet. The mica of this rock is altered to chlorite.

El Capitan, Yosemite, granite. This analysis, by T. M. Drown, is taken from the volume on Systematic Geology, of the Fortieth Parallel survey.

No. 359, Plumas county, is from the granodiorite area about 1 mile northeast of the Sulphur spring house, in Mohawk valley, on the Downieville sheet.

No. 95, Butte county, is from the north side of the south fork of the Feather river, opposite Enterprise, on the Bidwell Bar sheet. The ferromagnesian silicates in this rock are largely altered to chlorite.

No. 330, Amador county, is from the north side of the north fork of the Mokelumne river, about 2.8 miles northeast of West Point. The mica of this rock is now largely chlorite.

Nos. 345 and 359, Plumas county, and Nos. 81 and 95, Butte county, were analyzed by Dr. Hillebrand and Mr. Steiger. No. 330, Calaveras county, was analyzed by Mr. L. G. Eakins.

GRANITE-PORPHYRY.

To the east of the granodiorite area of Yosemite valley is a mass of granitoid rock, in which are developed large pink orthoclase feldspars. The general appearance of the rock is shown in Fig. 50. About 9 miles nearly north of Mount Hoffmann, to the north of the Tuolumne river, is a little lake, which was visited a few years since by Mr. G. F. Becker and myself, and to it the name Granite lake was given, partly for the sake of a name to use in notes and partly on account of the mag-

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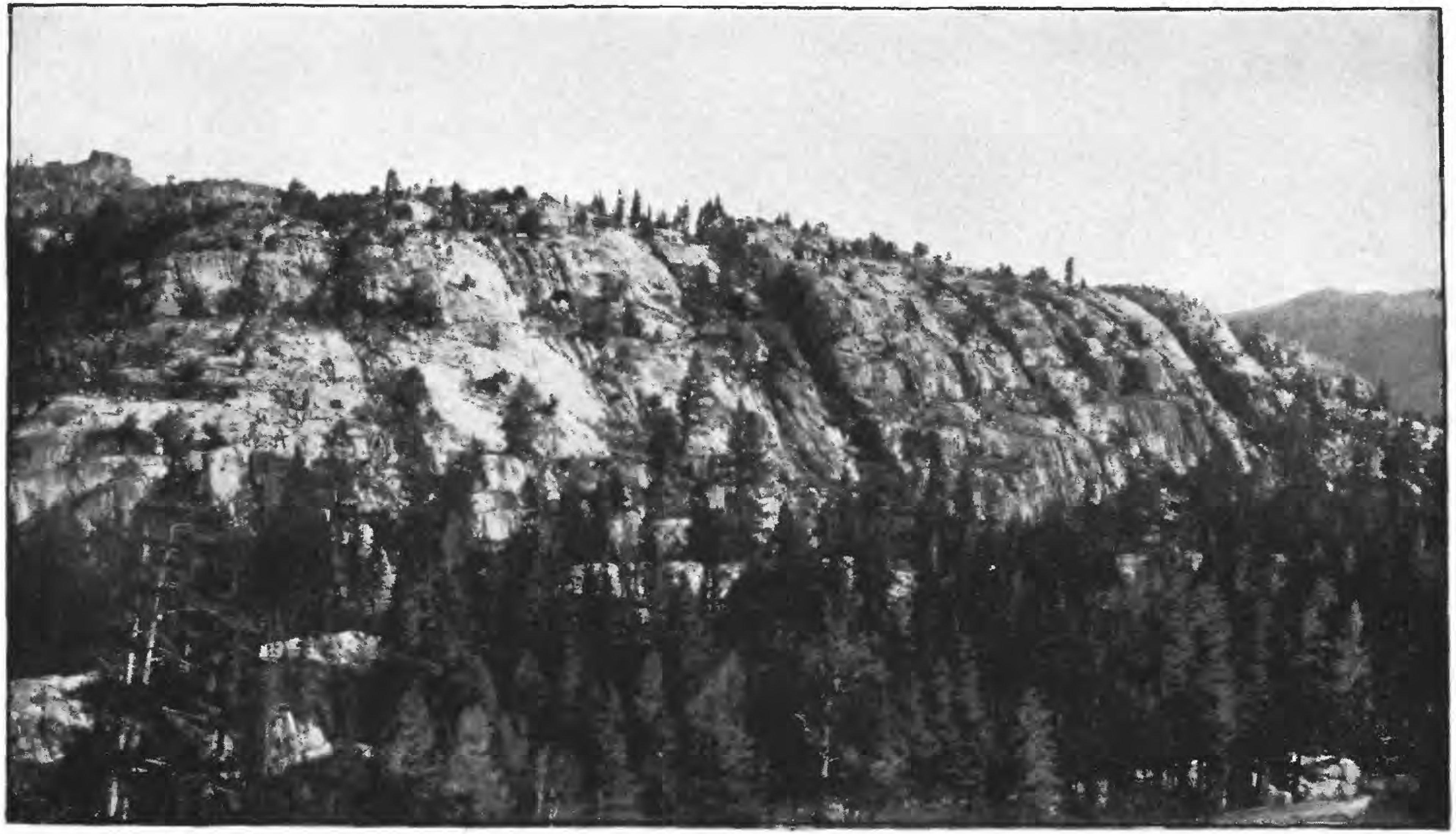
[1] Neues Jahrbuch, 1878, pp. 716-719.

[2] American Geologist, 1891, p. 211.



VERTICAL FISSURES IN GRANITE, CHARITY VALLEY, ALPINE COUNTY, CALIFORNIA.

nificent granite exposures about the lake. In fact there is nothing but granite in the vicinity, and as the loose material has been swept away by the glacier that formerly covered the spot the rocks are beautifully exposed. The granite-porphyry occurs about the head of the lake, and the contact there and at other points in the neighborhood with the biotite-hornblende-granite is everywhere sharp. Dike-like protrusions of the granite-porphyry were seen extending into the biotite-hornblende-granite, indicating that the former is the younger rock.

FIG. 50.—Granite-porphyry. Scale, $\frac{1}{8}$.

The granite-porphyry may be described as a holocrystalline rock of hypidiomorphic structure, with a coarse groundmass of plagioclase, orthoclase, and sometimes microcline, a good deal of brown mica, a little primary brown hornblende, and titanite and iron oxide. In this groundmass are developed large orthoclase phenocrysts, which usually contain abundant inclusions of the minerals of the groundmass, both in the interior and along the edge of the phenocrysts. Plagioclase, biotite, quartz, titanite, and iron oxide were noted in the porphyritic orthoclases, which are often more than 2 inches in length. It is evident that the phenocrysts were formed after some of the other constituents of the rock, and in this particular the granite-porphyry appears to strongly resemble the porphyrite with large orthoclase phenocrysts, described by Mr. W. Cross in this volume as forming part of the laccolites of the Elk mountains, Colorado. Prof. A. C. Lawson[1] has lately described a granite-porphyry from the Santa Lucia mountains, in the coast ranges of California.

[1] The Geology of Carmelo Bay. Bull. Dept. Geology, University of California, vol. 1, pp. 1–59.

According to Prof. Lawson, all the quartzes included in the orthoclase phenocrysts of the Santa Lucia granite have a common orientation, with the optic axis perpendicular to the basal pinacoid of the host, and the feldspars have a common orientation by groups. This is not the case with the inclusions in the rock here described. They do not extinguish simultaneously, nor have they any definite position in relation to the axes of the hosts.

The granite-porphyry forms a large part of the crest of the Sierra Nevada about the headwaters of the Tuolumne river. It has been noted by the writer at several points to the north of that region, but its relation to the biotite-hornblende-granite or to the granodiorite has not been studied except near Granite lake. Mr. Becker states that he found the same relation between the granite-porphyry and the hornblendic granite, in the district between Highland lakes and Blue lakes, in Alpine county, as at Granite lake, and also that, according to Clarence King, granite-porphyry occurs at Mount Whitney.

In the table of analyses No. 25, Mariposa county, is a granite-porphyry from one-fourth mile north of Lake Tenaya, in the Yosemite National park, and No. 19, Mariposa county, is the biotite-hornblende-granite from about 1 mile west of Lake Tenaya.

BIOTITE-HORNBLENDE-GRANITE.

The biotite-hornblende-granite or hornblende-granitite, as it might be called, has a higher percentage of potassa and less lime in the specimen analyzed (No. 19) than is normal with the granodiorite, and as its relations to that rock have not yet been carefully studied it is here given a separate designation, although it is part of the great granite area of the Yosemite valley, which has there been called granodiorite.

Concretions or segregations in the biotite-hornblende-granite.—There are numerous nodules or "schliere," as they have been called by German writers, in the biotite-hornblende-granite about Granite lake. These are particularly abundant on a vertical bank of granite a little west of Granite lake, and a photograph of this exposure was taken, which is reproduced in Pl. LIV. The bulk of the rock shown in the plate is the biotite-hornblende-granite (No. 240, Tuolumne county); the dark masses are the nodules or schliere, and both the biotite-hornblende-granite and the schliere (No. 239) are cut by dikes or pegmatitic veins of a coarse granite (No. 241). The nodules are composed of feldspar in part polysynthetically twined, brown hornblende, and brown mica. There appears to be also a little orthoclase. Very similar nodules have been described by J. Arthur Phillips[1] from granites in the British Isles, and by Prof. G. P. Merrill[2] from the granites of Maine, but in neither of these cases are the constituents of the nodules altogether the

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[1] Quart. Jour. Geol. Soc., Lond., Vol. XXXVI, pp. 1-22.

[2] Proc. U. S. Nat. Museum, Vol. VI, pp. 137-141.

EXFOLIATING GRANITE, CREST OF SIERRA NEVADA, SOUTHWEST OF SILVER MOUNTAIN CITY.

same as the constituents of the Granite lake nodules. Both Profs. Merrill and Phillips consider these nodules to be of concretionary origin, and that they do not represent inclusions of foreign rocks altered by metamorphism.

According to F. von Adrian, as translated in Prof. Phillip's paper,[1] similar nodules occur in Bohemia and exclusively in the hornblende granite.

Weathering of the granite.—The granite of the Sierra Nevada weathers in very different ways, producing strikingly different scenic results. According to Mr. G. F. Becker,[2] the great granite domes of the Yosemite are merely gigantic cases of exfoliation, similar except in scale to those observed in basalt and other rocks. Mr. Becker says:

> If the theory of an original controlling ball structure were correct, it should account for the spheroidal weathering of the fragments as well as the colossal domes, for between the two extremes of size there is every possible gradation. * * * The large domes show no indication of a tendency to resolve themselves into smaller spheres excepting when they have first been intersected by fissures.[3]

The surface waters acting along these fissures would cause decomposition, the exposed corners would scale off, and as a result more or less nearly spherical bodies would finally be produced.

A good example of the exfoliation of granite on a small scale is shown on Pl. LIII. This is from a photograph taken on the very crest of the range in Alpine county, not far north of the road from the Calaveras big trees to Silver Mountain city. This might be explained as resulting from an original concentric structure, as suggested by Vogelsang (see p. 475, under Gabbro and Norite), without any definite arrangement of the minerals, but it is more probably due to the weathering process described by Mr. Becker, although in this case the rock is so much decomposed that the fissures are not evident.

Prof. N. S. Shaler[4] considers the concentric structure of granite to be due to external forces, apparently chiefly heat and cold, or in other words, changes of temperature. He notes that in certain quarries the exposures show that the concentric arrangement is confined to the external portion of the mass, never being discernible at a greater depth than 4 or 5 feet.

Considerable portions of the Sierra Nevada are intersected by systems of fissures more or less nearly parallel. As has been shown by Becker,[5] these are a result of pressure from forces acting in definite directions. As a consequence the granite in places possesses a laminated structure, which is perhaps nowhere better shown than in Alpine county, to the northeast of Charity valley. There are here a set of vertical north and south fissures and another set nearly hori-

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[1] Ibid., p. 3.

[2] Tenth Ann. Rep. U. S. Geol. Survey, p. 142.

[3] Mr. Becker discusses this subject more fully in Monograph XIII, U. S. Geol. Survey, p. 68.

[4] Proc. Bost. Soc. of Nat. Hist., Vol. XII, pp. 289-293.

[5] Bull. Geol. Soc. Am., Vol. II, pp. 49-74.

zontal. These are shown in Pl. LII. Erosion of the granite produces vertical walls along the vertical fissures and terraces along the horizontal system.

That portion of the crest of the range between Tower peak and Mount Conness is composed chiefly of granite-porphyry, which is intersected by very abundant fissures, so that the rock is divided into small polyhedrons of varying shape. As a result, the crest here assumes a very serrated outline.

Analyses of the granite series.

	No. 345, Plumas.	No. 81, Butte.	No. 25, Mariposa.	El Capitan, Yosemite.	No. 359, Plumas.	No. 95, Butte.	No. 19, Mariposa.	No. 330, Calaveras.
SiO_2	59·83	63·43	66·28	66·40	67·02	70·36	72·48	....
TiO_2	....	·73	·54	....	....	·20	·28	....
Al_2O_3	....	14·20	16·03	17·13	....	15·47	14·06	....
Fe_2O_3	....	1·54	1·80	....	....	·98	·89	....
FeO	....	4·56	1·88	....	....	1·17	1·05	....
MnO	....	·03	·05	·30	....	trace.	trace.	....
CaO	6·49	5·51	3·75	4·05	4·42	3·18	2·17	....
SrO	....	trace.	trace.	....	....	trace.	trace.	....
BaO	....	·06	·08	....	....	·06	·08	....
MgO	....	2·35	1·12	·97	....	·87	·62	
K_2O	1·69	2·19	3·49	2·08	2·72	1·71	4·75	3·05
N_2O	3·53	3·49	4·10	4·49	3·70	4·91	3·30	2·65
Li_2O	....	none.	trace.	....	....	trace.	trace.	....
H_2O, below 100° C	....	·15	·11	....	....	·06	·16	....
H_2O, above 100° C	....	1·50	·39	....	....	1·00	·35	....
P_2O_5	....	·11	·30	....	....	·11	·09	....
	....	99·85	99·92	....	....	100·08	100·28	....

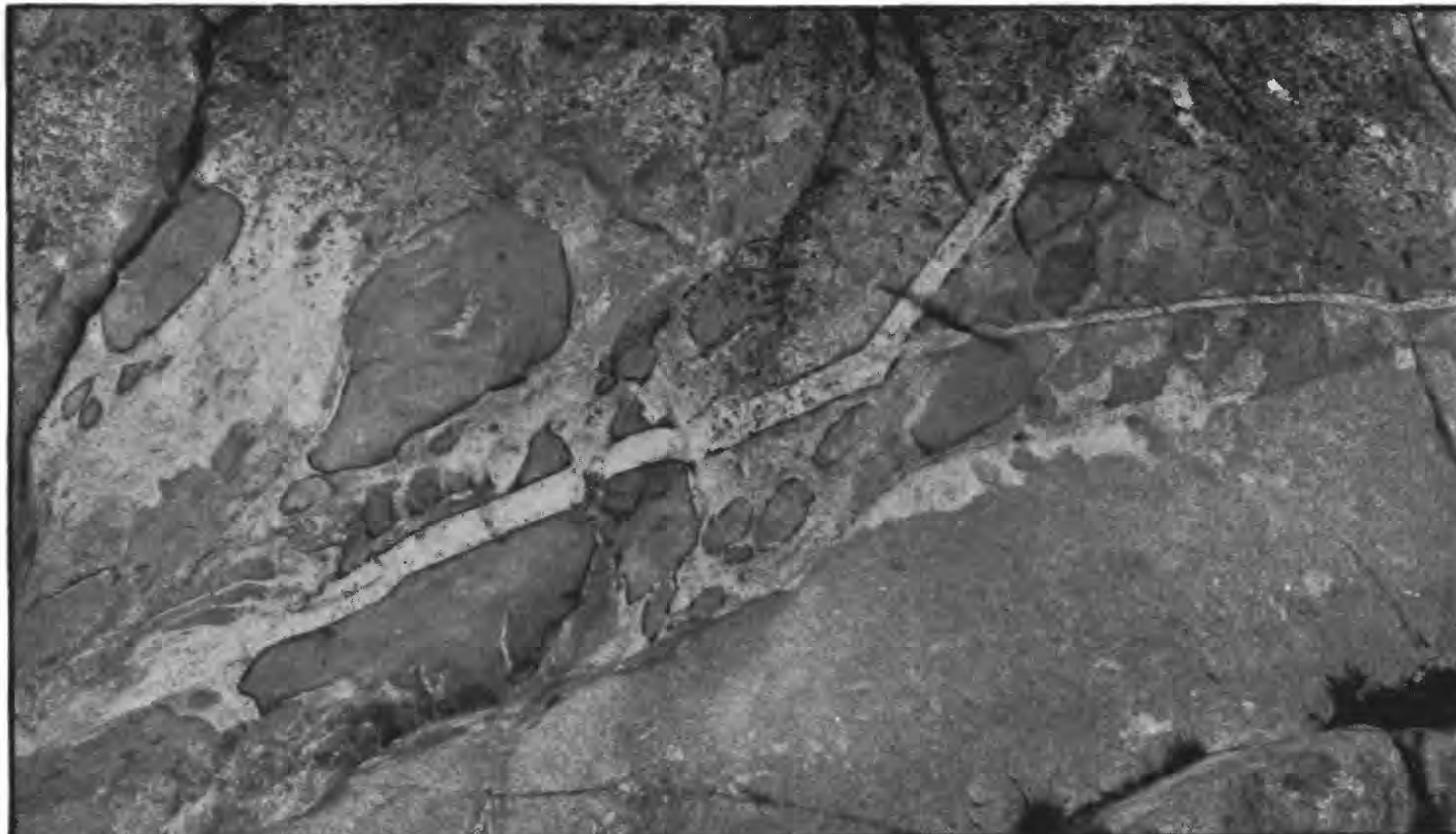
QUARTZ-PORPHYRITE.

In Amador, Calaveras, and Tuolumne counties are considerable areas of pre-Tertiary rocks, usually showing abundant porphyritic quartzes. These rocks are usually light greenish in color, weathering nearly white. Considerable portions of these areas are schistose, but even then the porphyritic quartzes are usually plainly discernible.

In Calaveras and Amador counties dike-like areas of quartz-porphyrite or quartz-porphyrite-schist were noted in the diabase and amphibolite-schist areas. Some of these are shown on the Jackson atlas sheet. In other places, as stated under diabase and porphyrite, the quartz-porphyrite seemed to grade over into porphyrites of the diabase series, that is to say, augitic porphyrites.

No. 151, Amador county, is from a narrow area (dike?) in a belt of amphibolite-schist about 2½ miles southeast of Buena Vista peak. It is thoroughly schistose, and is called a quartz-porphyrite-schist, although it will be noted that it closely approaches a quartz-porphyry in composition. The porphyritic quartzes are nearly idiomorphic, and there are developed abundant minute prisms of slightly pleochroic hornblende. Calcite is abundant. Dr. Hillebrand states that nearly all the ferrous iron is carbonate, and this is true likewise of part of the magnesia.

No. 553, Calaveras county, is from about 1½ miles northeast of Milton, at the west base of the Gopher ridge. It is a typical quartz-porphyrite, without any evidence of schistosity.



NODULES AND DIKES IN GRANITE, WEST OF GRANITE LAKE, TUOLUMNE COUNTY, CALIFORNIA.

The rock is composed of idiomorphic phenocrysts of feldspar and quartz in a microcrystalline groundmass that is largely feldspar. There is some epidote. Only a few of the feldspar phenocrysts show polysynthetic twinning.

No. 252, Calaveras county, is a granitoid variety of the quartz-porphyrite, from about three-fourths of a mile northwest of Jenny Lind. It consists of porphyritic feldspars and quartz in an allotriomorphic groundmass of quartz and feldspar. Some of the porphyritic feldspars do not show polysynthetic twins.

No. 549, Calaveras county, is from the west base of the Gopher ridge, 1¾ miles southeast of Milton. It, like No. 252, resembles and is locally called granite. It consists of phenocrysts of quartz, feldspar, and hornblende in an allotriomorphic groundmass of quartz and feldspar.

No. 384, Plumas county, is from the north slope of Eureka peak. It closely resembles No. 553, Calaveras county, but is from the same area as Nos. 128 and 153, Plumas county, which are classed as quartz-porphyry on account of the small amount of lime and more potassa than is normal with a porphyrite.

QUARTZ-PORPHYRY.

In Plumas county there are two belts of white schistose quartzose rocks that do not differ in general appearance from the quartz-porphyrite schists just described. One of these areas forms a belt a mile or less in width and about 12 miles long in the Grizzly mountains, lying just east of a belt of argillite that appears to be a continuation of the Grizzly formation of Mr. Diller, which is Silurian in age; the other belt forms the summit of Eureka peak and continues thence south into Sierra county. It is the rock about Wade's lake, where it contains numerous dikes of diabase, as previously noted, and at the Sierra buttes. The first belt is represented in the table of analyses by Nos. 323 and 288, and the second belt by Nos. 153, 384, and 128.

The distinction between the quartz-porphyries of Plumas county and the quartz-porphyrites of the Jackson atlas sheet evidently rests on a slender basis and may be discarded later. The quartz-porphyry of the Grizzly mountains may, however, prove to be Paleozoic in age. This is suggested by its association, as noted above, with presumably Silurian argillite. The quartz-porphyry is, in part at least, as late as or later than some of the diabase known to be Mesozoic in age. This is probably the case with the long belt extending from Eureka peak to the Sierra buttes.

No. 323 is a fresh rock from a terminal moraine at the mouth of a ravine on the east slope of the Grizzly mountains. that heads just south of Tower rock. The moraine is largely made up of bowlders of this rock, and as these bowlders came manifestly from the area of quartz-porphyry of the Grizzly mountains, above referred to, and being fresher than any rock found in place, it was selected for analysis. This rock is not schistose. There are abundant porphyritic quartzes and feldspars in a fine groundmass. The rock contains more lime than is normal with a quartz-porphyry and more potassa than is normal with a quartz-porphyrite. In the analysis Hillebrand states that all the iron other than that in the pyrite is considered as FeO. In the pyrite the sulphur was 0·31 per cent.

No. 288, Plumas county, is from in place on the crest of the Grizzly mountains, bout 2 miles southeast of Tower rock. It is somewhat schistose. From the low percentage of lime it is evident that soda-lime feldspars enter into its composition to a limited extent only.

The other belt of quartz-porphyry above referred to afforded the following specimens:

No. 153, Plumas county, is from the east slope of Eureka peak. At the contact of this rock with the gabbro that forms the lower part of the slope it contains fragments of the gabbro, showing the quartz-porphyry to be later than the gabbro. It consists of feldspar and quartz phenocrysts embedded in an allotriomorphic groundmass of quartz and feldspar.

No. 384, Plumas county, corresponds more nearly in composition to quartz-porphyrite and is noted under that head. Nevertheless it forms part of the same area as Nos. 153 and 128.

No. 128, Plumas county, from Bunker hill, is a thoroughly schistose rock. The quartzes are idiomorphic, and there is developed in the groundmass a large amount of a slightly greenish fibrous mineral with bright polarizing colors. This appears to be muscovite, since, as the rock contains no magnesia, it can not be talc.

The analysis of No. 323 is by Dr. Hillebrand, No. 252 by Mr. L. G. Eakins, and the remainder by Messrs. Hillebrand and Steiger.

Analyses of quartz-porhyrites and quartz-porphyries.

	No. 151, Amador.	No. 553, Calaveras.	No. 252, Calaveras.	No. 549, Calaveras.	No. 323, Plumas.	No. 384, Plumas.	No. 153, Plumas.	No. 288. Plumas.	No. 128, Plumas.
SiO_2	70·29	71·19	71 67	72·24	73·25	73·62	75·06	76, 69	79·41
TiO_2	·29	·35		·41	trace.				
Al_2O_3	11·83	13·81		13·85	13·25				
Fe_2O_3	1·30	1·45		1·45					
FeO	2·08	1·68		1·86	1·74				
MnO	·12	·07		·12	trace.				
CaO	2·30	2·87		3·40	2·23	2·55	·38	·97	·09
SrO	trace?	trace?		trace.	trace?				
BaO	·07	·16		·08	trace.				
MgO	1·24	·74		1·10	·28				none.
H_2O	3·05	1·82	·19	·39	3·79	2·23	4·27	2·29	2·75
N_2O	2·68	4·24	4·00	4·43	2·69	2·46	3·78	4·62	2·81
Li_2O	none.	none.		none.	trace.				
H_2O below 100° C.	·10	·15		·17	·07				
H_2O above 100° C.	1·35	·92		·69	1. 03				
P_2O_5	·07	·08		·10	trace.				
CO_2	3·25	·82			1·05				
FeS_2					·58				
	100·02	100·35		100·29	99·96				

EFFUSIVE IGNEOUS ROCKS.

RHYOLITE.

The rhyolitic rocks of the Sierra Nevada are chiefly white or pink in color and seem to have issued as flows from various sources, chiefly near the crest of the range. These rocks usually occur overlying the Neocene auriferous river gravels. At Valley Springs peak, in Calaveras county, and at other points they overlie the Ione formation. The rhyolite flows evidently followed the old river channels to a remarkable extent. The exact nature of these flows is not in all cases determined. They have been considered as tuffs or mud flows, but in thin section some specimens show trains of spherulites and other evidences of having been molten lava. This is the case with some of the rhyolite near Mokelumne hill (see geologic map of Golden Gate hill), which has been spoken of as a tuff.

Occasionally, as at Valley Springs peak, the rhyolite contains pebbles of other rocks, but fragments of foreign material are, so far as known to the writer, rare in the rhyolite. This would seem to preclude the idea of the material being thrown out as volcanic ashes, which falling on the river waters would be carried down many miles, and if the ash eruptions were sufficient in amount would finally displace the rivers. In such a case ashes would be washed into the rivers from surrounding slopes and, it would seem, would soon necessarily carry with them a good deal of foreign material. It has been thought that the so-called rhyolitic tuffs also reached their present positions as mud flows, and this may be true of some of the areas.

The rhyolite occurs in unquestionably massive form as dikes in the granites and schists. One of these (No. 400, Plumas county) is remarkable as containing large amounts of gold in little quartz seams which penetrate the dike in all directions. This dike, which lies about 1 mile east of Onion valley at the headwaters of Poorman creek, is much decomposed in the auriferous portion. It is a white rock with abundant foils of brown mica, sanidine, and plagioclase, and a few rounded quartzes in a microcrystalline groundmass.

The rhyolite tuff under the microscope is seen to consist of porphyritic plagioclases and sanidines, which are often fragmental, brown mica foils, and in some sections quartzes, in a groundmass that is usually largely glass.

The rhyolite of the Sierra Nevada appears to be all of about the same age. The flows overlie the Neocene auriferous river gravels and underlie the andesite-breccias, and may have occurred early in the Pliocene.

It has been suggested that the clays of the Ione formation have resulted from the decomposition of rhyolite. In this case, since the Ione formation appears to be in part Miocene in age, the rhyolitic flows may have commenced earlier than the Pliocene.

To the south of Mono lake and just east of the escarpment of the Sierra Nevada are some small extinct rhyolitic volcanoes, perhaps of Pleistocene age. These have been described by Prof. I. C. Russell.[1]

Rhyolite is especially abundant in the foothills of Amador and Calaveras counties, forming, when it caps the points, the level tops of table mountains, of which Buena Vista and Valley Springs peaks are conspicuous examples. No place has been noted in the foothills from which rhyolitic eruptions issued. The occurrences seem always remnants of former extensive areas from other sources.

At Buena Vista peak and other points a peculiar feature in the weathering of the rhyolite was noted. The exposed surfaces are more compact than the interior, presenting as a fractured surface a vitreous

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[1] Eighth Ann. Report, U. S. Geol. Survey, p. 378.

appearance. This seems to be due to the silica of the rhyolite being leached out by atmospheric moisture and deposited nearly in place. The same phenomenon was previously noted by Mr. Goodyear[1] at several places.

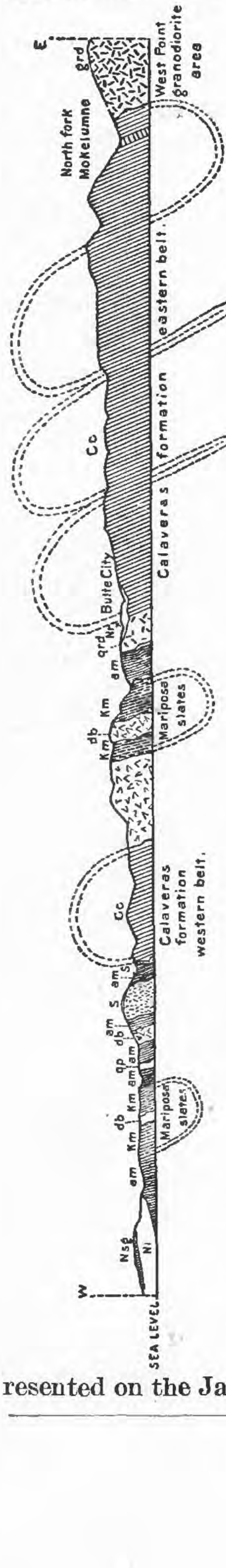


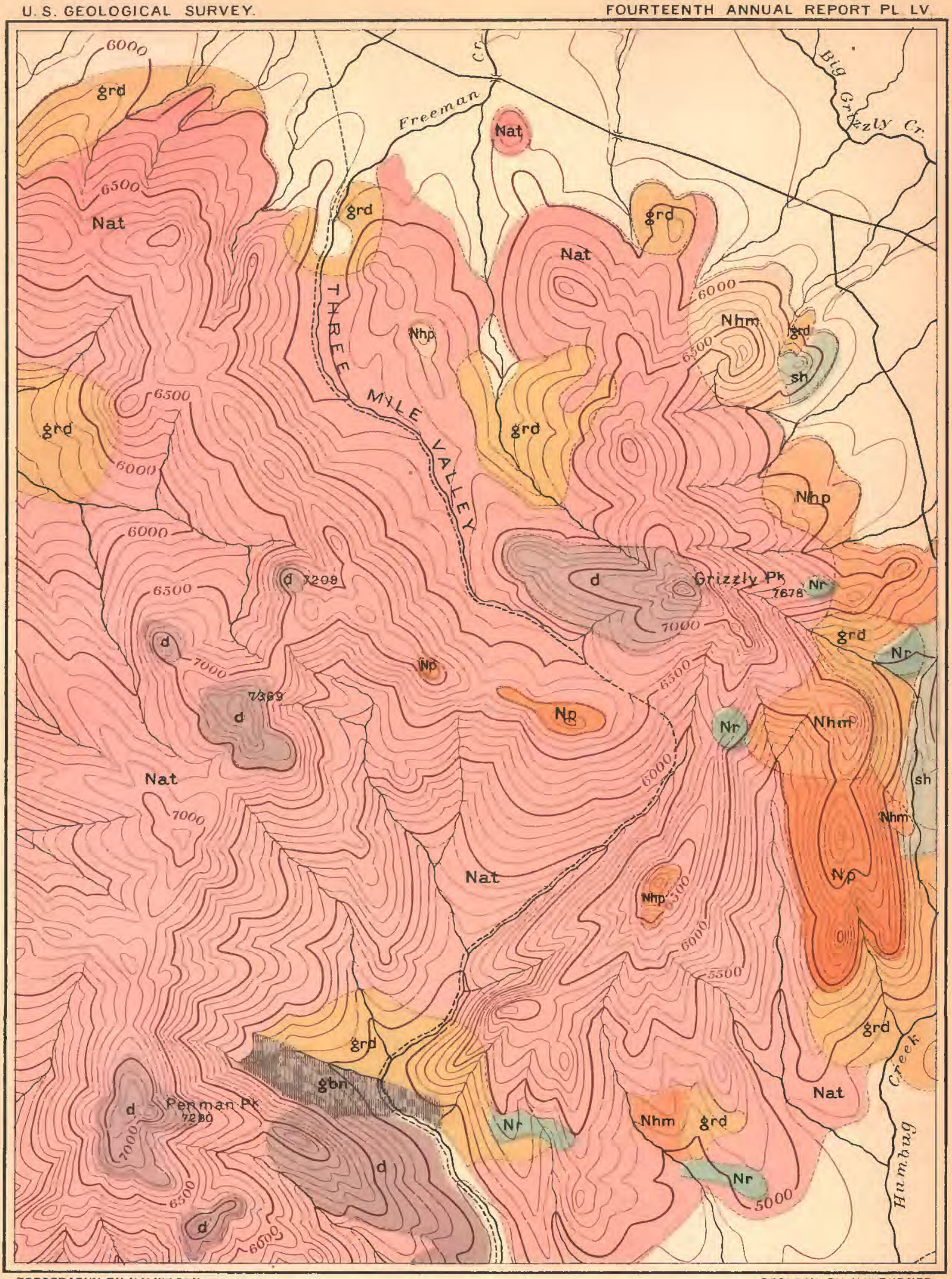
FIG. 51.—Section across the Gold Belt in Amador county, Cal. Horizontal scale, about 5 miles to the inch; vertical scale, about 8,000 feet to the inch.

The old mining town called Butte, 1 mile southwest of Jackson butte, in Amador county, is on an area of fragmental rhyolitic material. A careful examination of this area disclosed the curious fact that there is here a basin entirely surrounded by rocks of pre-Tertiary age (the bed-rock series.) This basin was evidently formed by orographic or volcanic disturbances after the old river gravels were deposited, for these Neocene river gravels now occupy higher points on the surrounding ridges.

According to a resident of Butte, who was there at the time, four shafts were sunk some years ago in this white detrital material. Three of these, 220, 180, and 130 feet in depth, respectively, did not reach bed rock or gravel; another which I saw, near the margin of the basin and 80 feet in depth, struck the bed rock. The rhyolitic material shows evidence in its slightly rolled fragments of having been washed into this basin from rhyolite areas in the neighborhood. There are some pebbles of pyroxene-andesite and fragments of the neighboring diorite mixed with the rhyolitic detritus, showing that a portion of the deposit formed after the andesite eruptions had begun. A stream has made a narrow cut in the bed-rock rim of this basin at one point on the south side, and the stage road from Jackson to Mokelumne hill passes through this cut, which has an elevation of about 1,000 feet, and the bottom of the basin must be at least 150 feet below the cut. The section across the Gold Belt (Fig. 51) north of the Mokelumne river shows this basin and the rhyolitic area.

It is by no means improbable that we have here an old volcanic orifice, and that underneath the surface fragmental rhyolitic material there is rhyolite in place. The area is represented on the Jackson sheet.

[1] See Auriferous Gravels, p. 520.



TOPOGRAPHY BY H. M. WILSON.

GEOLOGY BY H. W. TURNER.

PLEISTOCENE.	PLEISTOCENE?	NEOCENE.					JURA-TRIAS AND OLDER.		
	d	Nhp	Np	Nat	Nhm	Nr	grd	gbn	sh
	Dolerite	Hornblende-Pyroxene andesite.	Pyroxene-andesite	Andesite-tuff and breccia.	Hornblende-mica andesite.	Rhyolite.	Granodiorite.	Gabbro and norite.	Pre-Tertiary Schists.

Scale $\frac{1}{62.500}$

0 1 2 miles.

Contour interval 100 ft.

GEOLOGICAL MAP OF GRIZZLY PEAK. CALIFORNIA.

JULIUS BIEN & CO. N.Y.

The following are partial analyses of the Sierra Nevada rhyolites, made chiefly by Dr. W. F. Hillebrand:

	Silica.	Lime.	Potassa.	Soda.
No. 365, Plumas county	72·70	1·15	4·81	3·46
No. 160, Plumas county	70·64	....	....	....
No. 337, Plumas county	71·14	....	....	....
No. 111, Amador county	71·21	....	4·16	1·82
No. 133, Amador county	69·45	....	5·25	·80
No. 136, Amador county	71·85	....	5·11	1·48
No. 279, Calaveras county	69·99	....	....	....

ANDESITE.

The rocks of the andesitic series occur in enormous amounts, chiefly in the form of a tuff or breccia, and it is evident that the areas now existing are but remnants of a vast sheet of this material that formerly covered a large part of the Sierra Nevada to the north of the Tuolumne river drainage, or about the latitude of parallel 38° north.

The andesite-breccia ridges are monotonous in the extreme. They are nearly level, frequently almost bare of vegetation, and are often difficult of travel because of the bowlders that have weathered out from the breccia and are strewn upon the surface everywhere.

Andesite in the massive form occupies but small areas, and these chiefly near the summit or on the east slope of the range. One of the districts where massive andesite is more than usually abundant is that about Grizzly peak, in Plumas county.

As may be seen by referring to the geologic map of Grizzly peak, (Pl. LV) even here the andesite-breccia forms the larger part of the volcanic material. It may be remarked also that a greater variety of lavas are here represented than can perhaps be found in any area of similar size in the Sierra Nevada. We have:

First, some small areas of rhyolite, which is perhaps the oldest lava;

Second, four areas of hornblende-mica-andesite, which may be of about the same age as the rhyolite;

Third, several areas of hornblende-pyroxene-andesite in the massive form, and the very abundant breccia;

Fourth, two areas of pyroxene-andesite;

Fifth, several areas of the late basalt or dolerite.

We will now consider briefly the andesite lavas of this district. In the table of analyses on page 490 the andesites are arranged in the order of their silica contents. Under the microscope, with crossed nicols, the darkness of the groundmass of most of the andesites suggests the presence of glass, although when examined with high powers the groundmass usually seems microcrystalline to cryptocrystalline. It may be remarked that nearly all of the hornblendic andesites of the Sierra Nevada are trachytic in aspect.

Hornblende-mica-andesite.—This rock is light gray in color and is found in two areas, one a mile and a half northeast, and the other a mile and a quarter southeast, of Grizzly peak. It strongly resembles the dacite of the Lassen peak region, but shows in the thin section examined no quartz phenocrysts. The composition of this rock, also (see No. 198, Plumas county, table of andesite analyses), would indicate that it is too low in silica for a dacite.

The coarse No. 198 andesite contains a large amount of basaltic hornblende and very little brown mica. Some of the feldspar phenocrysts have a nonstriated but corroded interior surrounded by a border of fresh striated feldspar. The groundmass is cryptocrystalline, and is apparently largely feldspar, with magnetite grains.

No. 350, Plumas county, is another example of the hornblende-mica-andesite, in which the ferro-magnesian constituents are in small amount. This specimen is from the area 3½ miles south of Grizzly peak. As may be seen in the table, the silica percentage is unusually high, yet there are no quartz phenocrysts in the thin section examined. Macroscopically the rock is a light gray, rather fine grained rock, in which the feldspar phenocrysts show as lighter spots, with a few black prisms resembling hornblende. Microscopically the rock is composed of feldspar phenocrysts with few twin striations, and black grains and prisms of iron oxide, in a microcrystalline groundmass of feldspar microlites and magnetite. Some of the feldspar phenocrysts, which show no polysynthetic twinning, but possesses a marked cleavage, are perhaps sanidine. The black prisms of iron oxide may represent original ferromagnesian silicates. The hornblende-mica-andesites are, on the whole, the most acid of the series.

Hornblende-andesite.—Included in the table of analyses is an andesite (No. 12) which contains neither mica nor pyroxene. Although not occurring on the Grizzly peak map, it is described here for convenience:

No. 12, Plumas county. This occurs in a massive form 4 miles from Pilot peak, in Plumas county. At one point, near the road to Johnsville, andesite resembling this is cut by a dike of basalt. The rock is coarse grained, with large irregular feldspathic spots and abundant basaltic hornblende. Under the microscope it is seen to be composed of plagioclase and hornblende phenocrysts in a cryptocrystalline groundmass, containing abundant magnetite grains.

Hornblende-pyroxene-andesite.—This rock in a massive form occurs to the east and southeast of Grizzly peak and elsewhere. As no analyses have been made of this rock from the area of the Grizzly peak map, two specimens, whose analyses are given (No. 69 and No. 123, Plumas county), will be briefly characterized. These two specimens may be taken as average samples of the bowlders of the andesite-breccia areas, although one of them (No. 123) occurs in the massive form.

No. 69, Plumas county, is from a bowlder in the andesite-breccia 2 miles northeast of Laporte. It is a purplish gray, porous, rather coarse grained rock, with abundant black hornblendes. Microscopically it consists of phenocrysts of hornblende, augite, hypersthene, and plagioclase in a groundmass of feldspar microlites and grains of magnetite and pyroxene.

No. 123 strongly resembles one of the pyroxene-andesites described hereafter (No. 308, Plumas county), except that it is finer grained and shows a few hornblende needles. Under the microscope it is seen to be composed of idiomorphic phenocrysts of plagioclase, hornblende, and hypersthene in a microcrystalline groundmass of feldspar, magnetite, and pyroxene, with perhaps some glass.

There are included in the table of analyses three tuffs that are characteristic specimens of the fine layers in the breccia areas.

ANDESITE BRECCIA RIDGES OF MOUNT RAYMOND, ALPINE COUNTY, CALIFORNIA.

No. 278, Calaveras county, is a rather fine grained brownish tuff from near Valley Springs.

No 121, Amador county, is from the butte 5 miles north of west from Buena Vista peak. It represents the very fine grained light buff colored layers that may be found in the tuff at many localities. Under the microscope this is seen to be composed chiefly of plagioclase fragments with many bits of brown hornblende; a few light brownish streaks marked with rows of dots seem to be the siliceous epidermis of some vegetable forms.

No. 139, Amador county, is from about 2½ miles northeast of Camanche. It is a coarse tuff, or volcanic sandstone, with numerous bluish grains, and is composed of grains of plagioclase, augite, and quartz, with microlitic fragments, some of which are hornblendic.

The andesite-breccia and tuff masses appear to have, in some cases at least, reached their present position in the form of mud flows. The andesite-breccia weathers into the most fantastic shapes, especially high up along the crest of the range, or, in other words, near the source of eruption. Frequently at such places there is no evidence whatever of stratification. This is the case with a part of the material of Mount Raymond, in Alpine county, and a view of two serrated ridges which extend from this point as spurs is given in Pl. LVI. These are the ridges represented on page 446, plate IX, of Geological Survey of California, Vol. I, Geológy. When the material is finer grained and stratified, as is the case with the majority of the andesite-tuff and breccia areas in the foothill region, the rock weathers into smoother forms, frequently with perpendicular bluffs at the sides.

Pyroxene-andesite.—This rock is represented on the Grizzly peak map by two areas on the ridge south of Grizzly peak. It is macroscopically a light gray, medium grained rock (No. 308, Plumas county). Under the microscope it is seen to be made of plagioclase, augite, and hypersthene phenocrysts in an almost cryptocrystalline groundmass of feldspar and magnetite. It thus differs very little in mineralogical composition from such of the dolerite as contains no olivine, but differs in structure in that it has a definite groundmass. If andesite, it should contain more silica than the dolerite, but no analysis has been made of this rock. It greatly resembles the hornblende-pyroxene-andesite and may be considered merely a variety of that type.

There is also a peculiar pyroxene-andesite that appears to be later than the other andesites. It is macroscopically a light gray, fine grained rock, with frequently a slaty fracture. Microscopically it is nearly or quite holocrystalline and is composed of slender laths of plagioclase or augite, and of a slightly pleochroic rhombic pyroxene, with magnetite grains.

There is a dike-like occurrence of this rock (No. 332, Plumas county) on the east side of Mohawk valley, and a little east of the bridge over the middle fork of the Feather river, at Denten's. In contact with this dike the Pleistocene lake beds of Mohawk valley dip at an angle of 25° from horizontality. This lava occurs at various points in Plumas and Sierra counties, but has not been noted by the writer elsewhere in the Sierra Nevada. It forms the high point 1½ miles northeast of Goodyear's bar, the ragged crest 1 mile northeast of Saint Charles ranch, and occurs on the southwest slope of Saddle Back, one also 1 mile south of Deadwood, all of these points being on the Downieville sheet.

A specimen (No. 387, Plumas county) of this late pyroxene-andesite from the area about 2 miles west of Eureka peak, contains 61·47 per cent of silica, as determined by George Steiger.

Analyses of andesites.

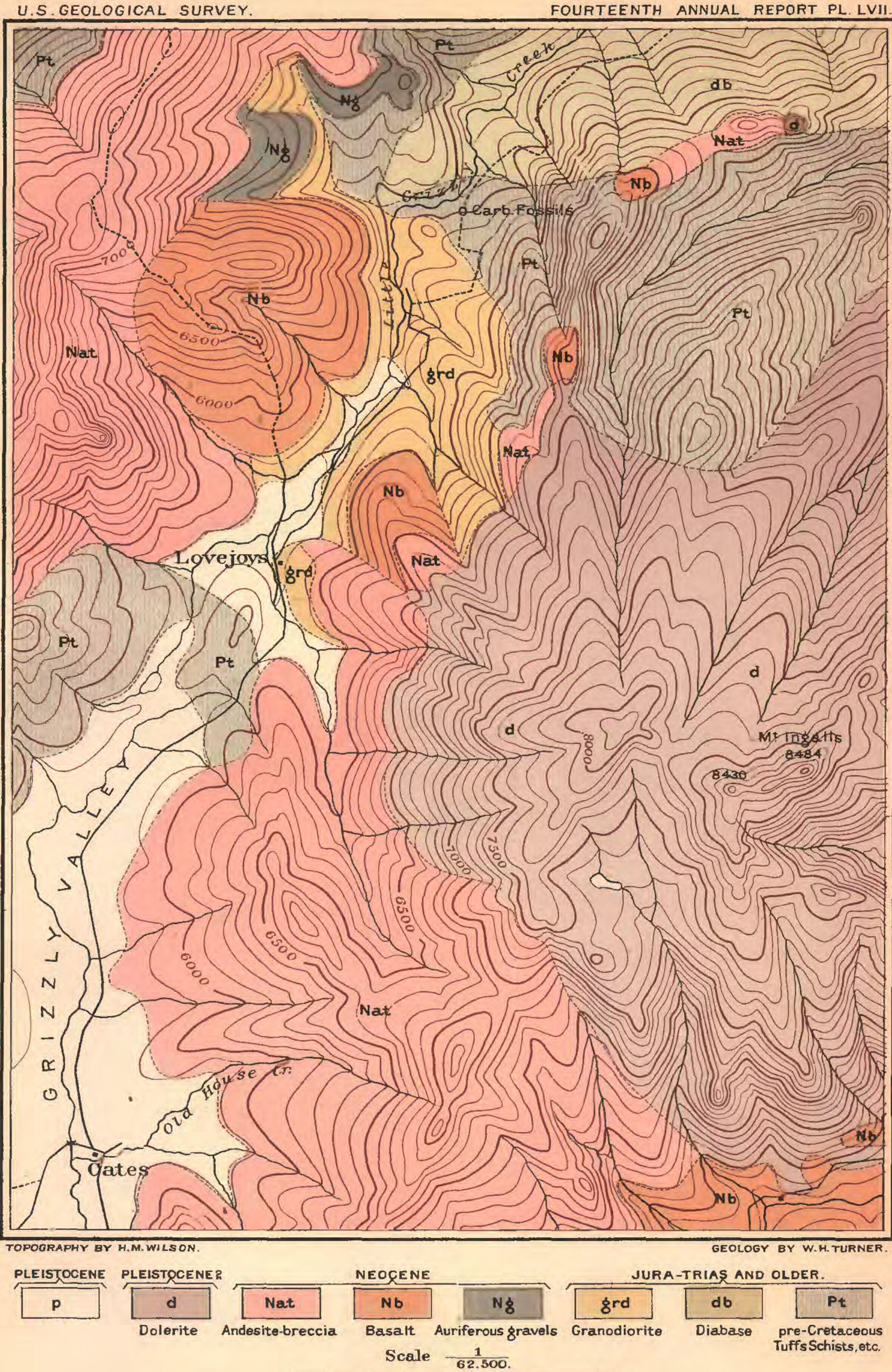
	No. 278, Calaveras.	No. 121, Amador.	No. 69, Plumas.	No. 139, Amador.	No. 198, Plumas.	No. 123, Plumas.	No. 12, Plumas.	No. 350, Plumas.
SiO_2	54·15	55·35	57·32	59·53	59·97	60·00	60·20	66·88
TiO_2							·57	
Al_2O_3							17·21	
Fe_2O_3							3·12	
FeO							2·69	
MnO							·12	
CaO			7·13		6·09	6·33	6·04	3·54
SrO							trace.	
BaO							·11	
MgO							3·18	
K_2O	1·62	1·51	1·39	2·28	1·35	1·71	1·44	1·84
N_2O	3·31	3·67	4·14	2·72	3·98	3·62	3·35	4·62
Li_2O							trace.	
H_2O below 100°C							1·12	
H_2O above 100° C							1·18	
P_2O_5							·17	

OLDER BASALT.

This is a dense black rock showing macroscopically no porphyritic constituents except occasional olivines. It is frequently roughly columnar, the prisms being small, seldom more than 3 or 4 inches in diameter. This rock has nowhere been seen by the writer except in the massive form.

Microscopically the rock is composed of lath-like plagioclase with more or less olivine and some augite in a groundmass which is rendered dark by the abundant magnetite. The groundmass sometimes contains considerable glass and frequently grains and prisms of augite. Much of the olivine is altered to serpentine. The plagioclases are usually small and of nearly even size. One slide, from the basalt of the Mooreville ridge at the Dodson hydraulic mine, shows comparatively little magnetite, and is nearly holocrystalline, with a few porphyritic plagioclases and olivines. The rock at this locality is interesting from containing abundant crystals of chabazite in cavities. Although differing in microscopic character at different points, the rock is never coarse grained and is always dark in color.

So far as known to the writer, this older basalt only occurs in Plumas and Butte counties. It is shown on the geological map of Mount Ingalls, in which neighborhood it is very abundant. It is the lava of the Walker plains in Plumas county, and also occurs to the north and south of Onion valley creek, and in small areas at numerous points. In Butte county it caps the Mooreville ridge and several ridges north of that ridge; also Oroville Table mountain and Kanaka peak, and at all



TOPOGRAPHY BY H.M. WILSON. GEOLOGY BY W.H. TURNER.

PLEISTOCENE	PLEISTOCENE?	NEOCENE			JURA-TRIAS AND OLDER.		
p	d	Nat	Nb	Ng	grd	db	Pt
	Dolerite	Andesite-breccia	Basalt	Auriferous gravels	Granodiorite	Diabase	pre-Cretaceous Tuffs Schists, etc.

Scale $\frac{1}{62.500}$.

0 1 2 miles

Contour interval 100 ft.

GEOLOGICAL MAP OF MOUNT INGALLS. CALIFORNIA.

JULIUS BIEN & CO. N.Y.

of these places it rests upon Tertiary deposits, chiefly auriferous river gravels, or upon the pre-Tertiary bed rock. It forms the lava of Iron canyon of Chico creek, apparently resting there directly on Cretaceous sandstone of the Chico formation. As will be shown hereafter, the basalt above described is older than the hornblende-pyroxene-andesite-breccia.

The black lava capping the Millerton Table mountain in Fresno county resembles macroscopically the older basalt of Butte and Plumas counties.

The basalt of the Tuolumne Table mountain is also a dark, heavy rock, but as may be noted below, has an unusually high percentage of silica for a basalt. It is also characterized macroscopically by containing numerous cavities and tabular porphyritic feldspars which are sometimes half an inch long. Microscopically the Table mountain basalt shows large tabular feldspars, smaller augites, and numerous olivine grains in a nearly opaque groundmass, in which are very abundant feldspar microlites. This groundmass doubtless contains a large amount of magnetite and strongly resembles some of the sections of the older basalt. There is a good deal of brownish serpentinoid substance in the groundmass. The porphyritic feldspars are polysynthetically twinned and have a corroded appearance, due to the abundant inclusions of aggregates of opaque particles, with some glass inclusions. There is also some serpentine in the large feldspars. The relative age of this basalt has not been determined. Pebbles of hornblende-pyroxene-andesite (No. 165, Calaveras county) occur under a basalt table mountain on the north side of the Stanislaus river, near the Byrnes' Ferry bridge. This basalt is doubtless part of the Tuolumne Table mountain flow. This would suggest that the Tuolumne Table mountain basalt is later in age than the hornblende pyroxene-andesite breccia. For convenience, however, it is included here.

Analyses of the older basalt.

	No. 276, Plumas county.	No. 148, Butte county; Oroville Table mountain.	No. 36, Sierra Nevada; Tuolumne Table mountain.
SiO_2	50·56	50·66	56·19
TiO_2	1·71	2·39	·69
Al_2O_3	14·71	13·97	16·76
Fe_2O_3	3·54	2·55	3·05
FeO	8·90	10·20	4·18
NiO	....	trace.	....
MnO	·13	·29	·10
CaO	7·58	8·08	6·53
SrO	trace?	trace.	strong trace.
BaO	·25	·22	·19
MgO	4·07	4·45	3·79
K_2O	2·10	1·95	4·46
N_2O	2·94	3·32	2·53
LiO_2	trace?	none.	trace.
H_2O below 100° C	1·06	·27	·34
H_2O above 100° C	1·12	·43	·66
P_2O_5	1·14	1·01	·55
Cl	....	·02	....
	99·81	99·81	100·02

DOLERITE.

This lava was described under the name of "late basalt"[1] in a previous paper. Some areas of it are shown on the geologic maps of Grizzly peak and Mount Ingalls. It occurs at numerous points in Plumas and Sierra counties. Through the kindness of Mr. J. S. Diller I was permitted to examine a series of basalt slides of the Cascade range collection, and found that a considerable number of the basalts to the north of Plumas county are of the same type. The "hypersthene basalt," mentioned by Mr. Diller in his paper on fulgurite from Mount Thielson, Oregon (No. 181, Cascade range collection), is practically identical with some of the dolerite of Mount Ingalls.

Almost all the areas examined by the writer overlie the hornblende-pyroxene-andesite breccia. In the ravine that heads about 1½ miles south by east from the summit of Mount Ingalls the dolerite is marked by glacial striæ, and the pond indicated on the map near this point has been formed by a terminal moraine. It is, therefore, earlier in age than at least the latter part of the glacial period. On Mount Ingalls it presents the appearance of having issued after the present drainage system had been partially formed, suggesting the age to be Pleistocene.

The rock is macroscopically a medium to coarse grained light gray rock, sometimes pinkish, usually with large scattered olivines. Under the microscope it is seen to be nearly or quite holocrystalline, and to be composed of lath-like plagioclase, augite, and magnetite, with occasional olivines, and frequently hypersthenes. One of the slides shows a hypocrystalline base containing abundant grains of magnetite with numerous phenocrysts of plagioclase and augite and a few hypersthenes and olivines. In general, however, no glass is to be seen.

The dolerite of Grizzly peak, in the slide examined, contains no olivine and comparatively little pyroxene. In the slides examined of the dolerite of Penman peak and other areas near that point, there appears to be no hypersthene, but olivine is more abundant than at Mount Ingalls.

The two following analyses of dolerite were made by W. F. Hillebrand; both specimens came from Mount Ingalls. No. 311, Plumas county, is from 1 mile a little west of south from the summit of the mountain. It is a light gray, rather coarse grained, almost granular rock. Under the microscope it is seen to be apparently holocrystalline and nearly panidiomorphic. It is composed of lath-like plagioclase, greenish augite, and abundant hypersthene, magnetite grains, and a few olivines. No. 314, Plumas county, is a medium grained grayish rock from the extreme summit of the mountain, and is very similar in mineralogical composition to 311, but with scarcely any olivine:

ANALYSES OF DOLERITES.

	No 311, Plumas county	No. 314, Plumas county		No 311, Plumas county	No. 314, Plumas county.
SiO_2	53·91	52 81	MgO	5 52	6·12
TiO_2	52	·84	K_2O	1·34	1 05
Al_2O_3	17·95	16 60	N_2O	2 90	2 79
Fe_2O_3	2 21	2 66	LiO_2	trace	trace
FeO	4·80	6 13	H_2O at 100° C	20	38
MnO	10	undet	H_2O above 100° C	·20	·54
CaO	10 40	10 14	P_2O_5	·21	23
SrO	trace.	trace			
BaO	05	·03		100 31	100 32

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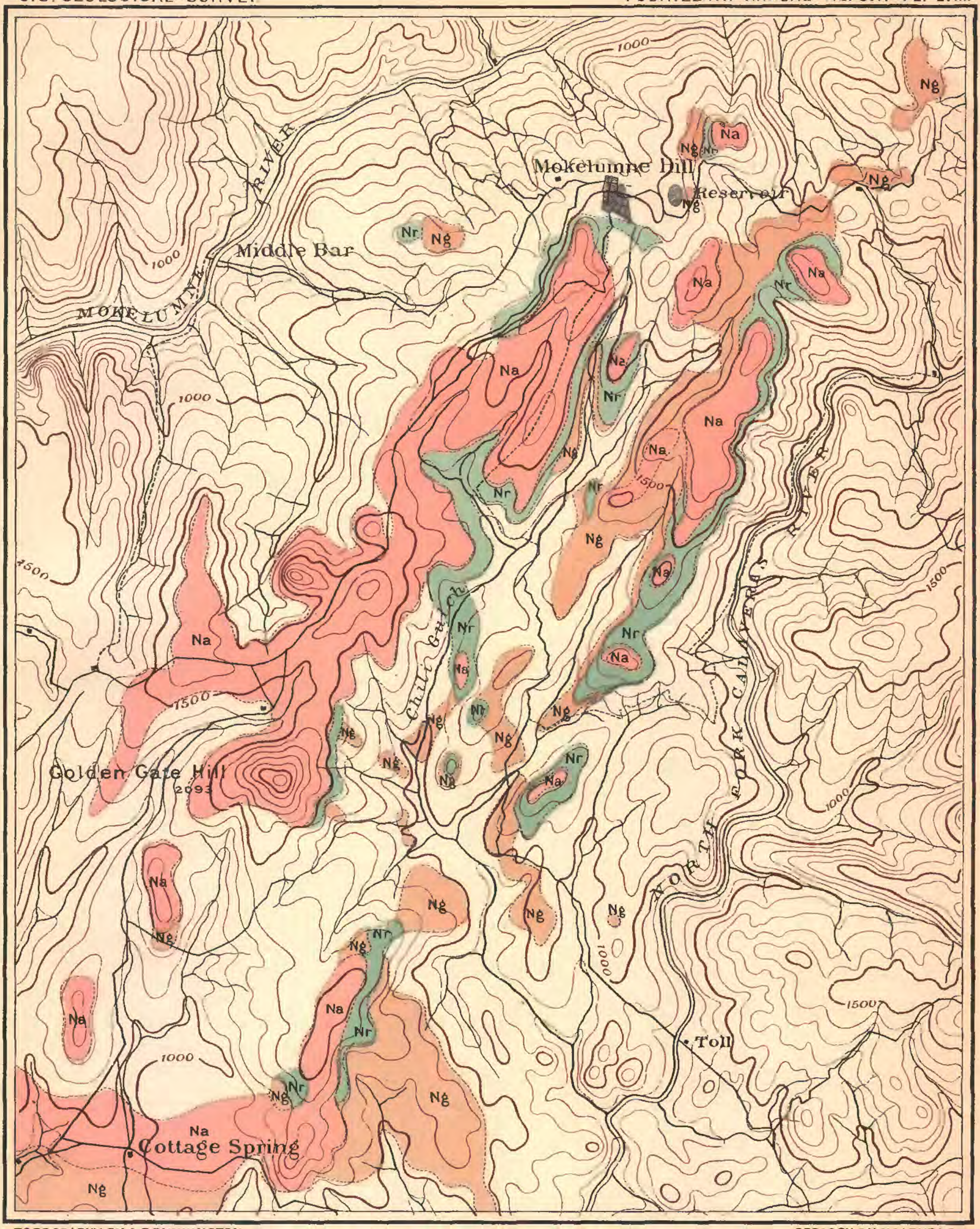
[1] Am Jour Sci, Vol XLIV, p 455.



TOPOGRAPHY BY A.F. DUNNINGTON. GEOLOGY BY H.W. TURNER

NEOCENE			PRE-TERTIARY.
Na	Nr	Ng	
Andesite massive and fragmental	Rhyolite-tuff.	Auriferous river gravels.	

Scale $\frac{1}{62.500}$.

0 1 2 miles.

Contour interval 100 ft.

GEOLOGICAL MAP OF GOLDEN GATE HILL AND VICINITY. CALIFORNIA.

OTHER LATE BASALTS.

Occurring usually in small areas and often forming little buttes are dikes and flows of basalt, some of them probably Pleistocene in age. The basalts referred to are nearly all dark and rather fine-grained, differing chiefly from the older basalt macroscopically in containing an abundance of olivine. The columnar dike forming Lava peak, on the Downieville sheet, appears to have cut through the Neocene gravel beds that cap the ridge about the peak. The age of these small, usually isolated areas of basalt in reference to the Tertiary volcanic rocks is in many cases doubtful.

THE SUCCESSION OF THE TERTIARY VOLCANIC ROCKS.

There is a considerable variety of Tertiary volcanic rocks in the Sierra Nevada, but there are only a few general types that have an extensive distribution. The oldest of the series are perhaps the hornblende-mica-andesites, which occur in small areas on the Downieville sheet and elsewhere, but the earliest flows of which the relative age is definitely known are of rhyolites and basalts.

Of these two older rocks the rhyolite has much the wider distribution, it being found throughout the Gold Belt. The basalt referred to above as the older basalt is, so far as known to the writer, confined to Butte and Plumas counties. That the rhyolite and older basalt of the Sierra Nevada in general underlie the hornblendic pyroxene-andesite, which in the form of a breccia covers so much of the range, has been noted in two previous papers.[1] It appears, however, that the writer was not the first to call attention to these relations. In a report made to Prof. J. D. Whitney in 1879, Prof. W. H. Pettee writes:[2]

> On the crest of the ridge just above the mining claim on the Oroville road, at an altitude of 5,060 feet, there is a gray andesitic lava. If these observations are correct, this part of the Mooretown ridge shows basalt at the base and andesite above. This, I believe, is an order of arrangement just the reverse of what has been supposed to be the rule in the Sierra Nevada.

In a report in the same volume Mr. W. A. Goodyear[3] states:

> Moreover, the white lava, enormous as is its quantity at many localities, whenever it occurs in close association with other and coarser volcanic materials (which is oftener than otherwise the case), always underlies them, forming the lowest volcanic structure. * * * There may possibly be another point of interest in this connection, too. If the white lava and its allied materials are essentially rhyolitic in character, and the gray and darker-colored compact rocks which constitute the bowlders and solid fragments in the conglomerates, the breccias, and volcanic gravels are generally trachytic in their nature, then this fact would seem inconsonant with Richthofen's general theory; for it would then appear, not as an isolated instance, but as a general fact all over this section of the country, that trachyte had succeeded rhyolite in point of time of its ejection.

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[1] Bull. Phil Soc. Washington, Vol. XI, p 389, and Am Jour Sci, Vol XLIV, pp 455-459

[2] Auriferous Gravels, p 468

[3] Auriferous Gravels, p. 522.

The "trachyte" of Richthofen has been shown by Becker,[1] and afterward by Hague and Iddings,[2] to be andesite, and the rocks so called by Goodyear are now well known to be hornblendic pyroxene-andesites.

The geologic map of Golden Gate hill and vicinity shows the rhyolitic and andesitic tuffs in their usual relation, while the geologic map of Mount Ingalls shows the relation of the andesite to the older basalt. This relation, however, is best seen in the vicinity of Red Clover valley, to the southeast of Mount Ingalls, where there is a large area of the older basalt, covering 5 or more square miles, which is overlain by andesitic breccia. The later age of the andesitic fragmental material is best shown about 4 miles east-southeast from Mount Ingalls, to the north of Red Clover valley. Here a nearly horizontal bluff of andesite rests on the older basalt. This bluff is shown in Pl. LIX.

The older basalt reaches from Red Clover creek below to the base of the andesite bluff, a vertical distance of about 500 feet. Resting directly on the basalt is an andesitic conglomerate 15 feet thick, containing some fragments of the older basalt, as well as granite pebbles, but chiefly made up of pebbles and fragments of andesite.

Resting on the conglomerate is a layer of fine even-grained andesite tuff from 1 to 4 feet thick. The tuff layer is approximately horizontal. It is made up of minute fragments of plagioclase, augite, hypersthene, green hornblende, and apparently some quartz with opaque and discolored particles. It is very plainly fragmental, and contains also fragments of plant stems.

Above the tuff is andesitic breccia 30 feet in thickness. This shows no evidence of stratification. A little to the east of the bluff, lying on this breccia and presumably weathered out of it, were found fragments of silicified wood (No. 259, Plumas county).

The same superposition of andesite-breccia on the older basalt may be seen 5 miles southeast of Quincy, by the road to Laporte; 9 miles northeast of Pilot peak, to the north of the middle fork of the Feather river; about 2 miles northwest, and again 3 miles southwest, of Onion valley, Plumas county; and both north and south of the south fork of the Feather river, in Plumas county. Mr. Diller has described some fragmental volcanic beds which cover large areas in Butte county as the Tuscan formation.[3] This tufaceous formation consists in part of breccia, and resembles in a general way the andesitic breccia areas farther south, but it appears to consist in part of basaltic material of the type of the later basalt or dolerite. The exact relation of the Tuscan formation to the andesite-breccia areas of the Gold Belt therefore remains to be determined.

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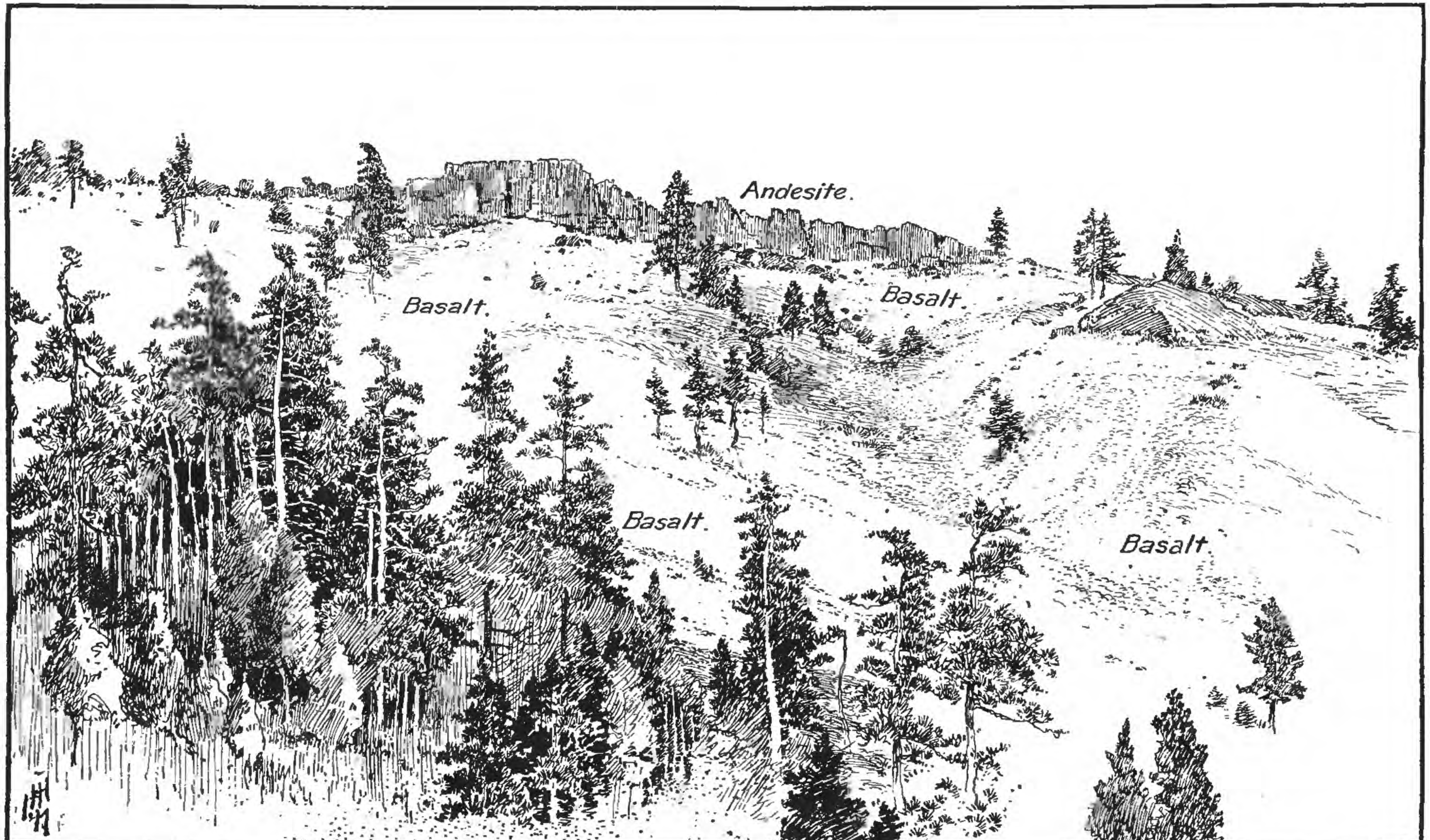
[1] Geology of the Comstock lode; Monograph III of the U. S Geol Survey. I am informed by Mr. Becker that the later hornblende-andesite described on pages 66 to 70 of the above memoir is one of the trachytes of von Richthofen.

[2] Am. Jour. Sci., 3d series, Vol XXVII, p. 453.

[3] Descriptive text, Lassen peak sheet



ANDESITE BRECCIA ON OLDER BASALT.

The relation of the older basalt to this tuff is shown in the Iron canyon of Chico creek, where the older basalt (No. 1, Butte county) rests directly on Chico sandstone and underlies the Tuscan formation.

I also obtained confirmation of this relation by finding pebbles of the older basalt under the tuff at two points, one (No. 15, Butte county) from a tunnel about 3 miles southwest of Nimshew, and another (No. 52, Butte county) from a little butte about 1 mile west of Pentz post-office.

The geologic map of Mount Ingalls likewise illustrates the relation of the later basalt or dolerite to the andesite. It seems plainly later than the andesite. It forms the summits and slopes of Mount Ingalls down to and in places below the 7,000-foot contour, and evidently poured forth from the volcano as a molten flood of lava, covering the andesitic breccia and other rocks. The dolerite may be seen capping the andesite on Penman peak, Mount Jackson, Big hill, about 3 miles northwest of Mohawk valley, on the ridge one-half mile northwest of Bell's bar, and at other points.

The flow of dolerite 1 mile southeast of Penman peak appears to have taken place after the andesitic areas had been much eroded, and the slopes of the mountain were approximately as they are to-day, suggesting that the age of the dolerite flows is post-Tertiary.

Since many of the mortars found among the gravels of California, and which have led to so much discussion as to the age of man in that part of the world, are of volcanic rocks, it follows that, in investigating these evidences of prehistoric man, the anthropologist may in some cases get some evidence as to their age from the kind of rock composing the mortar.

Two of the mortars collected by the writer are of hornblendic andesite, probably the hornblende-pyroxene-andesite. If these had been reported as occurring under rhyolite, a reasonable doubt might arise as to the genuineness of the occurrence, in the light of the succession above indicated.

PRE-CAMBRIAN IGNEOUS ROCKS

OF THE

UNKAR TERRANE,

GRAND CANYON OF THE COLORADO, ARIZONA.

BY

CHARLES D. WALCOTT.

WITH NOTES ON

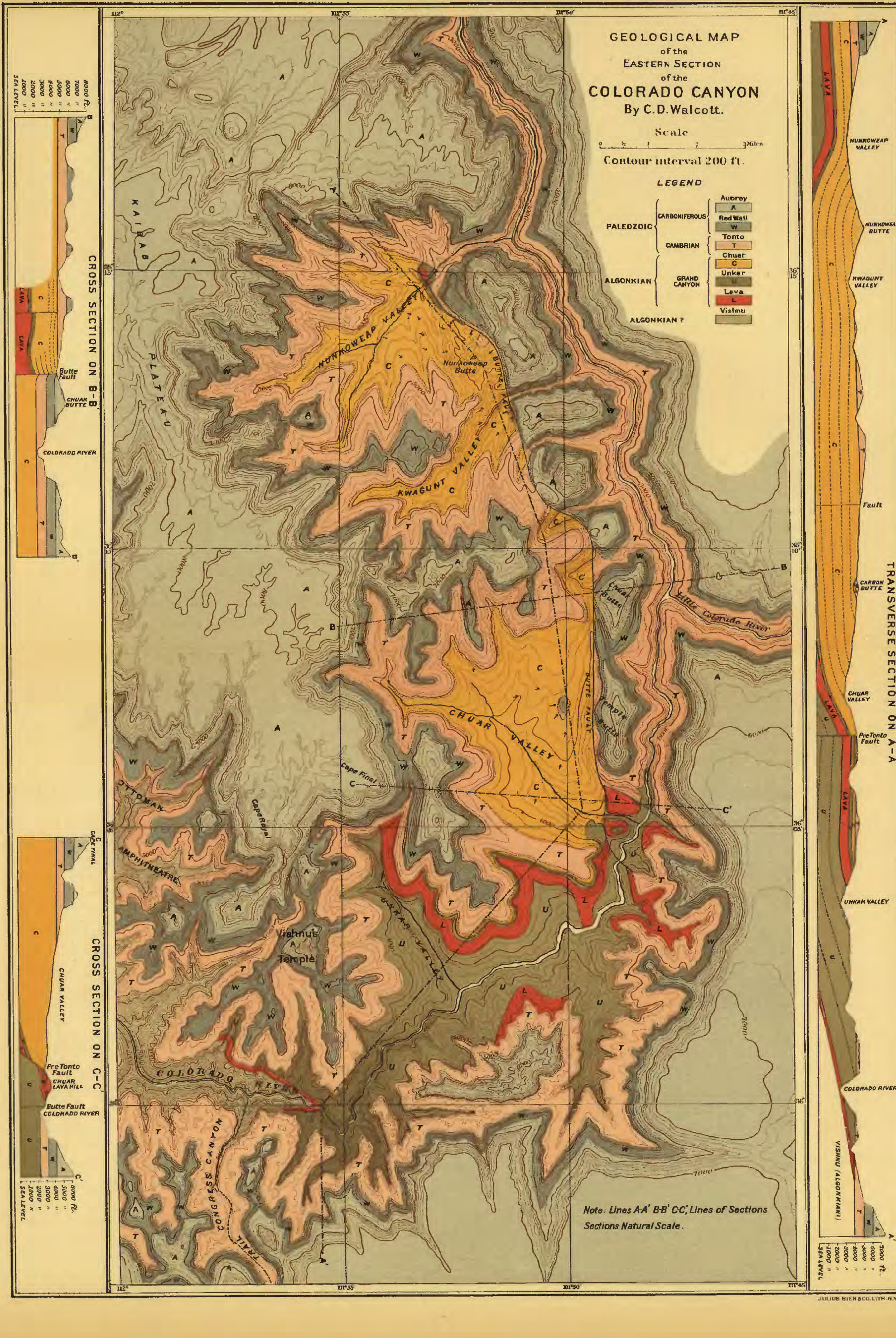
THE PETROGRAPHIC CHARACTER OF THE LAVAS.

BY

JOSEPH PAXSON IDDINGS.

CONTENTS.

ILLUSTRATIONS.


GEOLOGICAL MAP
of the
EASTERN SECTION
of the
COLORADO CANYON
By C. D. Walcott.
Scale
Contour interval 200 ft.
LEGEND
PALEOZOIC
CARBONIFEROUS
Aubrey
Red Wall
CAMBRIAN
Tonto
ALGONKIAN
GRAND CANYON
Chuar
Unkar
Lava
ALGONKIAN ?
Vishnu
CROSS SECTION ON B-B'
CROSS SECTION ON C-C'
TRANSVERSE SECTION ON A-A'
NUNKOWEAP VALLEY
KWAGUNT VALLEY
CHUAR VALLEY
UNKAR VALLEY
Nunkoweap Butte
Chuar Butte
Temple Butte
BUTTE FAULT
Little Colorado River
KAIBAB PLATEAU
Cape Final
Cape Royal
OTTOMAN AMPHITHEATRE
Vishnus Temple
COLORADO RIVER
CONGRESS CANYON TRAIL
Butte Fault
CHUAR BUTTE
Pre Tonto Fault
CHUAR LAVA HILL
Butte Fault COLORADO RIVER
NUNKOWEAP BUTTE
CARBON BUTTE
VISHNU (ALGONKIAN)
Note: Lines A-A' B-B' C-C', Lines of Sections
Sections Natural Scale.
JULIUS BIEN & CO. LITH. N.Y.

PRE-CAMBRIAN IGNEOUS ROCKS OF THE UNKAR TERRANE, GRAND CANYON OF THE COLORADO, ARIZONA.

By Charles D. Walcott.

INTRODUCTION.

Rarely has the geologist an opportunity to study such a series of contemporaneous, interbedded igneous rocks as that dissected and laid bare in the walls of the Grand canyon. The igneous rocks of the pre-Cambrian (Algonkian) Keewenawan terrane of the Lake Superior basin are more or less clearly shown, and those of the classic Silurian localities of Wales have long been studied; but the Grand Canyon series remains unexcelled in completeness of exposure and certainty of stratigraphic position.

The first account we find of these igneous rocks is by Maj. J. W. Powell, who noted the occurrence of a dike as he was passing through the Grand canyon in his famous explorations of 1869–1872.[1] The locality was probably at the mouth of Chuar outlet, or at Lava canyon, a mile below. In summing up the geologic history of the formations within the canyon after the period of erosion that cut away the section of 10,000 feet of rocks of the Grand Canyon terranes,[2] he says:

> This region of country was fissured, and the rocks displaced so as to form faults, and through the fissures floods of lava were poured, which, on cooling, formed beds of trap or greenstone. This greenstone was doubtless poured out on the dry land, for it bears evidence of being eroded by rains and streams prior to the deposition of the overlying rocks.

He speaks of them again, in a note on the Grand Canyon group, as follows:[3]

> The plane of demarcation separating this group from the Tonto group is very great. At least 10,000 feet of the beds were flexed and eroded in such a manner as to leave but fragments in the synclinals. Then followed a period of erosion, during which beds of extravasated material were poured over the fragments, and these igneous beds also were eroded into valleys prior to the deposition of the Tonto group.

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[1] Report of Explorations in 1873 of the Colorado of the West and its tributaries, 1874, 8vo, p. 18; Exploration of the Colorado River of the West and its tributaries, 1875, 4to, p. 81.

[2] Op. cit., p. 213.

[3] U. S. Geol. and Geog. Survey of the Territories: Report on the Geology of the Eastern Portion of the Uinta Mountains, etc., 1876, p. 70.

When Capt. C. E. Dutton was studying the great unconformity between the horizontal series of rocks forming the upper 4,000 feet of the canyon walls and the subjacent unconformable series, he noted the presence of eruptive rocks in the lower series, and commented thus:[1]

> Just where the comparatively narrow gorge of the Marble canyon expands well out into the much ampler width of the Grand canyon, we perceive among the higher beds of this ancient series some layers which we do not hesitate to pronounce volcanic rocks—basalts or diabases. They are coal black and contrast finely with the rich colors all around them. They are interbedded with the Upper Silurian (?) strata, but whether they are intrusive sheets or contemporaneous coulées, outpoured while the rocks were accumulating, we can not say. The very dikes through which the lava came up are visible. Powell saw them on his boat journey down the river, but did not have an opportunity to investigate the many interesting questions which they suggest.

Captain Dutton's observations were made from the summit of the Kaibab plateau, 5 or 6 miles away from the beds described, and hence his conclusions were necessarily tentative. On atlas sheet 11 of the atlas accompanying the report, the area including the lava beds is colored as Carboniferous and Silurian.

During the winter of 1882–'83, I studied in detail the Grand Canyon group of Powell, and found that it was, as stated by him, unconformably beneath the Tonto sandstone. The lava beds, however, were found to be interbedded and contemporaneous with the strata of the Grand Canyon group. In a preliminary note they were described as follows:[2]

> The summit of the Grand Canyon group is a massive magnesian limestone, 100 feet in thickness, that overlies red sandstone resting on a massive belt of greenstones, 1,000 to 1,300 feet in thickness; this belt is broken up into eight principal flows by partings of sandstones deposited between the flows. The first coulée flowed over the level ocean bed, in which 5,000 feet of sediment, that now forms a reddish-brown sandstone, had accumulated on the upturned and eroded edges of the Archean, the few layers of limestone and the one flow of lava, 150 feet in thickness near the base, scarcely serving to break the great sandstone series.

On account of the relative stratigraphic position of the Grand Canyon group and the Keweenawan group of Wisconsin[3] they were tentatively correlated in the geologic series. It was then found convenient to separate the "Grand Canyon group" of Powell into two divisions, the lower division retaining the original name "Grand Canyon," while for the upper Major Powell proposed that of "Chuar group." The stratigraphic position of the lava beds is shown in the diagrammatic section accompanying the paper.[4]

In 1886 I changed the reference of the pre-Tonto strata of the Grand Canyon section from the Cambrian to the pre-Cambrian,[5] and

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[1] Mon. U. S. Geol. Survey, Vol. II, Tertiary History of the Grand Canyon District, 1882, p. 180.

[2] Pre-Carboniferous strata in the Grand Canyon of the Colorado, Arizona. Am. Jour. Sci., Vol. XXVI, 1883, pp. 440, 441.

[3] Loc. cit.

[4] Op. cit., p. 484.

[5] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

published a diagrammatic section of the Cambrian and pre-Cambrian terranes. The same section was also published in 1884, in an article on the classification of the Cambrian system of North America,[1] in which the Grand Canyon terranes, including the lava beds, were compared with the pre-Cambrian rocks of Llano county, Texas, which were named the Llano group.[2] A few years later several detailed sections, showing the position of the lava beds of the Grand Canyon terrane, were published in a paper entitled "A study of a line of displacement in the Grand canyon of the Colorado in northern Arizona."[3] A year later, in a report upon the lower Cambrian rocks, a figure of the Grand Canyon section is introduced, and the terrane including the lava beds is referred to the Algonkian.[4]

GEOGRAPHIC POSITION AND DISTRIBUTION.

That portion of the Grand canyon of the Colorado in which the lava beds of the Unkar (Algonkian) terrane are exposed is situated in northern Arizona, between 35° 57′ and 36° 17′ north latitude, and between 111° 47′ and 112° west longitude. This area is in the valley portion of the canyon, between the mouth of Marble canyon and a point south of Vishnu's Temple, a little west of where the Colorado river changes its course from south to southwest. It is wholly within the greater depths of the Grand canyon, east and southeast of the Kaibab plateau. The intercanyon valleys of this portion of the Grand canyon extend back from 3 to 7 miles west of the river, and are eroded in the crest of the monoclinal fold that forms the eastern margin of the Kaibab plateau. All of the valleys have small lateral canyons that lead into them from the high margin of the plateau.

On the map (Pl. LX) showing the geographic distribution of the formations, the most northern outcrop of the lava beds occurs near the lower portion of Nunkoweap valley. The outcrop is small in area and does not materially affect the topography. The next outcrop is 11 miles to the south, in the lower portion of Chuar valley. The lava beds here form the prominent Chuar butte and a high bluff opposite, on the eastern side of the Colorado river. From this point they continue, with a slight interruption, 3 miles to the south, beneath the Tonto sandstone cliff. Another outcrop, about 2 miles long, occurs still farther south on the eastern side of the river, opposite Unkar valley. On the western side of the river the outcrop is continuous from the Butte fault line, below the outlet of Chuar valley, for a distance of 7 miles, to near the head of Unkar valley.

The outcrop of the lower bed of lava, near the base of the Unkar terrane, is confined to a narrow strip south of Vishnu's Temple. It rises from the water on either side of the river near the base of the

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[1] Am. Jour. Sci., Vol XXXII, 1886, p 144

[2] Am. Jour. Sci., Vol. XXVIII 1884, pp. 431-432

[3] Bull Geol. Soc. America, Vol. I, 1889, published in 1890, figs 1, 2, 8, and 9, pp. 51, 55, 56.

[4] Tenth Ann. Rept. U. S. Geol. Survey, 1890, p. 551.

Unkar terrane and the summit of the unconformably subjacent Vishnu rocks. Altogether there is about 18 miles of exposure of the outcrop of the lava beds, exclusive of the lower bed, near the base of the Unkar terrane.

We have no knowledge of the occurrence of the lava beds to the west in the Ottoman and Bright Angel amphitheaters. It may be that they have been brought up and exposed by the faulting and folding of the Unkar terrane and subsequent erosion; but, until further investigation is made, the question must remain in abeyance. The strike of the lower lava bed would expose it in the Ottoman amphitheater, unless the strata are diverted by a fold or fault.

NOMENCLATURE.

The name "Grand Canyon group" was given by Maj. J. W. Powell to the strata beneath the Tonto sandstone and above the "Grand Canyon schists." The latter were referred tentatively to the Eozoic,[1] and the 10,000 feet of the "Grand Canyon group" to the Silurian. Capt. Dutton considered the Grand Canyon rocks to be of pre-Carboniferous age, and probably Silurian.[2] In 1883[3] I referred the Grand Canyon group of Major Powell to the lower Cambrian and separated it into a lower and upper division, the "Grand Canyon" and "Chuar," respectively, the name "Chuar" being proposed by Major Powell.[4] In 1886 the reference to the lower Cambrian was changed to pre-Cambrian,[5] and comparisons were made with the "Keweenaw system" of the Lake Superior region.[6] In a section of the strata of the Grand canyon district published in 1890 the pre-Tonto strata were referred to the Algonkian group under the names Chuar, Grand Canyon, and Vishnu, the latter including the strata unconformably beneath the Grand Canyon group.[7]

At the present time it appears to be necessary to return to Major Powell's name "Grand Canyon,"[8] as applied to the entire series of strata between the Tonto and the "Grand Canyon schists," and to give to the lower terrane the name Unkar, from the valley in which its finest exposures occur. The name Vishnu is retained for the bedded, sedimentary, unconformable, pre-Unkar strata. The classification from Tonto down will then be:

Cambrian	Tonto.	
Algonkian	Unconformity.	
	Grand Canyon	Chuar. Unkar.
	Great unconformity. Vishnu.	

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[1] Geology of the Eastern Portion of the Uinta Mountains, 1876, p. 70

[2] Tertiary History of the Grand Canyon District, 1882, p. 180.

[3] Am. Jour. Sci., Vol. XXVI, 1883, p. 439.

[4] Am. Jour. Sci., Vol. XXVI, 1883, p. 440.

[5] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[6] Am. Jour. Sci., Vol. XXXII, 1886, pp. 144, 153-157.

[7] Bull. Geol. Soc. Am., Vol. I, 1890, p. 50.

[8] Changing the spelling of "cañon" to canyon, in conformity with the decision of the U. S. Board on Geographic Names.

STRATIGRAPHIC POSITION.

The stratigraphic position of the strata forming the Grand Canyon series will be first considered, and then the position of the lava beds within that series.

With the exception of a trace of unconformity by erosion at the summit of the Unkar terrane, there is no recognized interruption in the sedimentation between the base of that terrane south of Vishnu's Temple and the summit of the Chuar terrane at Nunkoweap butte. At the base of the Unkar terrane there is a bed of conglomerate that rests unconformably on the eroded edges of indurated sandstones and micaceous schists. The unconformity is absolute from the line of contact at the base of the Tonto sandstone to the point where the plane upon which the conglomerate was deposited passes beneath the river. A sketch (Fig. 52) made from the south side of the canyon by Mr. G. K. Gilbert presents an extended view of the unconformity.[1]

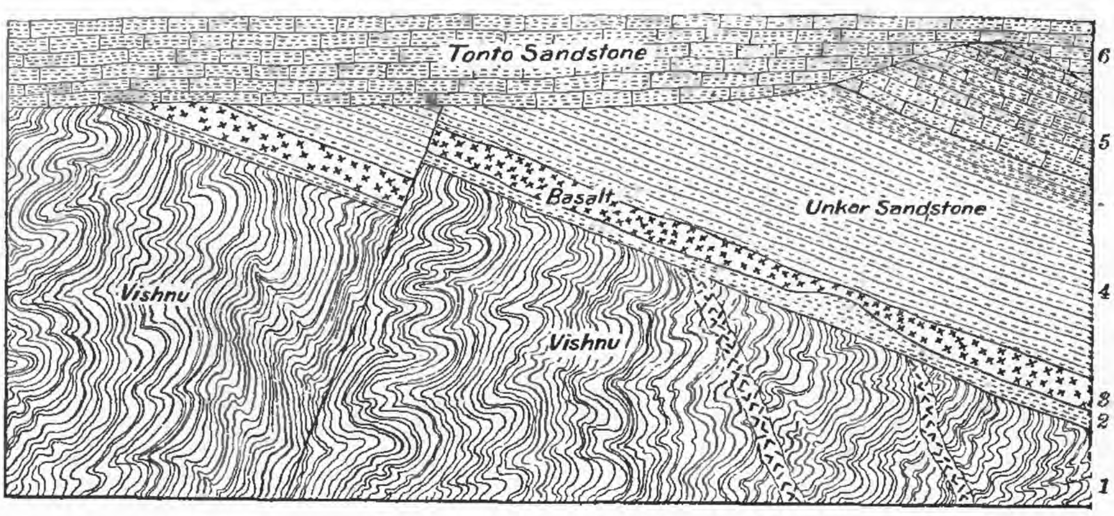

FIG. 52.—Section of the north side of the Grand canyon of the Colorado, as seen from the south wall near the mouth of Congress canyon. 1, Vishnu terrane (Archean ?); 2 to 5, Unkar terrane (2, conglomerate, sandstone, etc.; 3, sheet of basaltic lava; 4, reddish sandstone and sandy shale; 5, thick-bedded, reddish brown sandstone); 6, Tonto sandstone.

From the base of the Unkar terrane south of Vishnu's Temple the strata dip 10° to the northeast, and then, as shown on the map (Pl. LX and accompanying section), they flatten out on the line of the divide between Unkar and Chuar valleys, dip 25° to the north in the heart of Chuar valley, and thence extend in low, broad undulations to the syncline of Nunkoweap butte. North of the butte the strata rise, the dip being from 20° to 25° southeast. The summit of the series is at Nunkoweap butte, between Kwagunt and Nunkoweap valleys. From the point south of Vishnu's Temple to where the strata of the Chuar terrane pass beneath the basal beds of the Tonto sandstone, on

[1] In many places the pre-Unkar strata are gneisses and schists, cut by dikes of granite that are probably of Archean age. The Vishnu strata were clearly shown where my section crossed, and from photographs taken by Mr. Robert B. Stanton they appear to be extensively developed a few miles farther down the river.

the north side of Nunkoweap valley, there is a marked unconformity between the strata of the Grand Canyon series and the superjacent Cambrian sandstones. The former were planed off to a baselevel before the deposition of the latter, as shown in the section on the map and on Pls. LXIV and LXV.

The stratigraphic position of the series of strata in which the lava beds occur is between the unconformably superjacent Tonto (Cambrian) sandstone and a series of unconformably subjacent sandstones, schists, etc. With the exception of one interbedded flow just above the base, the lava beds are all near the summit of the Unkar terrane. The Chuar terrane has been faulted against the lava beds in both pre-Cambrian and Tertiary time (see Pl. LXII), and on this account the entire section, from the summit to the base of the Grand Canyon series, is here inserted.

CHUAR TERRANE.

The first division of the Chuar terrane is from the summit of Nunkoweap butte, on the divide between Nunkoweap and Kwagunt valleys, down the south side of the butte to the base of a massive belt of reddish brown sandstone. The latter stratum was traced to Chuar valley, where it caps the lower division of the terrane on the north side of the valley. The lower division terminates in argillaceous shales resting on a massive magnesian limestone south of Chuar brook.

SECTION READING FROM THE SUMMIT DOWNWARD.

Upper division.

		Feet.
1. *a.* Massive, reddish brown sandstone, with irregular layers of similar color and containing numerous fragments of sandstone-shale of lighter color		125
b. The sandstones of 1 become shaly near their base and pass into a reddish, sandy, and then argillaceous shale, with a few thin, compact layers of sandstone in the shale		75
2. Black, fissile, argillaceous shale, that crumbles on exposure to the weather.		225
3. Compact, gray limestone in massive layers; buff on weathered surface		50
4. Shale similar to 2		60
5. Gray limestone similar to 3		50
6. Black, argillaceous shale similar to 2 and 4		140
7. Hard, buff limestone with irregular oolitic, cherty bands that at times constitute most of the stratum		4
8. *a.* Black, argillaceous shale with compact layers two or three inches thick.	30	
b. Dark, earthy limestone	1	
c. Black shale	2	
	—	33
9. Gray, Stromatopora[1] (?) limestone		8
10. Black, argillaceous shale with variegated shales below, containing more or less arenaceous matter in the form of arenaceo-argillaceous shale and thin layers of sandstone. On the slopes light drab, pea-green, vermilion, chocolate, maroon, and buff-colored shales of various shades alternate		740
11. Massive stratum of concretionary limestone		10–25

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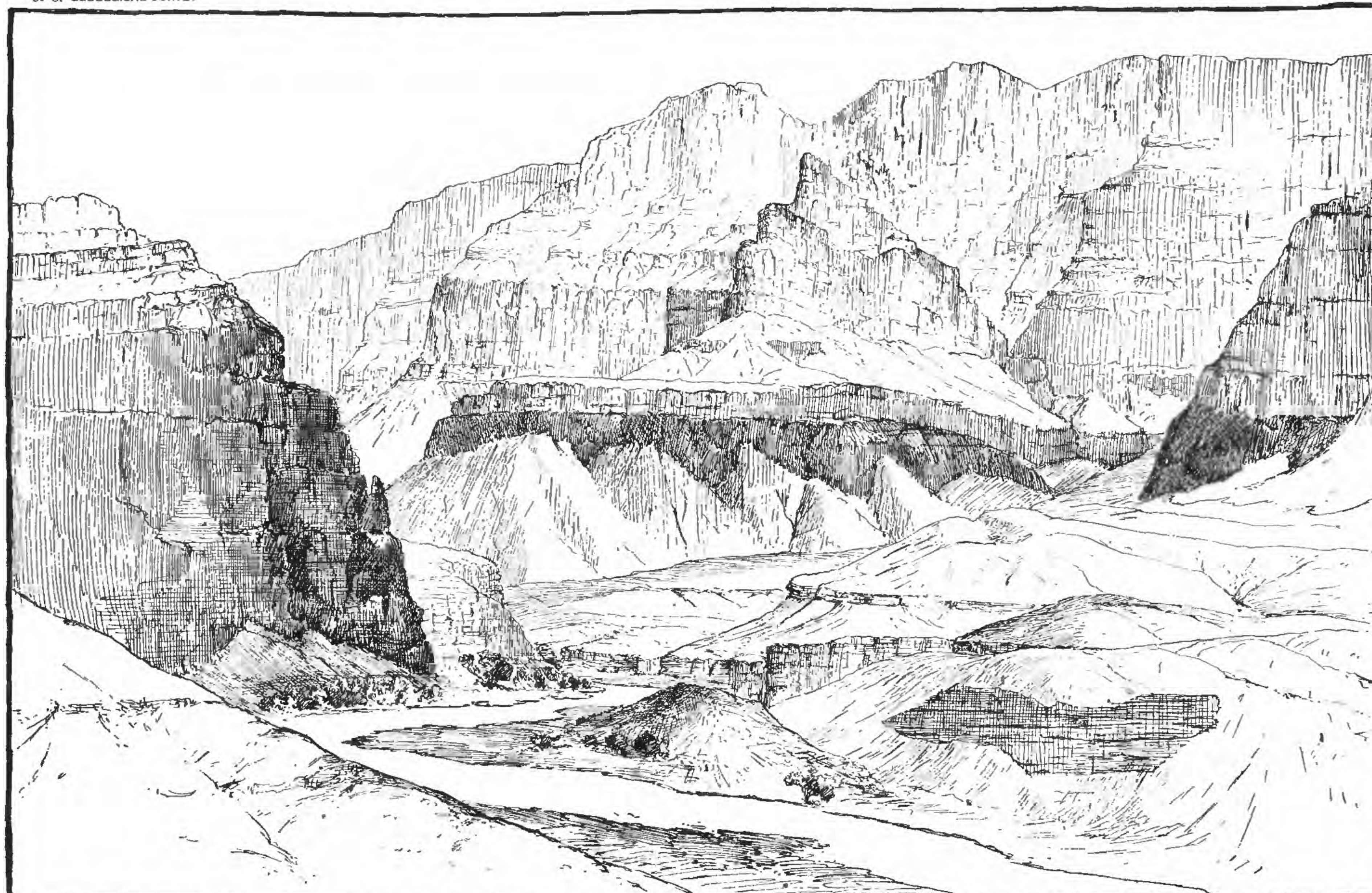
[1] Probably a species of Cryptozoon



CLIFFS FORMED BY LAVA BEDS ON THE COLORADO RIVER ABOUT TWO MILES SOUTH OF CHUAR LAVA HILL.

From a sketch by B. L. Young.

		Feet.
12. Reddish brown, sandy shale		25
13. *a.* Thick-bedded, dark reddish brown sandstone	70	
b. Same, thinly bedded	70	
		140
Total thickness of upper division		1700

Limestone, 138 feet.

The last two beds form so strongly marked a horizon in the shaly beds that it is taken as a rough division line in the terrane; the strata beneath containing a different character of limestone, that serves to distinguish them.

Lower division.

		Feet.
1. Brown, sandy shales, passing below into chocolate and dark, argillaceous shales that alternate with brown and greenish, sandy shales. Near the summit a layer of oolitic iron ore occurs		300
2. *a.* Alternating sandy and argillaceous shales, with thin belts of limestone from 6 inches to 4 feet in thickness		310
b. Stromatopora limestone	4	
c. Dark, shaly limestone	3	
d. Dark, argillaceous shale	6	
e. Dark gray, shaly limestone in massive layers	2	
		15
3. Chocolate-brown, dull and yellowish green, sandy and argillaceous shales, with sandstone in narrow bands, and 21 feet of limestone in thin layers near the middle and base of the stratum		625
4. *a.* The sandstone and sandy shales become less prominent, the argillaceous and calcareous strata replacing them, 54 feet of limestone occurring in 500 feet of strata		500
b. Dark clay-shale	4⅓	
c. Dark, shaly limestone	1	
d. Dark, argillaceous shale	4	
e. Gray limestone, having a tendency to break up into shaly layers; strongly bituminous near the base	5⅔	
f. Friable, rather coarse, gray to buff sandstone	5	
g. Compact, lead-colored limestone	2	
		22
5. Black, argillaceous shale with chocolate and greenish, sandy and argillaceous shales beneath, carrying hard layers of sandstone. In a few localities white and pink gypsum occurs in masses a few feet in diameter, or as seams in the upper, black shales		100
6. Three feet of compact, mottled, buff limestone interbedded in fifteen feet of brown, sandy shale		18
7. *a.* Black and chocolate, sandy and argillaceous shales, with three thin layers of limestone near the base	180	
b. Black and brown, argillaceous shale, with interbedded layers of a somewhat friable sandstone	180	
c. Chocolate, green, maroon, drab, argillaceous shales, with thin layers of brownish sandstone interbedded, and, toward the base, sandy shales	360	
d. Brown sandstone in layers 8 to 18 inches thick, passing below to sandy and argillaceous shales, with layers of buff and chocolate sandstone	55	
e. Drab, argillaceous shale passing down into brown, sandy, ripple-marked shales	55	
		830

	Feet.
8. *a.* Massive band of irregular, thinly bedded limestone, gray and buff except near the chocolate-colored upper stratum. A variety of limestone occurs.	
b. Chocolate, compact layers, with a smooth, partially conchoidal fracture.	
c. Evenly bedded, thin layers, hard, lead-colored	
d. Thin, shaly, gray layers.	
e. Very irregular and concretionary layers.	
f. Compact, gray, bituminous layers.	
Total	50
9. Dark, argillaceous shale with a strongly marked band of a deep maroon color; drab, yellowish green, and dark or brownish black shales continue below to a dark chocolate band that is superjacent to 100 feet of drab and greenish shales. The shales are largely argillaceous, with arenaceous matter scattered through the section as sandy shales, thin-bedded sandstone, and arenaceo-argillaceous shales.	
In one locality a band of fine grained, gray limestone, 6 inches thick, occurs in the shales 3 inches above the base of the Chuar terrane.	450 to 650
Total thickness of lower division	3,420

The character of the strata of the lower division is shown in the foreground of Pl. LXII.

Total thickness:

Upper division	1,700
Lower division	3,420
	5,120

Limestone in upper division	138
Limestone in lower division	147
	285

UNKAR TERRANE.

The line of outcrop of the massive magnesian limestone below the base of the Chuar terrane extends south, in the face of the cliffs, to the north side of Unkar valley. The section was taken from this point south across Unkar valley and along the walls of the inner canyon of the Grand canyon to a point south of Vishnu's Temple, where the sandstones and conglomerates rest unconformably upon the sandstones, schists, etc., of the Vishnu terrane and the gneisses, schists, etc., of the Archean. The section is characterized by a great thickness of reddish brown sandstones.

SECTION FROM THE SUMMIT DOWNWARD.

	Feet.	Feet.
1. *a.* Massive beds of gray to reddish magnesian limestone, passing below into a calciferous sandrock	50–150	
b. Light gray, shaly sandstone	25	
c. Irregular, massive beds of yellowish brown sandstone	50	
d. Partially cross bedded, fine grained, purplish brown sandstone	50	
e. Reddish brown sandstone and sandy shales, ripple-marked	200	
		475

A. SOUTH FACE OF CHUAR LAVA HILL.

The various flows or sheets of basalt are clearly outlined by the narrow bands of sandstone.

From a sketch by B. L. Young.

B. WEST FACE OF CHUAR LAVA HILL. VIEW LOOKING EAST THROUGH CHUAR OUTLET.

Chuar lava hill is shown on the left, with the strata of the Chuar terrane thrown against it by the pre-Cambrian Butte fault. On the right side the Tonto sandstone is seen, capping the lava beds and the sandstones of the Unkar terrane outcrop in the lower portion of Chuar outlet.

From a sketch by B. L. Young.

		Feet	Feet.
2. Lava beds:			
a. Dark green, basaltic rock with a reddish tinge. Breaks into small angular fragments. Upper surface slightly irregular		100	
b. Layers of a reddish brown sandstone		8-10	
c. Solid, compact lava, of a dark green and reddish tinge, with a slight tendency to columnar structure		70	
d. A layer of sandstone, 1 foot in thickness, caps a massive flow of dark green lava, which breaks up and weathers into a fine talus of a lighter green than the rock in place		100	
e. A flow not unlike *d* and capped by a layer of sandstone 2 feet in thickness		70	
f. A layer of vesicular lava with a thin stratum of sandstone at the summit		10	
g. Soid, compact lava, of a dark green and reddish tinge, with columnar structure partially developed in the central portion. This band appears to be formed of three flows in quick succession, as no sedimentary material accumulated on the surface of the two lower; 25, 125, and 25 feet; total		175	
h. Reddish brown sandstone, compact and slightly metamorphosed toward the summit		15	
i. On the weathered surface this flow presents a slope of 25° to 30°, rarely forms a cliff, as do the flows above, and the rocks crumble into a rather light olive-green coarse sand. Thin beds of reddish brown sandstone occur in several places, and one, 125 feet from the base, is quite persistent in its horizontal extension. The upper surface of the flow is slightly undulating and more or less nodular		250	
			800
At Chuar lava hill the lava beds are 1,000 feet thick.			
3. Sandstones (upper):			
a. Shaly, vermilion, rather fine grained sandstones, with intercalated bands of a greenish gray, followed below by 700 feet of vermilion beds of a uniform character, and massive beds with arenaceous, shaly partings, the massive beds breaking up into shale and sandstone on the talus slopes. Ripple marks and shrinkage cracks characterize the upper, shaly beds		1, 730	
b. The vermilion sandstones of *a* pass into chocolate-colored sandstones, that for 125 feet down unite in the general slope of the beds above. Below, a cliff is formed of five massive bands of chocolate-colored, slightly micaceous sandstone, separated by shaly sandstone partings of a greenish color below and a chocolate color above		925	
c. Reddish brown to chocolate, more or less shaly sandstone, 125 feet, underlain by 300 feet of friable sandstone and arenaceous and micaceous shale		425	
d. Irregularly bedded, compact sandstone:			
Curiously twisted and gnarled layers	15		
Massive, grayish layer	10		
Light gray layer with reddish spots, friable, shaly in places	125		
		150	
			3, 230
4. Sandstones (lower):			
a. Compact, quartzitic, gray sandrock, 25 feet, with 65 feet of hard, compact sandstone		90	
b. Massive, compact, cliff-forming, brown, buff, and purplish brown sandstone		1, 200	

	Feet.	Feet	Feet.
4. Sandstones (lower)—Continued.			
c. 1. Reddish brown to vermilion, friable, shaly sandstone	200		
2. Brick-red, shaly sandstone	250		
3. Brown, friable, shaly sandstone, ripple marks and shrinkage cracks	300		
4. Same in more massive layers, with fine, siliceous conglomerate (10 feet) at the base	80		
		830	
			2,120
5. *a.* Light gray limestone with interbedded laminæ of quartzitic shale		8	
b. Brown sandstone with a bed of siliceous conglomerate, 2 feet		30	
c. Reddish, cherty limestone		10	
d. Reddish brown limestone		2	
e. Dark, reddish brown slate		5	
f. Light gray, compact, shaly limestone		14	
			69
6. Dark, compact, basaltic lava in one massive flow			80
7. Light gray, compact, shaly limestone with pinkish tinge between the laminæ; it is a little cherty near the base, or with thin, hard, interbedded layers of sandstone			26
8. Siliceous conglomerate formed largely of pebbles derived from the upturned edges of the pre-Unkar strata, upon which it rests unconformably			30
Total thickness of the Unkar terrane			6,830
Total thickness of the Chuar terrane			5,120
Total thickness of Grand Canyon series			11,950

THE LAVA BEDS.

The lava beds are crossed by this section on the north side of Unkar valley (see Pl. LXI), and are not so fully developed as at Chuar butte, on the north side of the outlet of Chuar valley. At the latter locality the section was studied more minutely, and a full series of lithologic specimens obtained. These were submitted to Mr. J. P. Iddings for examination, and a description of them will be found in the report following this paper.

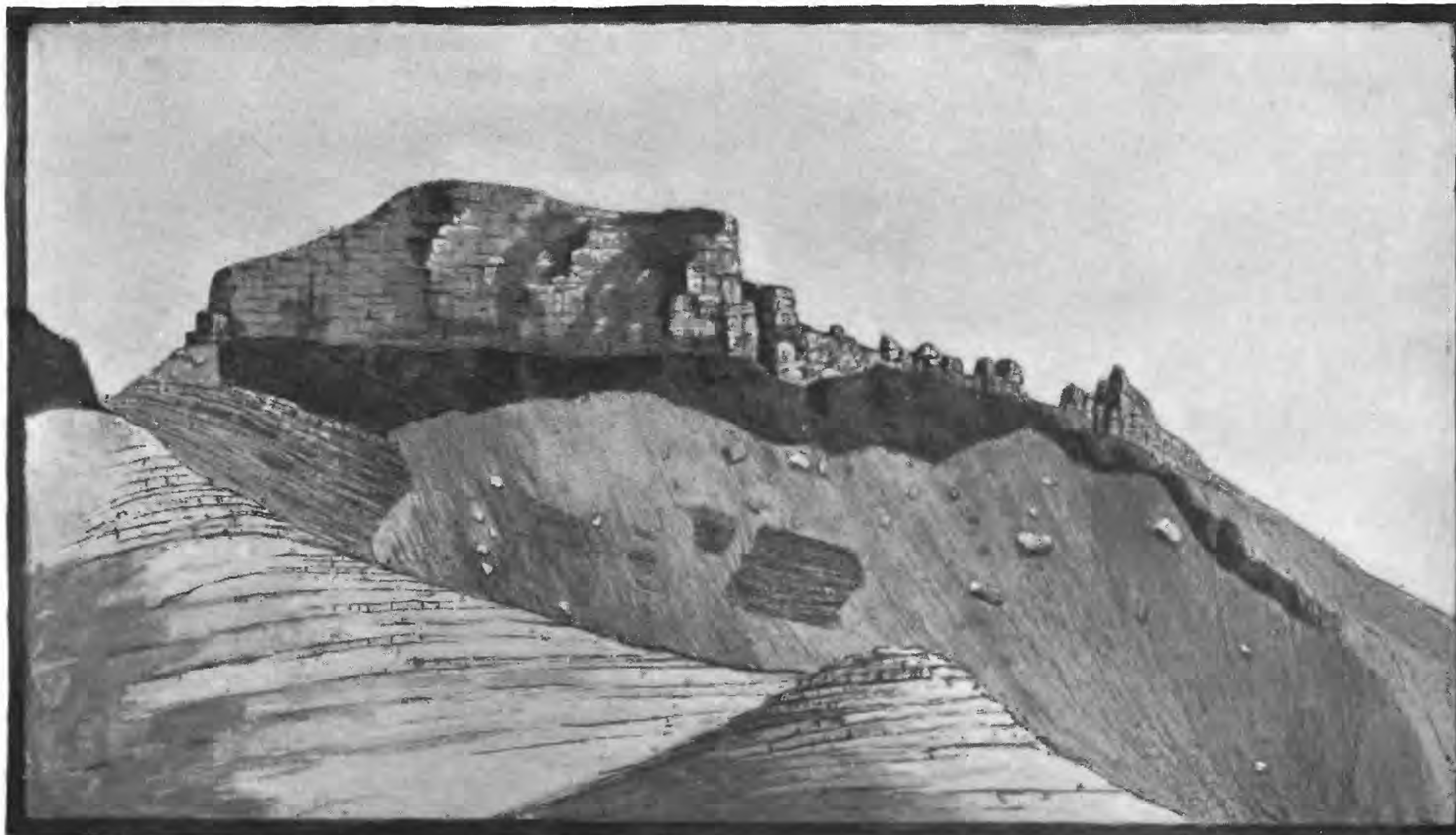
CHUAR LAVA BUTTE.

All along the south base of the butte the reddish brown sandy shales and sandstones of the Unkar terrane form a low arch, 150 to 250 feet in height and about 3,000 feet in length. The general dip of the strata is 5° to 10° north 5° east. The section of Chuar lava butte and its interbedded sandstone is as follows:

SECTION FROM BOTTOM UPWARD.

1.

The lower portion of this lower bed is a sandstone, formed of fine, angular grains of pure quartz, with a ferruginous cement. The sandstone shows lines of bedding below; above, it appears in places to grade into the superjacent lava, very much as if the sand and lava were more



SOUTH FACE OF HILL FORMING THE SOUTH SIDE OF CHUAR OUTLET.

The Tonto sandstone rests unconformably on the lava beds. A branch of the Butte fault cuts off the Unkar strata in the foreground from those beneath the lava beds.

From a sketch by B. L. Young.

or less commingled. Where it rests directly on the sandstone the lava is more or less porous, and 10 inches above the base small cavities occur, that are lined with quartz. Higher up, the mass becomes more compact and has a reddish tinge; the cavities have a green lining and inclose crystals of calcite (?) (2 feet). This passes above into a less compact rock that weathers into a coarse greenish colored sand, in which bunches or nodules of a harder, more compact rock occur. These general characters continue up toward the summit of the bed, where the more uniformly granular structure is replaced by longer, irregularly spheroidal cavities (amygdules), 1 to 20 millimeters in diameter, filled with quartz, calcite, etc. Sixty feet from the base a stratum of reddish brown sandy shale, 10 feet thick, occurs, and it is probable that this bed consists of several lava sheets with irregular partings of sandy sediment. Thickness, 180 feet.

1a.

A belt of sandstone and sandy shale, 12 to 25 feet in thickness, rests on the coarser, upper portion of the bed. The lower portions do not show metamorphism, but at and toward the summit the rock becomes hard, almost quartzitic, and weathers like a quartzite, breaking into fragments.

Bed No. 1, with its capping of sandstone (1*a*), is a marked feature in all the exposures of the volcanic rocks in the canyon for a distance of several miles. Its stratigraphical position is strongly defined, and, decomposing readily, it forms a sloping terrace that is marked by its smoothness and dark bottle-green color.

2.

This bed has a stratum of sand of irregular thickness at the base, followed by a massive stratum of fine, dark green to steel-gray, greenish tinged lava. The latter breaks into angular fragments, and high up in the flow has a slaty structure. Near the summit its macroscopic character changes, and little cavities, filled with calcite, quartzite, etc., occur. Where the section crosses the east end of the cliff the thickness is 100 feet, and at the west end, half a mile away, it is nearly 200 feet.

This flow is more irregular in its section than any of the others. Toward the western side of the butte (see Pl. LXI) a small flow seems to have preceded it. On the eastern side the upper portions of it are absent, either by nondeposition or erosion, and two smaller flows occupy the interval between it and the continuous capping of sandstone that marks off the bed to the west. The two latter may be regarded as subflows of No. 2.

Subflow a, of bed No. 2. (See Pl. LXI.)

The line of demarcation between the last-mentioned bed and the superior layer is based upon the change of color and the presence of a clearly defined creviced line all along the face of the cliff. The bed above this line is, to all appearances, a massive lava, but when broken looks like a sandstone of a reddish brown color. Higher up it changes somewhat and is filled with minute yellow spots and thin seams. Seventy-five feet from the base it passes into a reddish brown mass, with inclosed particles of a green color. Thickness, 100 feet.

Subflow b, of bed No. 2.

This flow is more uniform in its character than subflow *a*. A reddish brown rock occurs in it that is not unlike the central portion of *a* in appearance. It contains large cavities filled with quartz, etc. Thickness, 125 feet.

2a.

The entire mass of flow 2 and its subflows is adjacent to a belt of reddish brown, fine grained sandstone. Thickness, 5 to 15 feet.

3.

Bed No. 3 is superjacent to a thin stratum of sandstone and is delimited by another sandstone at the summit. At the base it is formed of a very tough, solid, and compact lava that breaks into angular fragments on exposure. Color, a greenish tinge, with minute reddish particles grouped in an irregular manner. Fifty feet from the base it is less compact, and the red and green particles are quite evenly distributed, the former predominating. Toward the summit the reddish brown rock forms the matrix, and the cavities of varying size (1 to 10 millimeters) are filled with calcite (?), etc. The entire thickness is about 150 feet, varying somewhat along the line of exposure, and in most places presenting a mural face that breaks off near the base into a sloping terrace.

3a.

Reddish brown sandstone, 10 feet.

4.

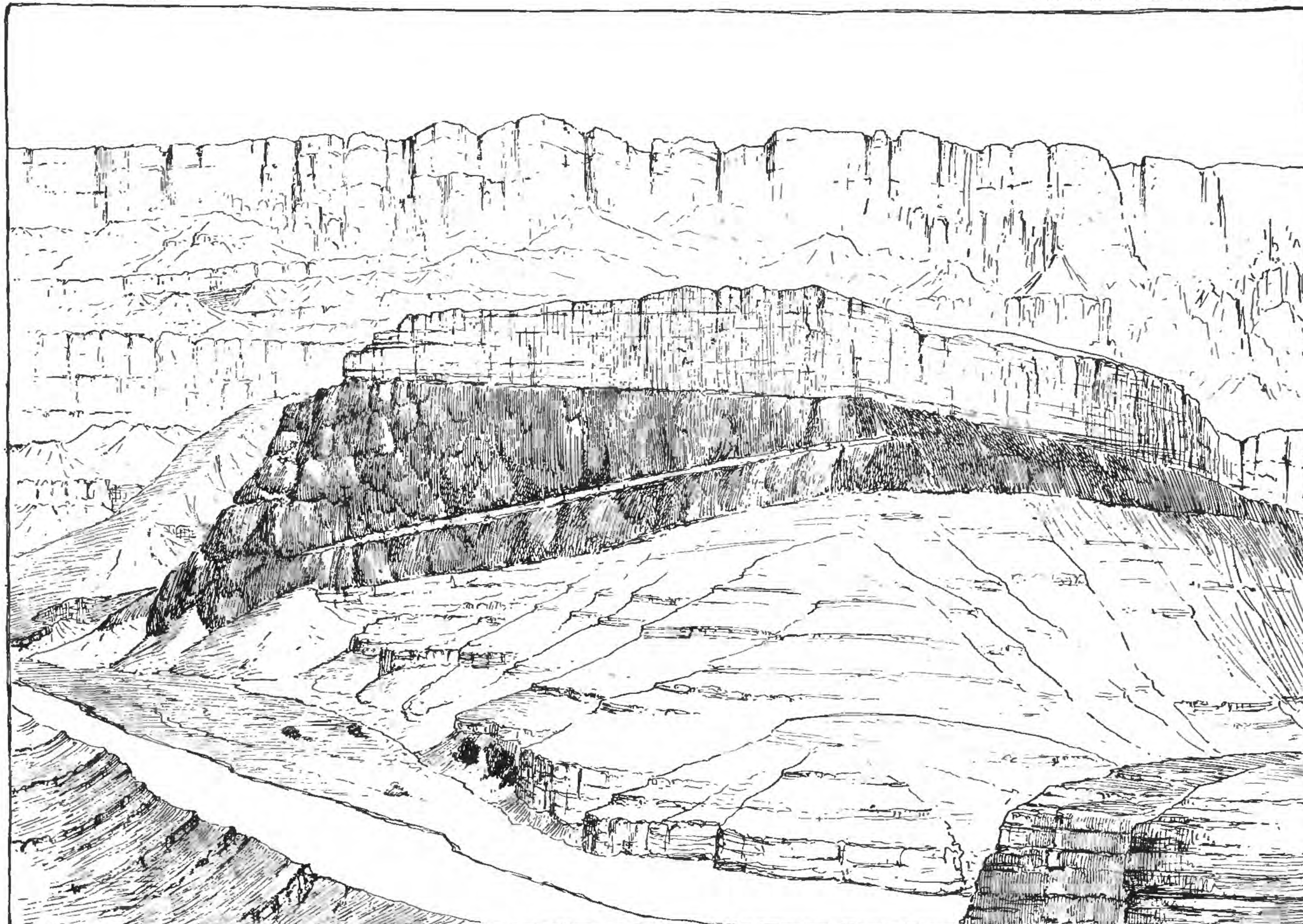
Compact iron-gray lava, breaking into angular fragments on the slopes. This bed is quite uniform throughout, except near the summit, where it has small, round, crystal-filled cavities. Thickness, 150 feet.

4a.

A belt of unaltered reddish sandstone conformably overlies this bed. Thickness, 33 feet.

5.

In the lower portion of the flow the lava is solid and compact, very much like that in flow 6. This extends up to a point within about 50 feet of the summit, where there are numerous vesicular cavities filled with quartz, etc. These occur with more or less frequency to the summit. Thickness, 200 feet.



LAVA CLIFF ON THE EAST SIDE OF THE COLORADO RIVER, OPPOSITE CHUAR OUTLET.

It is capped by the Tonto sandstone and underlain by the sandstones of the Unkar terrane.

From a sketch by B. L. Young.

5a.

The superjacent sandy layers are of a dark chocolate color, evenly bedded, and composed of three divisions, forming a band 6 feet thick. At the base, superjacent to the lava, there is a bed, 2 feet thick, of a more shaly sandstone. Thickness, 10 feet.

6.

Dark gray, compact lava, uniform in texture, with the exception of fillets of sand and quartz in crevices or dikes. The lava has a greenish tinge below and is decomposed into a green, crumbling debris. Thickness, 150 feet.

No. 6 is the upper bed of the series, and it is capped, on the Chuar lava butte, by 35 feet of the chocolate-brown sandstones and sandy shales of the Unkar terrane. At the summit of the butte there are a few bowlders remaining of the original Tonto formation that unconformably capped the shales of the Unkar terrane at this point. The latter dip north at an angle of 5°. Nnmerous ripple marks and mud cracks occur upon the layers.

Total thickness of lava beds and interbedded sandstones, 1,000 to 1,500 feet.

A comparison of the section of the lava beds in Unkar valley with that of Chuar lava hill shows a greater thickness for the latter and a more marked separation of the successive flows or sheets of lava. The two localities are about 5 miles apart, and the difference of 200 feet in the thickness of the sections, in connection with the variation in the individnal flows, proves the irregularity of the flows in different portions of the area that they covered. I was unable to cross the river to the eastern side, where the succession of the flows was apparently very little different from that of Unkar valley. My observations were made in detail on Chuar lava hill, which was taken as the type of the lava series. The exposures in the Colorado canyon to the south and in Unkar valley were studied with much less care, except on the line of the crossing of the section of the Unkar terrane. There is undoubtedly much of interest that might be noted by a trained observer of igneous rocks.

NUNKOWEAP LAVA HILL.

By an uplift on the line of the Butte fault,[1] in the lower portion of Nunkoweap valley, a portion of the lava beds of the Unkar terrane is brought to view in a rounded hill that rises nearly 400 feet above its base (Pls. LX and LXI). A small outcrop of the lava beds also occurs on the south side of the brook. The locality is 10 miles north of the Chuar lava butte, and the section, although retaining the same general succession of beds, is unlike that of Chuar or Unkar valleys in its details. Measured from the snmmit down to the south base it is as follows:

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[1] Bull Geol. Soc. Am., Vol. I, 1889 [1890], pp. 49-64.

SECTION.

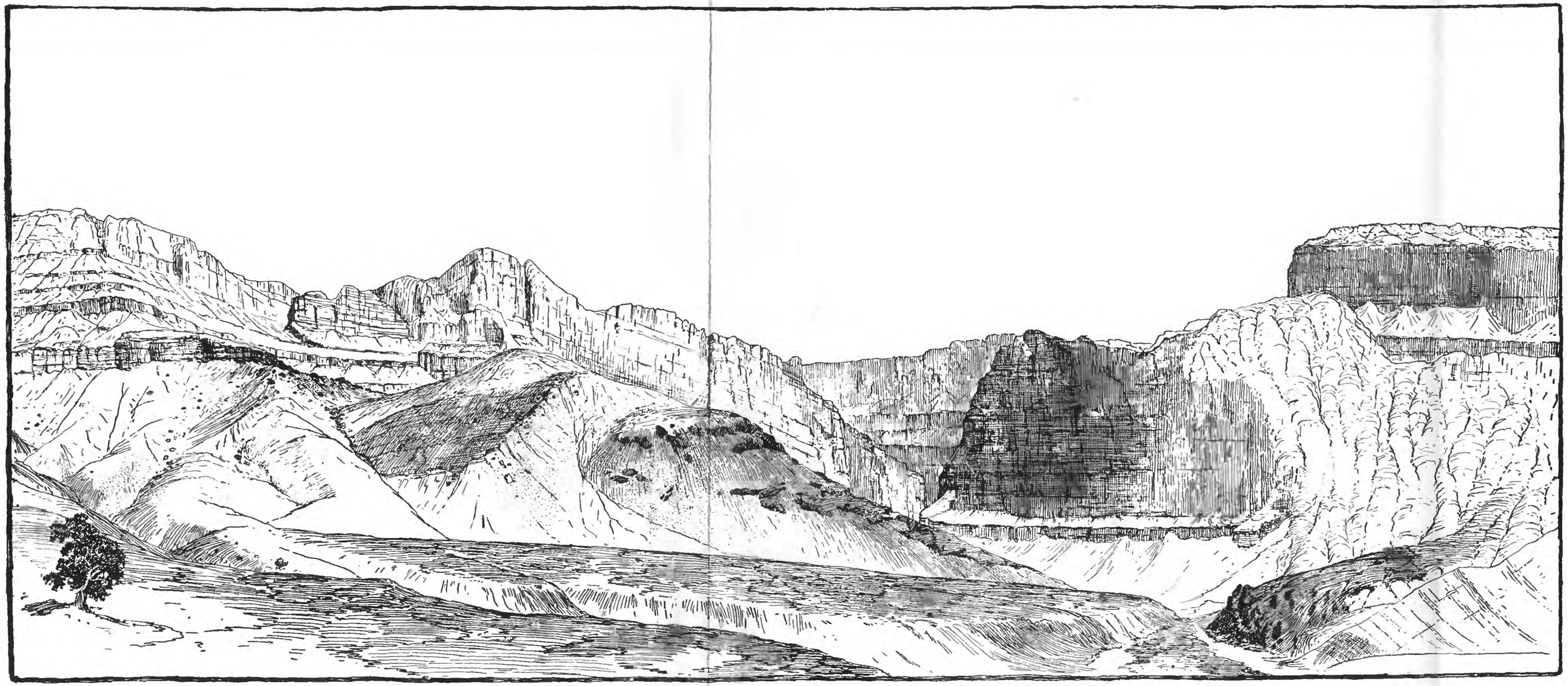
		Feet.
1.	The summit of the hill is covered with débris of the Carboniferous Red Wall limestone and Lower Aubrey sandstone	50
2.	Massive, irregular limestone	50
3.	Gray followed beneath by reddish sandstone, metamorphosed and almost quartzitic in places, the shaly character showing only in the banded colors	200
4.	Greenish black, compact, basaltic lava, uniform throughout. Breaks into small rectangular fragments	55
5.	Reddish brown sandstone, very much metamorphosed	15
6.	Greenish and reddish black lava, more or less amygdaloidal and vesicular on weathered surface. Thirty feet down it is compact, and then thin layers or fillets of shaly sandstone appear, and it becomes a decomposed crumbling rock	115
	General dip of beds north 30° to 35°; strike east and west.	
7.	Reddish brown sandstone, brecciated and hardened, mixed with lava	25
8.	Dark iron-gray lava with light, round spots (amygdules filled with quartz, etc.), near the summit. Lower down becomes like 4	55
9.	Compact, reddish sandstone	10
10.	Reddish green lava, amygdaloidal at summit, that extends down to the canyon bed	100
	Total	675
	Total lava beds, including interbedded sandstone	375

BASAL FLOW OF THE UNKAR TERRANE.

This is a massive bed, 80 feet in thickness, that rests conformably on a band of unaltered, compact, shaly limestone. It is 56 feet above the base of the terrane, and extends with a slope of 10° to the northeast from the plane of erosion, beneath the Tonto sandstone, down to the surface of the river. The sketch made by Mr. G. K. Gilbert from Congress canyon of a portion of this bed gives a clear impression of its relations to the subjacent unconformable Vishnu terrane, the superjacent Tonto sandstone, and to the embedding strata (see Fig. 52). A sketch made by me from the north side of the canyon shows the interbedded lava flow extending nearly two-thirds the distance from the river to where it is cut off by the plane of the pre-Tonto surface. It does not appear to be faulted out, as the strata above and below are unbroken. It simply ends, as if the limit of the flow had been reached.

DIKES.

Major Powell noted the presence of dikes in the red sandstones beneath the massive lava beds, and Captain Dutton saw them from the summit of the western wall of the canyon. I noted that several dikes occurred not far away from the base of the lava beds, but in no instance was there any actual connection seen between the dikes and the flows above. The lava of the dikes and that of the flows are of the same character, and there is no reasonable doubt that some of the larger dikes were the conduits through which the material of the flows was



LOWER PORTION OF NUNKOWEAP VALLEY, SHOWING THE OUTCROPS OF THE LAVA BEDS IN THE HILL ON THE LEFT SIDE OF THE BROOK AND AT THE BASE OF THE CLIFF ON THE RIGHT SIDE.

From a sketch by B. L. Young.

forced up from below. Several large dikes were seen cutting through the Vishnu series, but not in a position to connect with the Unkar lavas above. In one of the side canyons leading down to the east from Vishnu's Temple a section of 500 feet of the lower portion of the vermilion sandstones of the Unkar terrane is exposed above the chocolate-colored sandstones. A dike of basaltic lava, 6 feet in width at its base, cuts through obliquely to the bedding of the sandstone, and several offshoots occur that do not appear to have any relation to the stratification. The impression made upon me when examining this dike was that the lava found its way upward through crevices formed in a sandstone that gave resistance as a solid mass to the force that shattered it. The sketch

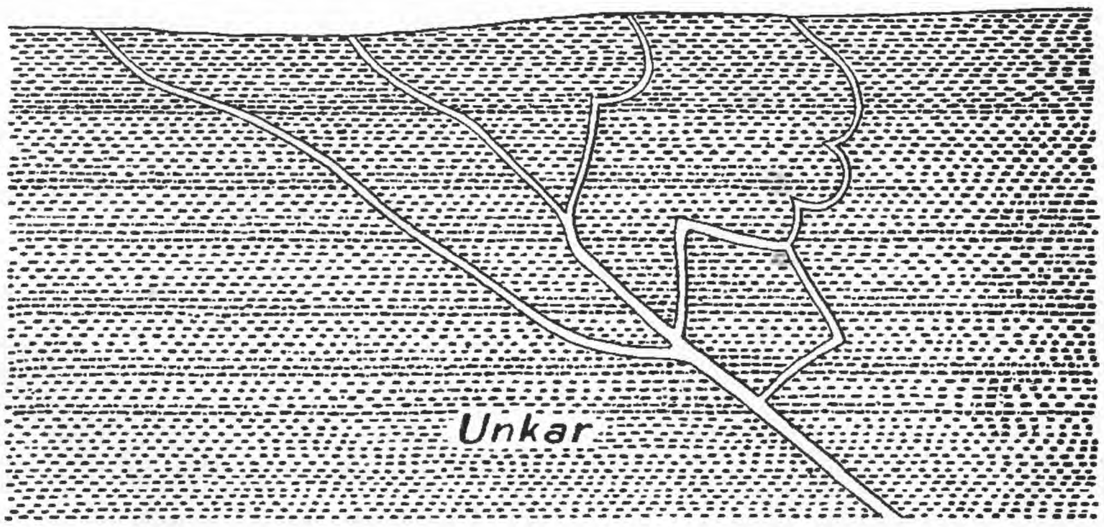


FIG. 53.—Dike in the sandstones of the Unkar terrane.

(Fig. 53) was taken from the opposite side of the canyon, on a cold winter day, but the general position of the various portions of the dike is approximately correct.

CONDITIONS OF DEPOSITION.

All of the igneous rocks appear to have come from true fissure eruptions, although, as Mr. Iddings has suggested, this does not necessarily follow from the data we now have. In the upper portion of the Unkar terrane the lava flowed out in successive sheets, a sufficient period of time intervening between the larger outflows to permit of the accumulation of from 3 to 35 feet of sand on the surface of the various flows. The wide distribution of thin layers of sandstone, shale, etc., of uniform thickness over considerable areas, indicates a relatively smooth sea bed at the time of the spreading of the first sheet of lava over it; and that the sea was shallow is shown by ripple marks and the filling of sun cracks. The occurrence of the latter just beneath the basal flow and the presence of beds of sandstone between the flows prove a gradual subsidence of the sea bed during the deposition of the lava. Portions of some of the lava sheets, especially the basal one, bear evidence of having been broken into fine, rounded fragments, apparently by the hot lava pouring into the sea. This phenomenon was not studied in detail, and it may have resulted solely from the disintegration of the lava by atmospheric agencies. Where the more solid rock is exposed to view on cliff surfaces there did not appear to be any evidence of rearrangement of the fragments by water.

The stratigraphic evidence of the contemporaneity of the lava sheets and the embedding strata is strengthened by the presence of amygdules and cavities in the upper portion of the flows, and it is not infrequent that small beds of sandstone occur that were apparently intermingled as sand in the flowing lava.

The lower flow of the Unkar terrane is a solid bed that rests on a shaly limestone. There is no apparent alteration of the limestone where it comes in contact with the lava; and the sandstone beneath the lava sheets shows very little change, if any, as the result of contact with the lava.

GEOLOGIC AGE.

The Tonto sandstone forms the base of the Paleozoic section in the Grand canyon district. It is massive-bedded and rather coarse in the lower portion, passing above into shaly, fine grained, fossiliferous sandstones. The presence of a well-marked middle Cambrian fauna in its upper portion clearly indicates its geologic age. It is only the absence at the base of the sandstone of the lower Cambrian or Olenellus fauna that prevents carrying the recognized Paleozoic section down to include its oldest known fauna. The period of erosion, represented by the unconformity between the Tonto sandstone and the Grand Canyon series, is considered to more than equal lower Cambrian time, and to constitute a well-defined boundary between the Paleozoic and pre-Paleozoic formations. In my earlier work, in 1883, I referred the Grand Canyon and Chuar strata to the Cambrian,[1] but upon further study of the Cambrian rocks and their contained faunas, and in view of the extent of the time break indicated by the nonconformity by erosion, this was changed in 1886, and all the pre-Tonto strata were referred to a pre-Cambrian series.[2]

In the scheme of nomenclature adopted by the Geological Survey in 1888 the clastic rocks beneath the Cambrian and superjacent to the Archean were grouped under the term Algonkian—of equivalent rank to Cambrian, Silurian, etc.[3] In this classification the system name—equivalent to Paleozoic, etc.—was not decided upon; but I am strongly in favor of adopting the name "Proterozoic," proposed by Dr. Irving and accepted by Prof. C. R. Van Hise.[4] Under this nomenclature the Grand Canyon series will be referred to the Algonkian system of the Proterozoic group.

There may be a difference of opinion among geologists as to the adequacy of the evidence that the Grand Canyon series is pre-Cambrian.

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[1] Am. Jour. Sci., Vol. xxvi, 1883, p. 441.

[2] Bull. U. S. Geol. Survey No. 30, 1886, p. 41.

[3] Tenth Ann. Rept. U. S. Geol. Survey for 1888-'89, 1890, p. 66.

[4] Bull. U. S. Geol. Survey No. 86, 1892, p. 493.

This can hardly be the case with those who have studied the questions of orographic movement and subsequent erosion. The long section on Pl. LX shows most clearly that the sediments of the Grand Canyon series were elevated, faulted, and more or less flexed prior to the period of erosion that cut away a section of the entire series, and not only reduced to a baselevel the land area formed by the latter, but reduced to the same plane the more resistant subjacent rocks of the Vishnu terrane of the Algonkian, and probably the Archean, to the west. The time required for the orographic movement, resulting in elevation and subsequent erosion, would exceed, in my opinion, the period of lower Cambrian sedimentation. It is not at all improbable that the sediments of lower Cambrian time in the Great Basin region of Nevada, Utah, etc., were derived from the Algonkian continent to the east, of which the Grand Canyon series of rocks then formed a part.

CORRELATION.

The Grand Canyon series, the Llano series of Texas, and the Algonkian series of the Lake Superior region afford an opportunity of comparing the stratigraphic succession of somewhat similar lithologic series of strata, but a definite correlation can not be made until a more reliable factor is obtained than lithologic resemblance of the various formations. It is quite probable that the Grand Canyon series and the Keweenawan series of Lake Superior represent the same time interval; also that the strata beneath Packsaddle mountain in central Texas are the equivalent of the Chuar terrane of the Grand canyon; but until paleontologic evidence is secured it may be said that these correlations are little more than possibilities. The Grand Canyon, Llano, and Keweenawan series may be referred to the Algonkian, as that system of rocks includes the strata of sedimentary origin between the Archean complex and the base of the Cambrian; beyond that any correlation on trustworthy data is impossible. Mr. Iddings's examinations of the specimens collected shows the basal flows of the Unkar terrane to be a true doleritic basalt, and that the dikes and the upper flows, as exposed in Chuar butte, etc., are basalts differing but little from the basalts of Tertiary age found in Nevada, Utah, and on the plains in the vicinity of the Grand canyon. This fact prevents any correlation of the lavas with those of other localities, even though basaltic rocks were found to occur in formations referred to the Algonkian. It is evident that until characteristic fossils are found in the various terranes now referred to the Algonkian, it will be practically impossible to make any correlations that will be any more than tentative suggestions.

PETROGRAPHICAL CHARACTER OF THE LAVAS.

By Joseph Paxson Iddings.

The specimens collected by Mr. Walcott from the pre-Cambrian lava sheets in the Grand canyon of the Colorado are basaltic rocks, more or less altered, which exhibit a considerable range of megascopical appearance. They are partly dense and compact, partly vesicular or amygdaloidal, and in several cases brecciated or scoriaceous. Most of them are reddish brown, mottled with green. A few are dark greenish or bluish gray. In some instances they are traversed by seams of calcite and quartz, which also compose the amygdules, the quartz often forming distinct spherulitic aggregates. The texture of the rocks is uniformly aphanitic in some cases and finely crystalline in others. There are no megascopic phenocrysts. In one instance the grain of the rock is as coarse as that of medium-grained dolerite.

In the Chuar lava butte the basal lava sheet, which is 180 feet thick, probably consists of a number of superimposed flows with a small amount of sedimentary material between them in places. The specimens from this belt present slightly different modifications of typical ophitic structure, with more or less cementing groundmass or base.

The rock some little distance above the bottom of the belt is partly dense and comparatively unaltered, forming compact dark nodules in more decomposed portions, which weather into loose fragments. In thin sections the two portions are alike in composition and structure, differing only in degree of alteration. With low magnifying power the characteristic structure is evident. Lath-shaped sections of feldspar lie in all directions, with serpentine pseudomorphs after olivine, considerable chloritic material in comparatively large patches, and gray aggregated substance, with abundant grains of magnetite and some skeleton forms of magnetite aggregates, besides occasional microlitic needles. The feldspar is partly fresh and brilliant, with high extinction angles, probably labradorite. It is largely altered to strongly polarizing amphibole (actinolite?). The altered olivines are characterized by opaque outlines, the same opaque material filling former cracks. Within these outlines there is sometimes serpentine, sometimes calcite. Olivine was abundant in the rock previous to alteration. The chloritic material is partly in nearly parallel aggregates, with a somewhat fibrous arrangement, and partly in spherulitic aggregates. Calcite is present in large amount, and with it microscopic quartz crystals in radiating clusters, approaching spherulites. The principal axes of the crystals are radially oriented, and the outline of the clusters is rounded to spherical. The original structure of the remnants of microlitic base is preserved. It contains, besides the magnetite grains and ilmenite rods, delicate acicular microlites, in part feldspar. With more advanced alteration the feldspars are completely changed to saussurite, and the serpentine has a more pronounced spherulitic arrangement, and small grains of titanite appear.

In one thin section from this part of the mass there is a small amount of augite left. It is pale green to colorless, and originally formed relatively large individuals allotriomorphic toward the feldspar.

The rock in the upper portion of this belt, which is amygdaloidal, with chlorite, calcite, and quartz, is reddish, and has the same general structure as that just described, with rather more cementing base. The alteration is somewhat different; the feldspars are clouded uniformly with reddish dust-like particles, retaining their optical properties in a modified condition. The twinned lamellæ remain, but the interference colors are dull and the extinction angles low. The serpentinization of the olivine is characteristic and is partly reddened about the opaque lines of cracks and boundary. There are comparatively large grains of magnetite. Calcite, quartz, and some chlorite are scattered through the rock. Calcite and quartz also form seams in the rock.

A very similar form of basalt occurs within 2 feet of the bottom of this belt. The crystals of feldspar are slightly smaller and closer together; there is less microlitic base, and olivine was very abundant in small crystals, now considerably decomposed. All trace of pyroxene has disappeared. It contains amygdules and seams of calcite.

Near the contact with the underlying sandstone the basalt is less crystalline and more amygdaloidal, and is dark red. Thin sections show a decrease in the size of the feldspar and an increase in the amount of base; the feldspars differ greatly in size, many being acicular. In the contact rock acicular microlites and needles of feldspar predominate over the stouter forms. The latter are forked and fringed at the ends, and the thinner crystals are often curved and arranged in fan-shaped or brush-like clusters. They sometimes inclose relatively large rectangular inclusions of the opaque base, which is reddish brown in part. The feldspar substance is somewhat clouded, but the twinning is noticeable, and the extinction angles are low, in many cases being zero. This indicates an approach to oligoclase.

In the second belt of basalt in the Chuar lava butte the specimens collected represent somewhat different varieties of basalt. The dense, dark colored rock at the bottom of the sheet is brownish in thin section, and consists of a brownish groundmass which is almost isotropic, with abundant grains and skeletons of groups of magnetite and minute needles. This is filled with lath-shaped to short rectangular feldspars, sometimes forked. There are numerous stout crystals, altered to chlorite, undoubtedly pyroxenes originally. Pseudomorphs after olivine are not distinguishable from those after pyroxene, but probably occur. Magnetite is abundant.

Higher up in the sheet the rock is darker, with a greenish tinge, and is more crystalline. There is less groundmass, or base. The general character of the rock is the same as that just described. Small altered pyroxenes abound. Olivine pseudomorphs are noticeable. In patches of chlorite there are compact idiomorphic crystals of hornblende, light brown and pleochroic, evidently secondary.

Near the summit of the sheet the rock is much finer grained, and is amygdaloidal. In thin section there is much opaque groundmass, with small crystals of feldspar, lath-shaped and rectangular, besides small pseudomorphs after olivine, and possibly some after pyroxene. Magnetite crosses and skeleton forms are plentiful. The amygdules are filled with spherulitic quartz, the rays being optically positive. The quartz also occurs in large grains.

The lava bed immediately over the first heavy belt is dense and massive in its lowest part, and when broken resembles a dark red, dense sandstone, as already observed by Mr. Walcott. In thin section it is a basalt with considerable groundmass, clouded with red oxide of iron. It is faintly polarizing and bears feldspar microlites. The microscopic phenocrysts are lath-shaped feldspars with pyroxene and olivine pseudomorphs, besides magnetite. The rock becomes somewhat more coarsely crystallized higher up in the bed, the skeleton crystals of feldspar being distinct.

Seventy-five feet from the base of the sheet it is markedly ophitic, with abundant olivine pseudomorphs. There was more or less microlitic base between the feldspars, but the whole mass is much altered in the manner already described. Serpentine and chlorite abound. The next subflow, 6, has the same character.

The base of the third sheet or bed is dense and dark gray, with a very even fracture. It is finely crystalline, with abundant tabular feldspars and small, irregularly outlined augites, pale green and colorless, which exhibit slight decomposition. There are olivine pseudomorphs and magnetite, some chlorite, and indications of a small amount of a once microlitic base. Fifty feet higher up the rock is similar in structure and composition, but unaltered, and is reddish brown in hand specimens. Near the top of the sheet it is much finer grained and amygdaloidal. One specimen is a compacted agglomerate of basalt fragments of a scoriaceous character.

The rock of the fourth sheet is dense, dark steel-gray, and very fine grained. It is an altered basalt similar to the lava sheet immediately beneath it.

The lower portion of the fifth sheet is compact and dark bluish gray, with very fine, even fracture. In thin section it resembles the basalt just described, but is finer grained and fresher. The augite is partly fresh and almost colorless. Olivine pseudomorphs are numerous, and the cementing base is globulitic and faintly polarizing, with magnetite forms of growth. In one place there is an ophitic development of the augite. Toward the top of the flow it is less crystalline, and is vesicular, being in part an agglomerate of scoria, much altered.

The uppermost or sixth sheet is formed of basalt, the freshest part of which is like the basalt below. The augite is more abundant, in irregular grains, and nearly colorless. The other constituents are more or less decomposed.

The lavas of the Nunkoweap lava hill are altered basalts, with the same composition and variations of microstructure as those just described. All the other specimens of pre-Cambrian lavas collected by Mr. Walcott from this vicinity, with one or two exceptions, are like those in Chuar lava butte. Some of them represent flows and others dikes, their microstructure being the same in both cases.

The rock from the lower part of the lava bed at the southern base of Vishnu's Temple is an exceedingly fresh-looking, bluish black dolerite, in which the characteristic ophitic structure is noticeable without the aid of a lens. In thin section it is found to be a typical dolerite, with ophitic structure. The plagioclase is but slightly altered to saussurite. The augite is violet colored and the olivine is almost perfectly fresh and colorless. A little serpentine and chlorite have formed in places. Iron oxide is present in large grains, and some characteristic aggregates and rods, probably in part ilmenite. It is uncertain whether there were any patches of microlitic base between the feldspars or whether the rock was originally holocrystalline. This is the freshest and most crystalline form of these pre-Cambrian lavas and is identical with many dolerites of recent age. In fact, all these lavas are remarkably well preserved for basic rocks of such antiquity. This is undoubtedly due to the small amount of dynamic metamorphism they have experienced. In structure and mineral composition they resemble certain forms ot modern basalt and dolerite, even to the minutest detail.

Similar Tertiary or recent basalts have been described by Zirkel from Nevada and Utah. The dolerite and less crystalline forms of the pre-Cambrian basalts of the Grand canyon of the Colorado have their counterparts in the rocks from Diabase hills and other localities in the Truckee range, Nevada. Others have their equivalents in basalts from the Kawsoh mountains, Nevada, and in numerous other localities in this region. The facies of the ancient basalt, with needle-like and forked feldspars, however, has not yet been found among these recent basalts.

Through the kindness of Mr. J. S. Diller, the modern basaltic lavas which occur over the surface of the country in the vicinity of the Grand canyon of the Colorado were compared with the pre-Cambrian lavas in the bottom of the canyon. They were found to differ from them in microstructure to some extent. The recent basalts have more of an andesitic habit, with fluidal arrangement of the feldspars, which are generally smaller than those of the ancient basalts. Augite is more abundant in the modern lavas, and olivine forms larger phenocrysts. These differences are small, and probably arise from a slight difference in chemical composition and in the physical history of their solidification.

The microstructure of the pre-Cambrian basalts of the Grand canyon of the Colorado, together with their vesicular and scoriaceous modifications, and their mode of occurrence with interbedded layers of sandstone, clearly indicate that they were extrusive lavas which flowed over a shallow sea bottom and solidified in the same manner as many lavas which have cooled as subaerial sheets on dry land. The importance of the facts here recorded rests upon the evidence they furnish of the identity of the basic lavas erupted in this region previous to Cambrian time and those erupted in Tertiary and recent times. This indicates a similarity in the magmas from which they were derived. It also adds to the number of known occurrences of ancient centers of volcanic activity in this country, which is steadily increasing, both in the Far West and along the Atlantic seaboard, the most extensive and best preserved occurrence of pre-Cambrian lavas being that of the Keweenaw series in the Lake Superior region.

ON THE STRUCTURE OF THE RIDGE BETWEEN THE TACONIC AND GREEN MOUNTAIN RANGES IN VERMONT.

BY

T. NELSON DALE.

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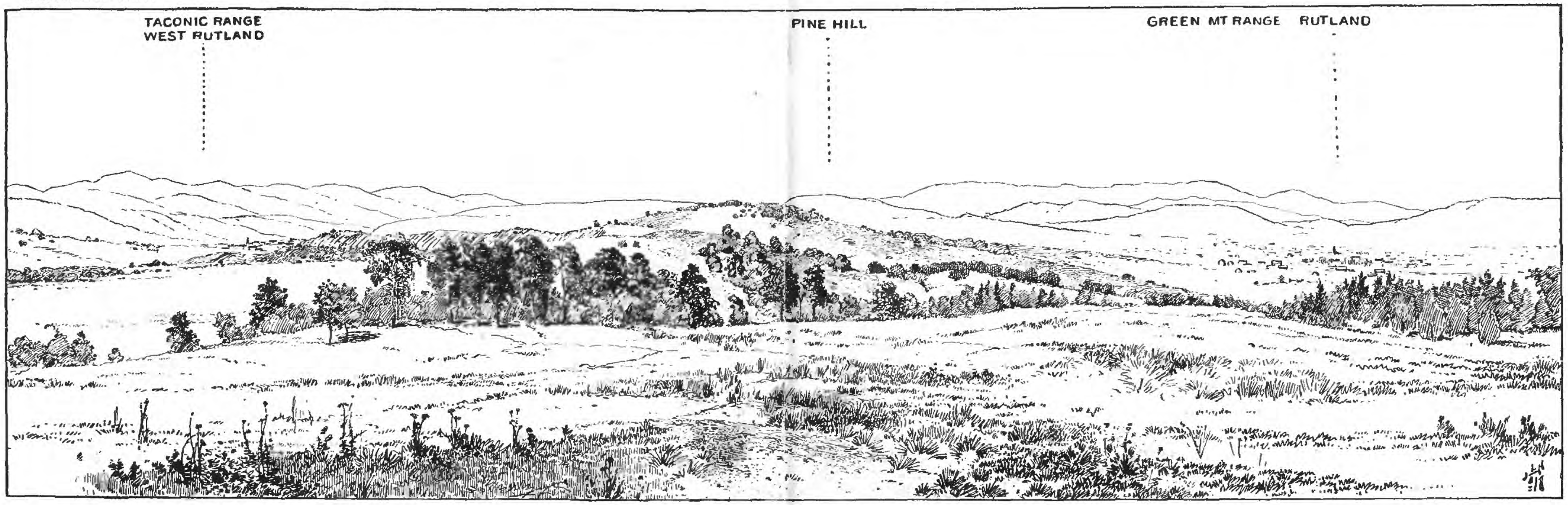
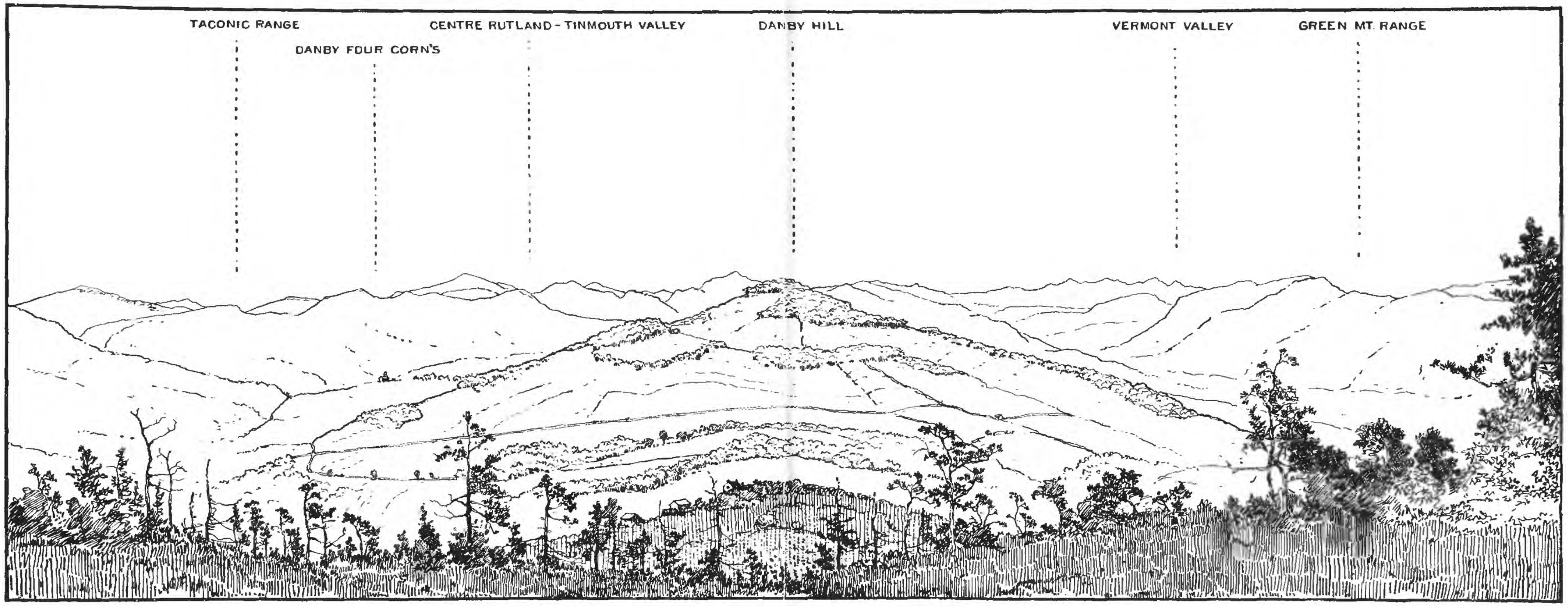
ILLUSTRATIONS



A. THE INTERMEDIATE RANGE AND PINE HILL, FROM THE NORTHERN PART OF THE CLARENDON RIDGE, NEAR LOCALITY 281.



B. THE INTERMEDIATE RANGE AND DANBY HILL, FROM THE NORTHERN SLOPE OF DORSET MOUNTAIN, WITH THE TACONIC RANGE ON THE WEST AND THE GREEN MOUNTAINS ON THE EAST.

ON THE STRUCTURE OF THE RIDGE BETWEEN THE TACONIC AND GREEN MOUNTAIN RANGES IN VERMONT.

BY T. NELSON DALE.

TOPOGRAPHY.

In the town of Manchester, Vermont, the Taconic and Green mountain ranges are conspicuously distinct. The former, in Mount Equinox, on the west, rises steeply more than 3,000 feet above the valley, while 2 miles east the Green mountain range presents an equally bold but less elevated front.

Three miles northeast of Equinox, Dorset mountain crowds in between the two ranges, leaving narrow valleys on either side. The Dorset mountain mass extends 7 to 8 miles north-northeast, terminating in Danby with a bold east-and-west face; but its northern base, still 500 feet above the Vermont valley, merges in Danby hill, which is the beginning of a series of hills and saddles ranging from 1,500 down to 500 feet above the Vermont valley, and extending 21 miles farther north to the Rutland-Pittsford line, where it dies out. The entire length of this intermediate range, including the Dorset mass, is 32 miles. The general topographic relations of this ridge are shown in Pl. LXVI.

LITERATURE

Edward Hitchcock (assisted by Albert D. Hager, Edward Hitchcock, jr., Ch. H. Hitchcock): Report on the Geology of Vermont; descriptive, theoretical, economical, and scenographical. 2 vols. Claremont, N. H. 1861.

James D. Dana: An account of the discoveries in Vermont geology of the Rev. Augustus Wing; American Journal of Science, Ser. III, Vol. XIII, p. 332. 1877.

Ch. H. Hitchcock: Geological sections across New Hampshire and Vermont; Bulletin American Museum of Natural History. New York. 1884.

N. H. Winchell and H. V. Winchell: The Taconic iron ores of Minnesota and western New England; American Geologist, Vol. VI, pp. 263–274, Nov., 1890. Also in Bulletin No. 6, on the iron ores of Minnesota, etc.; Geological and Natural History Survey of Minnesota. 1891. Appendix B.

J. E. Wolff. On the Lower Cambrian age of the Stockbridge limestone; Bulletin Geological Society of America, Vol. II, pp. 331–338. Rochester, N. Y. March, 1891.

T. Nelson Dale: On the structure and age of the Stockbridge limestone in the Vermont valley; Bulletin of the Geological Society of America, Vol. III, p. 514. 1892.

Aug. F. Foerste: New fossil localities in the early Paleozics of Pennsylvania, New Jersey, and Vermont. American Journal of Science, Ser. III, Vol. XLVI, p. 435, 1893.

T. Nelson Dale: The Rensselaer grit plateau in New York. Thirteenth Annual Report of the U. S. Geological Survey, pp. 291–340. 1893.

RESULTS OF PREVIOUS INVESTIGATORS.

This intermediate range was described by the geologists of the Vermont survey[1] as an anticline of quartzite flanked on both east and west, in places, by "talcoid schists," in others by "Eolian limestone"; and the schists forming its southern end were represented as cut off from the schists which cap Dorset mountain by an east-west fault. Prof. C. H. Hitchcock[2] omits the anticlinal structure from the quartzite, calls the schists on the east side "Cambrian slates," and the limestone on both sides "Cambro-Silurian."

Mr. J. E. Wolff[3] shows the composition of the northern end of the range to be as follows from east to west: (1) Cambrian limestone, fossiliferous, overlying (2) Cambrian quartzite and its associated conglomerates and gneisses; then (3) schist overlying (4) the lower Silurian limestone of the center Rutland valley. He also shows the continuity at the surface of the quartzite of the ridge with that of the west flank of the Green mountain range. He would explain the abnormal relations between the quartzite of the ridge and the Stockbridge limestone on the west "by a great thrust plane by which the Cambrian is made to overlie the lower Silurian limestone," but of which the Pine hill locality affords no decisive proof.

The bearing of Mr. Wing's discoveries on the subject is that they fixed the age of the upper part of the Stockbridge limestone as lower Silurian. The significance of the paper of the Messrs. Winchell is that from a comparison of the relations of certain limestones and quartzites in the Northwest, and also from a review of Taconic literature generally, they argued that a portion at least, if not all of the Stockbridge limestone must be of Cambrian age.

COWORKERS.

The microscopic petrographic determinations were made by Mr. J. E. Wolff, of this Survey, and the paleontological by Mr. C. D. Walcott, then paleontologist of the Survey. Mr. Aug. F. Foerste discovered Trenton-Chazy fossils in Wallingford, and made special collections for determination at the Cambrian locality in West Clarendon.

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[1] Op. cit., Vol. I, pp. 350, 353; Vol. II, p. 763; Pl. VIII, fig. 2; Pl. XVI, secs. 4, 5.

[2] Loc. cit., Pl. XVI, secs. 4, 5, 6.

[3] Loc. cit., figs. 1 and 2, and p. 337.

STRUCTURAL GEOLOGY.

CLARENDON SECTION.

TOPOGRAPHY.

A low and broad saddle about 6 miles south of Center Rutland in Clarendon affords access to the structure of the ridge.

The accompanying contour map (Pl. LXVII) shows the topography of about 4 square miles at this interesting point. The summit south of the saddle is 1,120 feet above Otter creek. The double summit north of it, 820 and 880 feet; the saddle itself, 420 feet. The Tinmouth valley here is 140 feet higher than the Vermont valley.

AREAL AND PETROGRAPHIC GEOLOGY.

The eastern half of the ridge here consists mainly of a quartzite continuous with that which at its north end crosses the Vermont valley to join that along the west face of the Green mountain range,[1] and is now recognized as of lower Cambrian age.[2] This quartzite is commonly interbedded with a very fine grained and finely banded gneiss or schist, consisting of bands of quartz and feldspar (orthoclase, plagioclase, and microcline) alternating with bands of muscovite (sericite) and biotite (see Fig. 59). In places, however, the quartzite is associated with a chloritic muscovite (sericite)-schist, sometimes with thickly disseminated crystals of magnetite. At locality 270 this sericite-schist contains a bed of blue quartz conglomerate 1 foot thick, the pebbles being one-half inch to 1½ inches in diameter. There are also on the eastern side of the ridge (localities 209–212, 220, 222, 279, 312, 315–317) certain coarse chloritic gneisses containing, as at locality 88, small beds of coarse crystalline limestone, rarely hornblendic, as at 221. At 265 there is a crushed or brecciated granite, slightly calcareous, and near it is a small well-determined metamorphic basic dike, trending with the ridge. On the map no attempt has been made to separate these gneisses and this granite from the Cambrian rocks proper. Whether they represent the base of the Cambrian or some older series or are extremely altered eruptives must be determined on the Green mountain range, where the outcrops are on a larger scale.

On the western side of the ridge is an irregular area of more or less quartzose, bluish gray and yellowish white, fine grained limestone. It is continuous with that of the Tinmouth and Center Rutland valleys.

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[1] See Mr. Wolff's map, loc. cit.

[2] See C. D. Walcott. The Taconic system of Emmons and the use of the name Taconic in geologic nomenclature, Am. Jour. Science, Ser. III, Vol. XXXV, 1888, pp. 232–236. Also The Fauna of the Lower Cambrian or Olenellus Zone, Tenth Ann. Rept. U. S. Geol. Survey, for 1888–89, pp. 593-594. 1890.

A small lenticular area of similar limestone occurs in the quartzite on the east side of the ridge. The steep isolated knoll southwest of Clarendon flats consists of such limestone, with a small area of quartzite on its east side. South of this a series of limestone outcrops stretches across the intervale to Clarendon falls. The Vermont report represents the limestone areas of the Vermont and Tinmouth valleys as uniting between Dorset and Equinox mountains. We have here to do, therefore, with the Stockbridge limestone, Hitchcock's Eolian limestone.

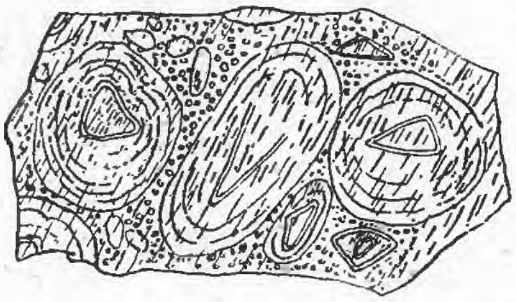

FIG. 54.—Concretionary structure of lower Cambrian limestone at West Clarendon, Vermont, with pteropod shells (Hyolithes) as nuclei. The rock also abounds in minute quartz grains.

In the northern part of the western side of the ridge is an area of graphitic sericite-schist much like that which forms the lower part of the schists of the Taconic range, both in Vermont and Massachusetts—the Berkshire schist. South of the saddle a narrow belt of this recurs with a strip of quartzite west of it and the quartzite and fine-banded gneiss east of it. A lenticular limestone area less than a quarter of a mile long occurs in the schist tract near the road in the northwestern corner of the map. This is the most southerly fossiliferous locality indicated on Mr. Wolff's map.[1] Another much smaller limestone area occurs at 260, about three-quarters of a mile southeast of this one and close to the quartzite.

PALEONTOLOGY.

Traces of fossils were observed by the writer near H, on July 9, 1891. On August 4 they were found in abundance at locality 292, and a few were sent to Mr. Walcott for determination. This fossiliferous bed measures about 25 feet in thickness, and crops out, off and on, for 1,600 feet in a northeast and southwest direction, as shown on the map. The rock is made up in many places of spherical or elliptical nodules from one-tenth to eleven-tenths of an inch in diameter. (See Fig. 54).

In structure, the nodules are oolitic, the calcite particles being arranged in concentric rings about the nucleus, and the form of the nucleus generally determining that of the nodule. The nuclei are more or less perfect pteropods (Hyolithes) which appear in longitudinal, transverse, or diagonal sections on the surface of the rock. The shells are sometimes partially filled with quartz.

Although, as Mr. Walcott suggests, the concentric arrangement of the limestone in the nodules resembles Stromatopora, the sections have not yielded any evidence of their organic origin.

Mr. Walcott's determinations are as follows:

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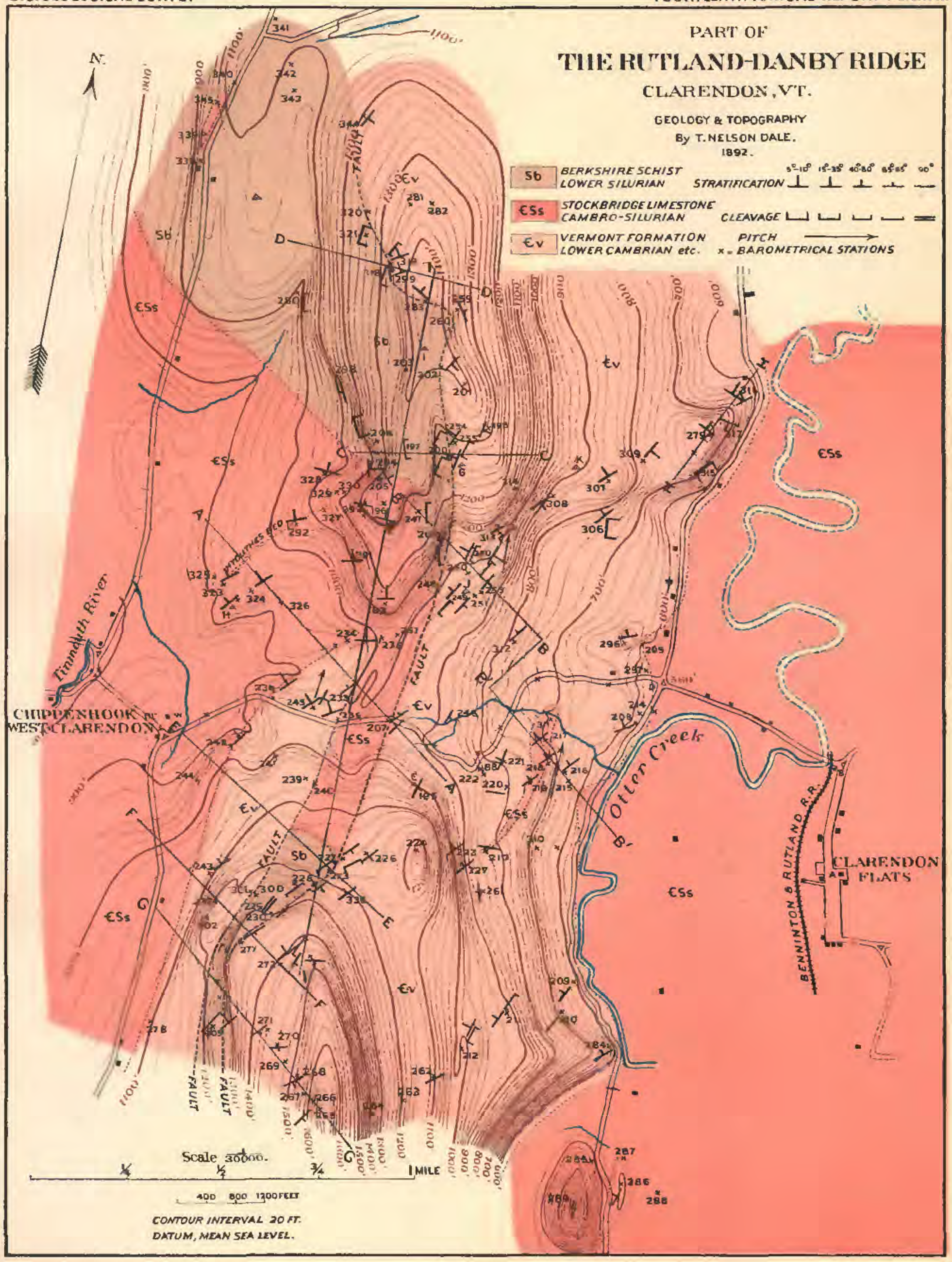
[1] Loc. cit.


PART OF
THE RUTLAND-DANBY RIDGE
CLARENDON, VT.
GEOLOGY & TOPOGRAPHY
By T. NELSON DALE.
1892.
Sb BERKSHIRE SCHIST LOWER SILURIAN
€Ss STOCKBRIDGE LIMESTONE CAMBRO-SILURIAN
€v VERMONT FORMATION LOWER CAMBRIAN etc.
STRATIFICATION
CLEAVAGE
PITCH
x = BAROMETRICAL STATIONS
N.
FAULT
Otter Creek
Tinmouth River
CHIPPENHOOK
WEST CLARENDON
CLARENDON FLATS
BENNINGTON & RUTLAND R.R.
Scale 1/30000
1 MILE
400 800 1200 FEET
CONTOUR INTERVAL 20 FT.
DATUM, MEAN SEA LEVEL.

Cambrian fossils.

	Localities.
Hyolithes americanus Billings[1]	292, 323, 324
Hyolithes similis?? Walcott (Newfoundland)	292, 323
Hyolithes impar? Ford (Troy, N. Y.)	292, 323
Hyolithes communis? Billings	292, 324
Salterella pulchella Billings[2]	324

Mr. Walcott adds: "Sections of a round tubular form of Hyolithes occur that resemble very closely the transverse sections of the smaller tubes of *Hyolithes communis.* With the exception of *Hyolithes impar*, which is a very doubtful identification, all of the species belong to the upper horizon of the Olenellus fauna. *Hyolithes americanus* has a very wide geographical and vertical range, as also *Hyolithes communis. Salterella pulchella* occurs on the Straits of Belle Isle and in Franklin county, northern Vermont, a little below the horizon of *Kutorgina labradorica* var. *swantonensis.*"

Silurian fossils.—In the small limestone area in the northwest corner of the map Mr. Foerste found in 1890[3] "numerous crinoid stems and occasional plates and rarely a small branching bryozoan with large cells." In the limestone at locality 260 he found in 1891, fragments of crinoid columns and a piece of a coral Heliolites ———?, indicating, as Mr. Walcott defines it, "the Trenton fauna, used in a broad sense to include the Chazy-Trenton and Lorraine faunas"—that is, the lower part of the lower Silurian or Ordovician.

STRUCTURE.

Only at three points in this area are the groups of strata in visible conformity. About a third of a mile north of the Clarendon-Chippenhook road, where it crosses the lowest part of the saddle, between localities 234 and 235, the uppermost layers of the Cambrian quartzite pitch northerly at 10° to 15° under the Stockbridge limestone. The transition is represented by a few feet of calcareous quartzite or quartzose limestone, from which the lime has been dissolved at the surface. About half a mile north of this locality (294) the uppermost strata of the Stockbridge limestone dip 20° easterly under the adjoining schist. There are also conformable contacts between the quartzite and the limestone at localities 218 and 219 on either side of the closed limestone area on the eastern flank of the ridge. This mass seems to be a compressed syncline with a westerly dipping axial plane, and thus represents about 65 feet of the base of the Stockbridge limestone. These and the other structural relations of the quartzite, limestone, schist, and gneiss are shown on the map by symbols and on the sections, Pl. LXVIII.

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[1] See E. Billings: On some new species of Paleozoic fossils; Canadian Naturalist, Dec., 1871, reprinted in American Journal of Science, Vol. III, p. 352. 1872. C. D. Walcott: Studies on the Cambrian Faunas of North America; Bull. U. S. G. S., No 30, p. 132 and Pl. XIII, 1886. Also in Tenth Annual Report of the U. S. Geol. Survey, p. 620, and Pl. LXXV.

[2] Found by Mr. Aug. F. Foerste, Aug. 17, 1891.

[3] J. E. Wolff, op. cit., p. 336, top.

Section A.

This passes through the lowest part of the saddle, from the southeast to the northwest. There is an anticline in the quartzite, then a possible fault plane dipping 70° to 80° west, followed by a strip of limestone 650 feet wide in contact on the west with quartzite strata dipping 35° west and a fault plane dipping 70° east. The steep easterly face of the quartzite, about 15 feet high, can be followed north of the road for a quarter of a mile, but no farther. The dip of the adjacent limestone can not be determined; the rock is crossed by a fine network of quartz veins. The quartzite continues west in minor folds for 600 feet, here and there with a well-marked northerly pitch. Its most westerly outcrop dips about 20° west, but the limestone is covered. The relations of the two rocks are manifest between 234 and 235, already described. A very low westerly dip (10°) may safely be assumed for the limestone here. At 326 the limestone crops out, but without determinable dip. From 324 to 325 it averages 30° west, and the exposed thickness is about 260 feet. Here occurs the Hyolithes bed, with only 15 feet of limestone exposed above it. Allowing a dip of 10° for the covered portion and for that between 324 and 326, i. e., a thickness of about 235 feet, the entire thickness from the top of the quartzite to the top of the fossiliferous bed would measure about 470 feet, and this much of the base of the Stockbridge limestone would therefore be of lower Cambrian age.

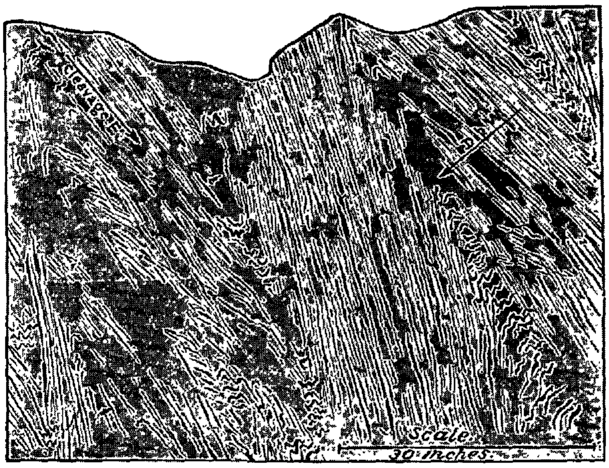


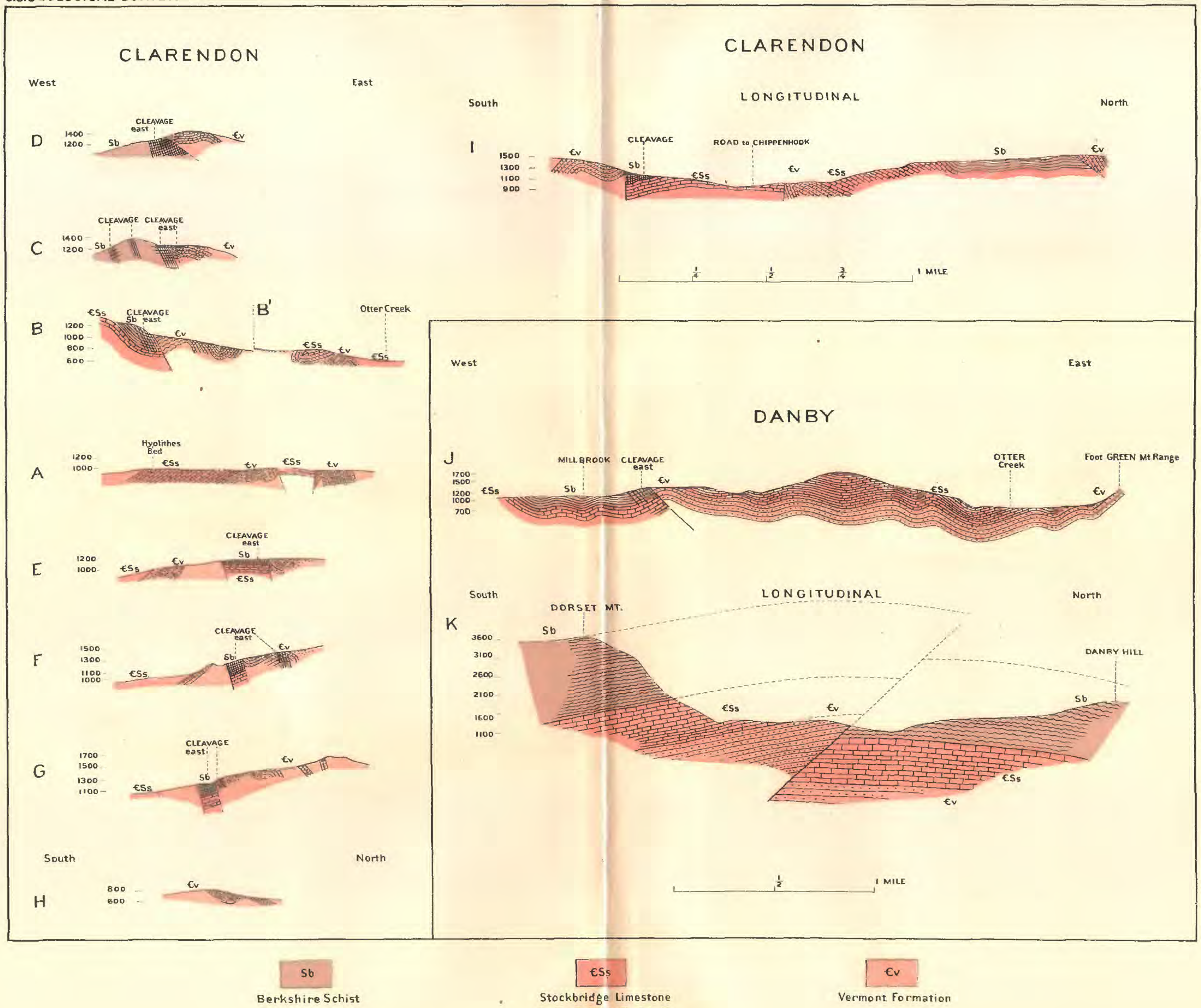
FIG. 55.—Acute folds in the Cambrian quartzite at locality 350, Clarendon, on the east side of the fault.

Section B.

This begins at the intervale along Otter creek and follows a northwesterly course, traversing the small limestone syncline. Here the pitch is 20° north. On the northwest side of the road is a jog of 900 feet in the section. A syncline followed by an anticline occurs in the quartzite and gneiss. At 249, south of the section line, the fine grained Cambrian quartzite is minutely and extremely plicated, dipping low west with a slip cleavage dipping 80° east.

At 350 the sharp compressed zigzags in the quartzite measure several feet in length (see Fig. 55), with the cleavage and the axes dipping 70° east, nearly like the cleavage at 249, but there is an actual dip of the stratification to the west.

Then the graphitic sericite schists (Berkshire schist, which overlies the Stockbridge limestone) are reached, here forming a steep hillside. The cleavage foliation dips high east, probably conforming to the hade of the fault, which is here entirely concealed. The position of the limestone in the section is necessitated by its surface relations to the schist and the contours.


CLARENDON
West
East
D
CLEAVAGE east
Sb
€v
C
CLEAVAGE
CLEAVAGE east
B
B'
€Ss
Otter Creek
A
Hyolithes Bed
E
F
G
South
North
H
CLARENDON
LONGITUDINAL
I
ROAD to CHIPPENHOOK
1 MILE
DANBY
J
MILLBROOK
OTTER Creek
Foot GREEN Mt Range
K
DORSET MT.
DANBY HILL
Sb
Berkshire Schist
€Ss
Stockbridge Limestone
€v
Vermont Formation

SECTIONS.

Section C.

In order to cross important outcrops this line has been drawn from east-northeast to west-southwest. There is an anticline in the Cambrian quartzite and gneiss. At 255 (Fig. 56) the westerly dipping stratification meets the fault plane, which dips 60° east. The Siluriau schists (sericite, biotite, quartz, and graphite)

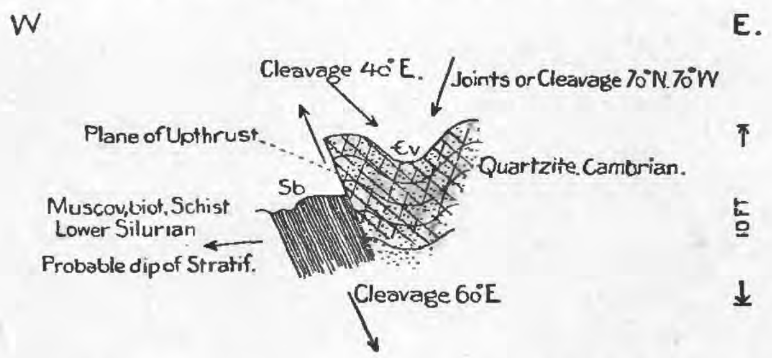


FIG. 56.—Structure of Cambrian quartzite and Silurian schist at the fault, locality 255, Clarendon.

are in contact with the Cambrian quartzite, and have a cleavage foliation parallel to the fault plane. They present an interesting case of a certain type of slip cleavage[1] (Fig. 57). The acute-angled folds of locality 350 (Fig. 55) are repeated here on a microscopic scale, but much more compressed, resulting in extreme slip cleavage.

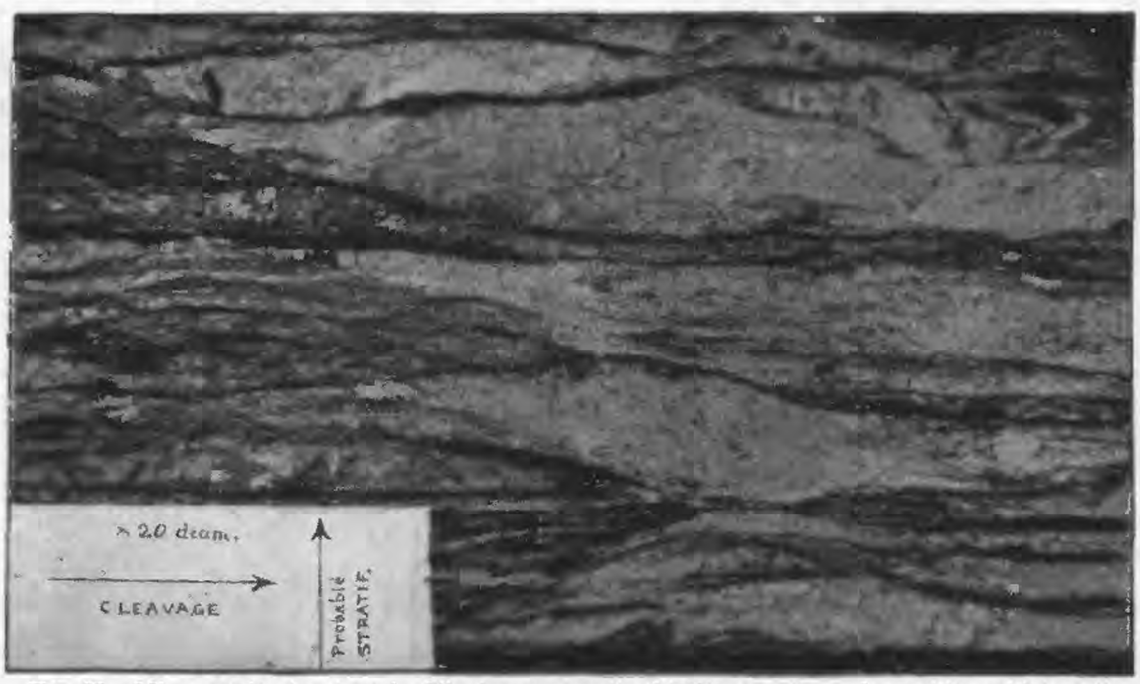


FIG. 57.—Microscopic structure in Silurian muscovite, biotite, quartz, and graphite schist at the fault shown in Fig. 56. The plications have been so compressed as to become extremely acute, then to rupture, and finally to merge into the slip-cleavage foliation thus caused.

Here and there some of the folia of mica have not yet entirely conformed to the cleavage foliation, and thus preserve some indication of the direction of the dip of the stratification, which was probably west or horizontal, i. e., about at right angles to the cleavage.[2] The fault line north of this section is marked by quartz veins. Easterly cleavage foliation pervades the entire mass of schist. On the west side of

[1] See Monograph XXIII, U. S. Geol. Survey, Part III, p. 158.

[2] See Henry Clifton Sorby: On the structure and origin of noncalcareous stratified rocks. Quarterly Journal Geol. Society, London, Vol. XXXVI, 1880, p. 73. Stages of slip cleavage, fig. 3, plication without cleavage; fig. 4, plications faulted. The structure in Fig. 57 above would form the next or third stage. See also J. E. Marr: On some effects of pressure, etc.; Geol. Mag., London, 1888, Vol. V, p. 219, figs. 1–1c.

the ridge the Stockbridge limestone dips conformably under the schist, which forms a westerly facing cliff in which there are indications (locality 298) of a westerly dip, and thus of a fold between that point and 294.

Section D.

Between sections C and D the fault line makes a sudden bend to the west, with the Silurian schists still on its west and south side. The north-northwest and north-

FIG. 58.—The contract of the Cambrian quartzite (Ꞓv) and Silurian schist (Sb) at the overthrust, locality 318, Clarendon, as seen looking east. The sharp edge of the hammer is exactly on the line which divides the two formations. Length of hammer handle, 30 inches. From a photograph.

northeast dip of the quartzite indicates a northerly pitching anticline. At locality 318 the Cambrian quartzite directly overlies the Silurian schists (Fig. 58). The strati-

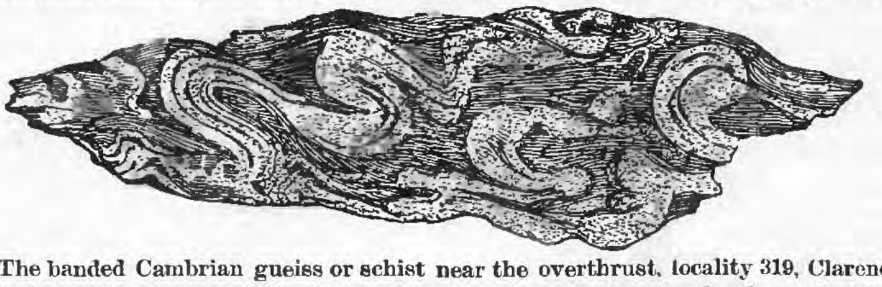


FIG. 59.—The banded Cambrian gneiss or schist near the overthrust, locality 319, Clarendon. The highly plicated light bands consist of a feldspathic quartzite, the dark bands of sericite-biotite schist with slip cleavage.

fication strike of the quartzite is north 60° east, and its general dip 20° to 30° north-northwest, while the cleavage strike of the underlying schist is north 25° east, and its dip 75° east-southeast, but decreasing a few feet away. Its stratification is indeterminable. The hade of the fault could not be exactly determined. The whole mass of the quartzite north of the angle in the fault line may have been thrust horizontally over the Silurian schists. The vertical west face of the quartzite (Fig. 58) strikes north to south and is very smooth in places, being either a joint or the vertical upper part of the thrust plane. At 319, 100 feet north of 318, the Cambrian is represented by the fine banded and plicated close grained gneiss described on page 533, dipping 20° north-northwest, with a cleavage dip of 45° south southeast. (See Fig. 59.) A few feet east this is conformably overlain by a thin-bedded quartzite.

Section E.

This is on the south side of the saddle. A syncline is shown in the Cambrian quartzite and gneiss, the west side of which dips nearly if not quite parallel to the

FIG. 60.—Structural character of the gneiss at locality 317, on the east side of the ridge in Clarendon, looking west-northwest. Area 20 by 20 feet. From a photograph.

fault plane and also to the cleavage of the adjoining Silurian schists. The stratification of this schist mass can only be conjectured from its surface relations. The absence of the schists in the deeper part of the saddle between the two fault planes is readily explained by erosion. The schist masses north and south of the road were once continuous, covering the limestone, and therefore necessarily dipping at a low angle east or west.[1] If horizontal the present extreme thickness south of the saddle would be 170 feet, and north of it at least 360 feet.

Section F,

A little south of Section E, shows an anticline east of the syncline of F and the narrowing of the schist mass. It probably also increases in depth.

Section G.

This section begins at the top of the southern summit at the contact of the Cambrian quartzite and sericite schist with the chloritic gneisses and altered granite. The Cambrian series here may measure about 1,000 feet in thickness. Between F

[1] A half mile south of the most southerly house shown on map, on west side of ridge, the Silurian schists dip west.

and G the fault line bends around to the south and the schist belt becomes still narrower. The easterly fault plane crosses the east line of the syncline shown in F. Here the fine banded schists of the Cambrian dip west in contact with the graphitic schists of the Silurian, which have a high easterly cleavage.

Section H.

This passes through the buttress of coarse chloritic gneiss on the east side of the ridge near Otter creek (locality 317). The strikes here are west-northwest to east-southeast, the entire mass of this small spur having apparently been twisted around 90°; or have we here some unconformable pre-Cambrian? Fig. 60 shows the general structural character of the gneiss. The relations on the east side of this mass are covered with drift.

Section I (longitudinal).

This section traverses the saddle from south to north, showing the northerly pitch of the quartzite and limestone in the northern part, and affords an approximate measurement of the entire Stockbridge limestone, which amounts to 1,200 feet. At 332, in the southern part, there is an east-to-west strike and southerly dip, possibly due to a southerly pitch. Owing to the curve in the easterly fault line, it is crossed twice by the section.

OTHER LOCALITIES.

Several localities not crossed by sections call for mention: At 295, near the crossroads, on the east side, the coarse chloritic gneisses, with a low easterly dipping foliation, are in contact with a very coarse crystalline limestone veined with quartz. At 215, a half mile south, masses of similar limestone crop out with the coarse gneiss near on the west.

At 337, south of the small limestone syncline on the eastern flank, the Cambrian quartzite and a sericite-biotite-quartz-schist, containing orthoclase, plagioclase, and microcline, stand erect in folds,[1] having been thrown up probably from the east, judging from the synclinal structure of the limestone north of this locality. The cleavage foliation, which traverses only the softer of the two rocks, had probably been formed during the earlier stages of the folding, before the erection of the folds into their present position. The folds of the quartzite are furrowed in a plane striking with the cleavage, but passing around them. (See Fig. 61.) These furrows are what a torsional motion of the folds on each other in a direction at an angle of 45° to their strike might be expected to produce. The data are: Strike of the folds north 40° to 50° east, dip 90° or high west; strike of the joints north 15° west, dip 90°; strike of the cleavage north, dip 20° east; strike of the furrows north.

On the east side of the steep limestone hillock at the southern edge of the map is a small area of westerly dipping quartzite, locality 286, with limestone dipping under it on its east side 25° to 30° west. Unless this quartzite occurs in the Stockbridge limestone, its structure is that of a greatly compressed anticline of the underlying quartzite overturned to the east.

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[1] This locality is figured in the 13th Annual Report of the U. S. Geological Survey, The Rensselaer grit plateau, fig. 25, p. 319, as illustrating the occurrence of nearly horizontal cleavage.

The small limestone areas, 339 to 345 and 260, in the schist area, may either be anticlines of the Stockbridge limestone protruding through a thin sheet of the Berkshire schist or may represent local calcareous sediments formed during the Berkshire schist period. The fossils of these areas, lower Silurian, indicate, therefore, the age either of the top of the limestone or of a portion of the schist itself.[1]

FIG. 61.—Specimen of Cambrian quartzite, two-thirds natural size, from locality 337, Clarendon, showing ridges and furrows crossing the fold diagonally. The front edge is a joint face. From a photograph. Size of specimen, 4 by 5½ inches.

INFERENCES.

From the foregoing data the following conclusions are drawn:

The ridge at Clarendon consists of the following series:

		Feet
Berkshire schist (Sb), upper Lower Silurian		360
Stockbridge limestone (€Ss) (1,000 to 1,400 feet.)	Lower Silurian; Upper and middle Cambrian (?)	730
	Lower Cambrian	470
Vermont formation, in part (€v), lower Cambrian		(?) 800
Total		2,360

[1] See The Rensselaer grit plateau, loc. cit., p. 312.

These form an anticline, the eastern and lower portion of which consists, at the surface, of at least five minor folds, all striking northeast to southwest, i. e., diagonally across the ridge. Possibly the saddle marks the place of a change in the pitch of this anticline, and there may be some connection between this and its erosion. However this may be, there is a northerly pitch throughout the northern half of the Clarendon map, which is more conspicuous and general on the west side in the limestone.

This anticline was ruptured and faulted in a general north-to-south direction, some of the upper layers of the quartzite being thrust up a distance equal to the entire thickness of the Stockbridge limestone, 1,200 feet, besides at least 360 feet[1] of the Berkshire schist, i. e., the vertical displacement amounted to about 1,500 feet (sections B and C). In the northern part this fault resulted in an overthrust, bringing the Cambrian quartzite over onto the Silurian schist (section D). In and south of the saddle the fault is double, a more or less wedge-shaped

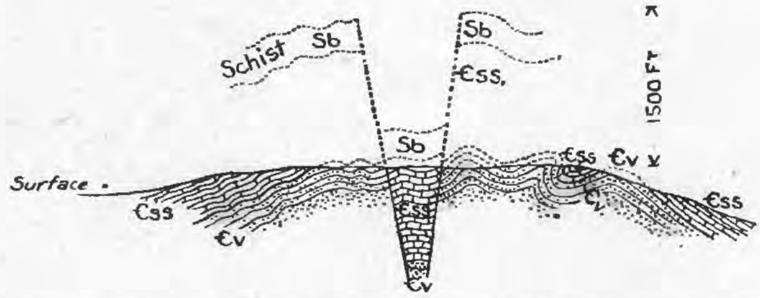

FIG. 62.—Diagram-section showing the general structure of the saddle in the ridge at Clarendon and the amount of erosion implied by the fault.

mass of the limestone and schist, 200 to 650 feet wide, having dropped down between masses of quartzite and gneiss.[2] It is quite possible that in this part of the fault the strata of quartzite and gneiss on either side of the wedge do not correspond vertically; in other words, there has been also some differential vertical motion. This interpretation of the Clarendon sections has been embodied in Fig. 62. The position of the schist between the faults is taken from its lowest outcrop north of the saddle.

The peculiar areal geology shown on the map is the complex effect of erosion, laying bare at different levels this northerly-pitching anticline of quartzite, limestone, and schist, faulted in these different ways along a line now intersecting the axes of its minor folds at an angle of about 20°, and now parallel with them.

It is also evident that if sedimentation during Cambro-Silurian time

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[1] This is calculated from the contours between localities 248 and 205.

[2] The westerly fault ending on the map at locality 235 probably joins the easterly one, perhaps near locality 248.

was equally great throughout this area a thickness of 1,500 feet of limestone and schist must have been removed from the eastern half of the ridge, as there certainly has been from the lowest part of the saddle.[1] (See Fig. 62.)

WALLINGFORD SECTION.

A few scattered observations were made in the area between Wallingford and Tinmouth villages and Tinmouth pond and South Wallingford. On the west side of the ridge the quartzite and the limestone appear to be in their normal relations. On the east there are several alternations of limestone and schist, possibly due to minor folds in the anticline. In a bed of limestone east of the central quartzite crinoid stems were found.[2] Mr. Aug. F. Foerste found Lower Silurian fossils at three points in the limestone on the east side. The most important of these is about 300 feet east of a schist belt.[3] Here a cyathophylloid coral, Streptelasma, and sections of strophomenoid shells were found. Both the fossils and the proximity of the schist indicate the upper part of the Stockbridge limestone. Mr. Foerste found also, about a mile northwest of South Wallingford village, on the east side of the upper road, a dike of camptonite continuing north for half a mile. Several smaller dikes occur in the schists between this and the village, parallel to the strike of the cleavage and in general to the fault.

DANBY SECTION.

TOPOGRAPHY.

The map (Pl. LXIX) shows the peculiar topography here. Danby hill on the north is about 1,300 feet above Otter creek. The saddle between Danby hill and Dorset mountain is as low as the Tinmouth valley, and about 500 feet above Otter creek. Into this saddle Mill creek, flowing west, has cut its channel, and in one place a small gorge nearly 200 feet deep. These relations are further shown in section K, Pl. LXVIII. The Dorset mountain mass[4] fills most of the space taken up farther north by the two valleys and the intermediate range. Its somewhat bold east-to-west face, its top rising 3,000 feet above the Vermont valley, and the 500-foot deep north-to-south incision in its western half make it a marked topographic feature. It is also deeply ravined on its north side. (See Pl. LXX.)

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[1] Owing to the pitch the vertical distance from the top of the quartzite, locality 235, to the top of the schist, locality 283, is only 450 feet.

[2] As there is hardly room enough for the entire thickness of the limestone between the quartzite of the central part of the ridge and the first schist outcrop on the east, it is probable that the fault here passes on the east side of the ridge.

[3] This locality is about two-thirds of a mile south of school 2, and about a mile west of school 5 (Otter creek), and 500 feet west of upper road near Allen Edson's house.

[4] This part of Dorset mountain, from its being in the town of Danby, is called Danby monntain in the Vermont report.

AREAL AND PETROGRAPHICAL GEOLOGY.

The Stockbridge limestone of the Tinmouth and Vermont valleys unite along the north foot of Dorset mountain, and the Silurian schists of Danby hill are bounded on the south by a fault, as shown in the Vermont report.[1] The course of this fault is not due east to west, but forms a zigzag, and there is a triangular area, about one-third of a mile square, of lower Cambrian quartzite, with blue quartz pebbles and sericite-gneiss of the Vermont formation, which on its northwest and southeast sides is by the fault brought in contact with the Silurian sericite-graphite schists of Danby hill, and on its south side is in normal relation to the Stockbridge limestone. At locality 394, in the Silurian schist area and parallel to its strike, is a highly metamorphic basic eruptive with large crystals "of albite, or a soda-lime feldspar near albite." At 429, on the northeast foot of Dorset mountain, near the old stage road, is a small dike of camptonite in marble of the Stockbridge limestone.

PALEONTOLOGY.

At 443, half a mile southwest of Danby Four Corners, Mr. Foerste found in the Stockbridge limestone sections of a small gasteropod, and possibly of a pteropod, Salterella, besides crinoid stems, indicating lower Silurian, i. e., the upper part of the limestone.

STRUCTURE.

The structural features are shown on the map (Pl. LXIX) and sections J, K (on Pl. LXVIII).

Section J.

From the foot of the Green mountain range, east of the top of Dorset mountain, northwest to the Tinmouth valley. At a waterfall in a rugged ravine southeast of School I, and near Benjamin Griffith's sawmill, in Mount Tabor, the quartzite and sericite-gneiss of the Vermont formation (lower Cambrian) are finely exposed for a height of about 80 feet, striking north 50° east and dipping 35° to 45° northwest. Although the Vermont valley is here very narrow, the section has some gaps in it. The outcrops, however, indicate two minor folds in the limestone. The section now crosses the foot of Dorset mountain. Between the Dorset road and the ravine on the northeast side of the mountain there is a syncline. The course of the ravine itself corresponds to the axis of a gentle anticline, and between this point and the quarries there is another syncline. West of this the limestone was not studied. The Cambrian quartzite north of Dorset mountain consists of small folds, more or less sharp, possibly slightly faulted in places along the strike, with a south-southwest pitch of 10° to 15°. Vertical joints strike north 75° west. Cleavage strikes northeast and dips 40° southeast. The general structure is a gentle anticline. The hade of the reversed fault on its west side can only be conjectured from the cleavage dip of the quartzite (40°) and of the adjoining Silurian schists (45° to 50°). The course of this part of the fault is about like that of the strike—northeast—and in line with the notch in Dorset mountain to the southwest; but no evidence of faulting could be found in the few exposures there. The amount of vertical displacement is at least equivalent to the entire thickness of the limestone, besides that of the schist,

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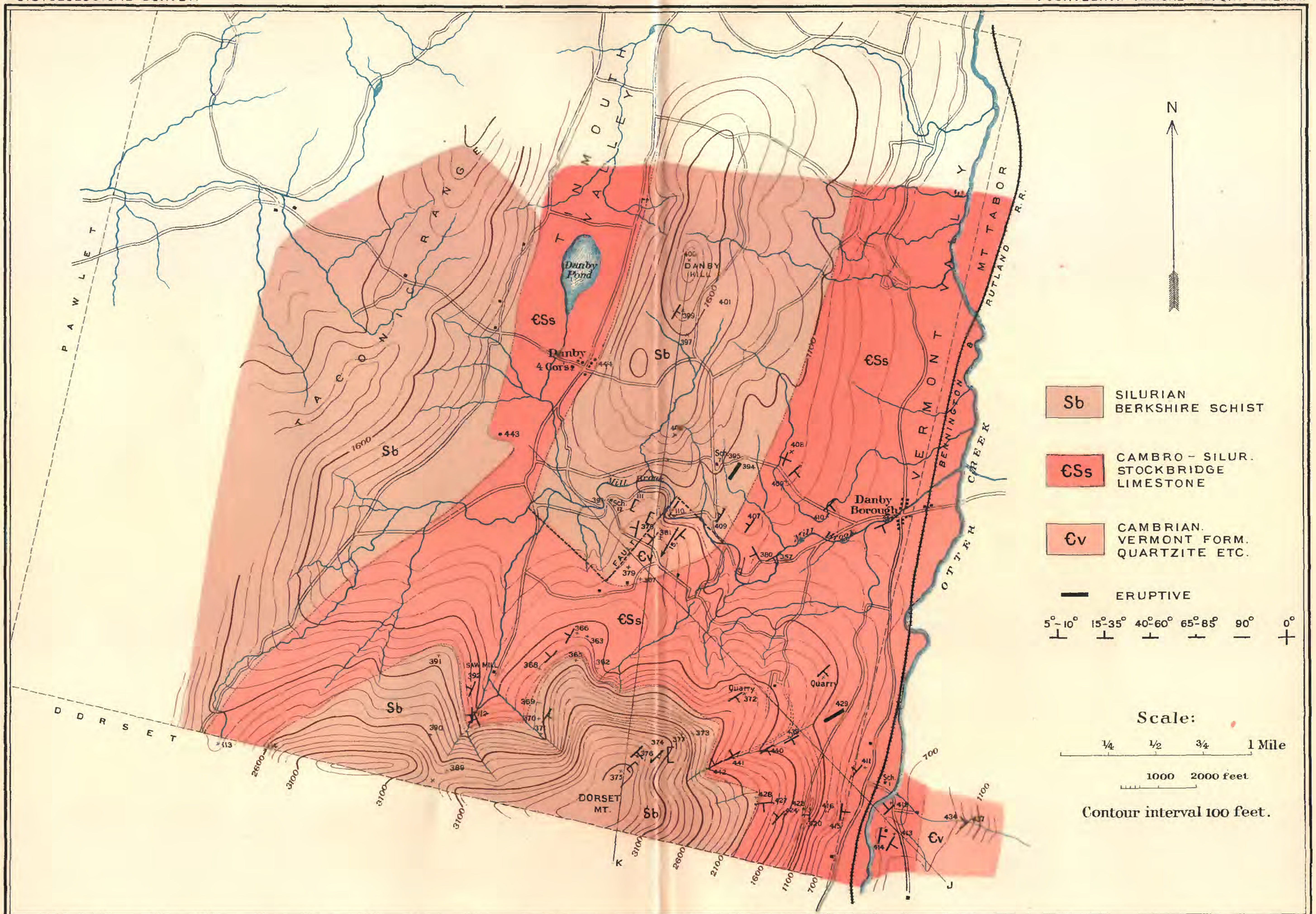
[1] Op. cit., Vol. II, Pl. VIII.



SKETCH MAP OF DANBY TOWNSHIP, RUTLAND CO., VT.

FROM BEERS' ATLAS

CONTOURS ROUGHLY DRAWN FROM PROFILE SKETCHES AND BAROMETRIC OBSERVATIONS

by T. NELSON DALE.

1892.

near the fault cut by Mill brook.[1] One thousand two hundred feet can be safely taken for the limestone and at least 250 feet for the schist. As the beds south of the fault are in their normal relations—quartzite, then limestone followed by schist—the entire Dorset mountain mass must have been thrown up about 1,450 feet. Neither the exact direction nor the hade of the western and eastern bends of the Danby fault can be observed, but the course of the eastern one is better defined than that of the other.

Section K (longitudinal).

This shows the general relations of the masses north and south of the fault to each other. The section should have been drawn at right angles to J and should traverse Dorset mountain just east of the notch, and then cross the eastern bend of the fault and that side of Danby hill, but the relations would not be materially different. A northerly pitch has been conjectured north of the fault.

INFERENCES.

The probable synclinal structure of the Vermont valley is indicated by the westerly dip in the Green mountain range east of Dorset mountain. The general anticlinal structure of the Danby hill schist mass naturally follows. The complex structure of Dorset mountain is shown by the observations. There is an anticline between the two roads on its east side, a syncline between the old stage road and the ravine on its northeast side, another anticline along that ravine, a syncline between it and the high shoulder near the top, and at least one other anticline between the top and the notch, and west of the notch another syncline, judging from the structure of the west side of Danby hill, which is on the line of strike.

The Silurian schists which cap Dorset mountain, there reaching a thickness of from 1,500 to 2,000 feet, were probably once continuous with those of Danby hill north of the fault. The ravines which now carve the north face of Dorset mountain and the gorge cut in the quartzite by Mill brook, are but insignificant evidences of erosion when compared to those afforded by the general structural relations of the masses on either side of the fault (see section K, Pls. LXVIII and LXIX). The difference in elevation between Dorset mountain and Danby hill is about 1,650 feet, and the vertical upthrust of Dorset mountain about 1,450 feet, so that the original difference in elevation between the two summits, allowing an equal amount of sedimentation and erosion, could hardly have exceeded a few hundred feet. If the erosion of the saddle between Dorset mountain and Danby hill was consequent upon the fault, a mass from 2,200 to 3,000 feet thick must have been removed from the quartzite area in the center of the map.

The structural significance of the bold north face of Dorset mountain (see Pl. LXX) now becomes apparent. It was the result, first, of a fault

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[1] If the pitch of 10° observed in the quartzite continues in the limestone south of it, the entire limestone would be about 1,200 feet thick; if 15°, about 1,300 feet. If the limestone is horizontal, it is 700 feet thick. Estimates made on the east flank of Dorset mountain west of the beginning of section J give 700 feet from the level of Otter creek to the base of the schist (there is an anticline below the old stage road which reduces the apparent thickness), but as there may be some sharp folding, if not faulting, in the Vermont valley, this can be taken only as a minimum estimate.

crossing the folds of the intermediate range, and thus of the Green mountain system generally, nearly at right angles, and second, of erosion, perhaps initiated by the fault itself, in the direction of the fault, and then working back onto the masses north and south of it.

PINE HILL SECTION.

MR. WOLFF'S RESULTS.

These have been referred to on page 532. In crossing the hill from east to west he found the Cambrian quartzite and cement rock just west of the summit in contact, within 2 or 3 feet, with certain schists *which farther down on the west side of the hill visibly overlie the upper* part of the Stockbridge limestone.

ADDITIONAL RESULTS.

There is some difficulty in following the contact between the quartzite and the schist because the quartzite is interbedded with fine banded and close grained gneisses, identical with those of Clarendon (p. 533 and Fig. 59), which in places come in contact with the graphitic sericite-schists and are difficult to distinguish. (See section G, Pl. LXVIII.) The cleavage of the Silurian schist dips east, as does the stratification of the Cambrian gneiss. However, at several points within a few feet of the contact the schists have a westerly stratification foliation crossing the easterly cleavage. Large quartz veins occur here along the contact, and at one point Mr. Wolff found an eruptive which is also in line with the contact. These results substantiate Mr. Wolff's theory that "a great thrust plane exists on the western side of Pine hill, by which the Cambrian is made to lie on the lower Silurian limestone,"[1] which needs only to be amended by adding the words, "and schist." The relations of the schist and limestone on the west side are normal, but a little above the contact westerly stratification crosses the cleavage of the schist.[2] The Silurian schist, which intervenes between the Cambrian quartzite and gneiss and the Stockbridge limestone, has at least one syncline in it. (See Fig. 63.) Mr. Wolff's section with these additions represents the probable structure. Fig. 64 serves to illustrate the topographic relations of the Pine hill overthrust.

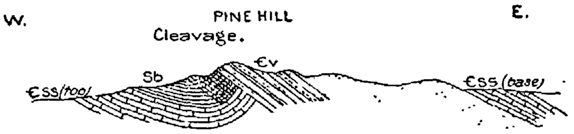

FIG. 63.—Diagram-section showing the probable structure at the Pine hill overthrust near Rutland. This presents the results of both Mr. Wolff's and the author's studies.

The relations between the Stockbridge limestone and the Berkshire

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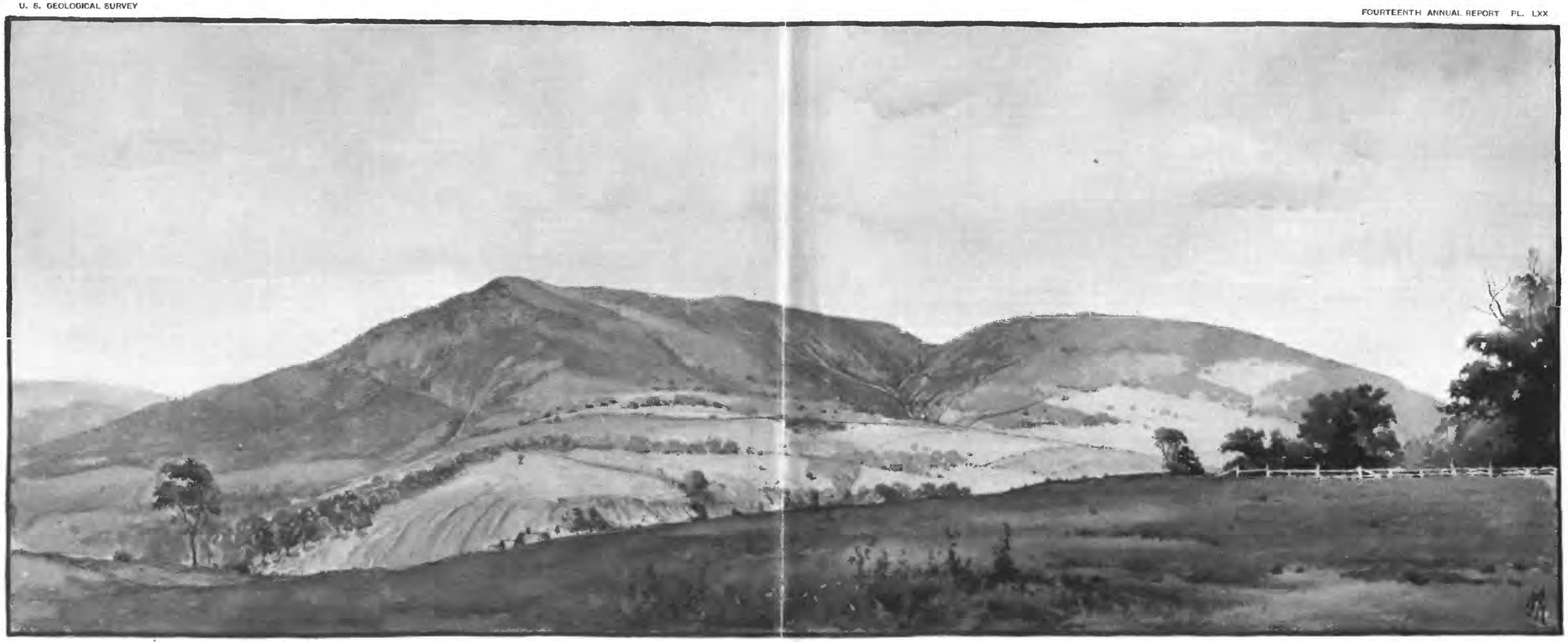
[1] Loc. cit., p. 337.

[2] This structure recurs about one-half mile southwest of center Rutland, on south side of railroad.



NORTHERN FACE OF THE DORSET MOUNTAIN MASS, FROM DANBY HILL.

schist were studied at two points—at Proctor (Sutherland Falls) on the west side of the center Rutland valley, and west of the extreme north end of Pine hill. In the most westerly marble quarry the bedding dips 85° east for a vertical distance of 100 feet aud then below turns west at an angle of 45°. The nearest schist at the foot of the ridge west has a cleavage dip of 55° to 65° east and indications of a westerly dipping stratification, but there is room for minor folds between the limestone and the schist.

At West Rutland, along the foot of the Taconic range and about three-fourths of a mile northwest of the Catholic church, there are some large, conspicuous, sericite-chlorite-schist ledges, with a cleavage foliation dipping 20° to 40° east and another dipping about 80° east, but stratification dipping 5° to 20° west, and vertical joints striking east to west.[1]

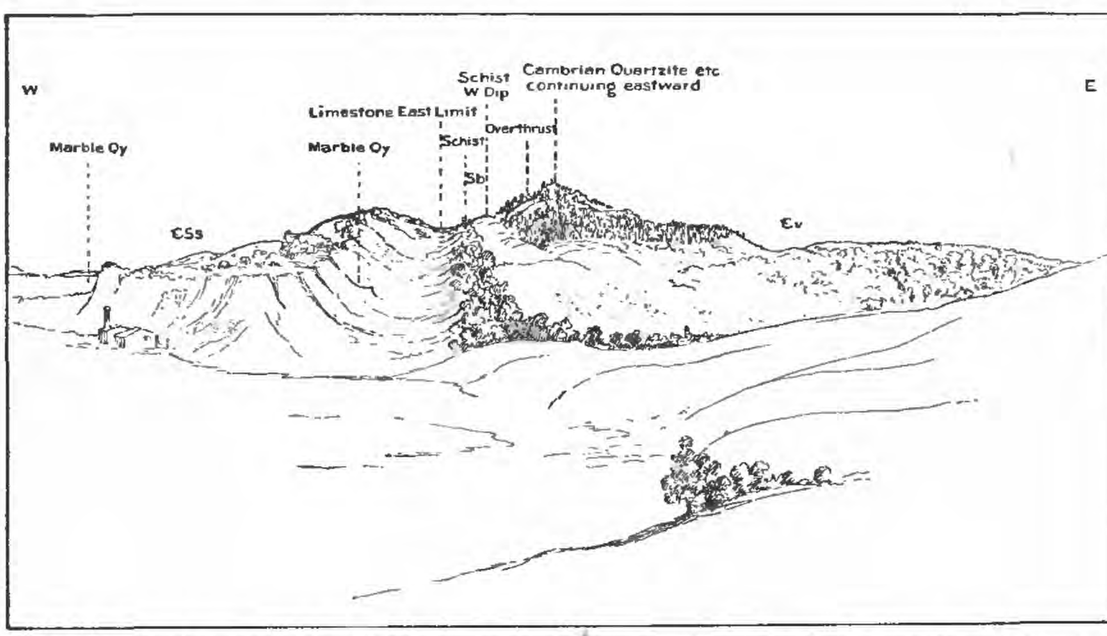


FIG. 64.—Southern side of Pine hill, near Rutland, showing the surface features at the overthrust.

A little farther north, about north-northwest of the Catholic church, the same schists crop out in the meadow east of the road, with a cleavage dip of 20° east and stratification dipping rather high west.

Both of these localities indicate, therefore, westerly dips for the limestone and schist on the west side of both the center Rutland and west Rutland valleys; but as those rocks are in minor folds it is quite possible that the contact may occur now on the east and now on the west side of a fold, or that these may be overturned in places.

ECONOMIC GEOLOGY.

The structure of the schist ledges on the west side of the West Rutland valley, as thus made out, may possibly prove to have an important bearing on the marble industry of that valley. As the real dip of the

[1] For full description of this interesting locality see Thirteenth Ann. Report U. S. Geological Survey, The Rensselaer grit plateau, p. 321, and Am. Jour. Science, 3d ser., Vol. XVIII, April, 1892, p. 317, On plicated cleavage-foliation.

schist is low west, it must form the west limb of some anticline; therefore the marble of the east side of the anticlinal valley may recur much nearer the surface on the west side than would be inferred from mistaking the schist for the west limb of a syncline.

INFERENCES.

Upon the basis of Mr. Wolff's general results,[1] thus supplemented, the Pine hill section would be interpreted as follows from east to west: The Vermont valley is a broad, shallow syncline of Cambrian quartzite, pitching southerly under the Cambrian base of the Stockbridge limestone. The eastern and greater part of Pine hill is probably a complex anticline of the Vermont formation (Cambrian quartzite, cement rock, and associated gneisses), ruptured and thrust over the lower Silurian schist (Berkshire schist) syncline, which forms the west side of the hill. The center Rutland and the west Rutland valleys are anticlines of Stockbridge limestone, but with some minor folds.[2] This limestone dips under the more or less complex synclinal ridges of Berkshire schist on both sides of these valleys. The vertical displacement by the overthrust on Pine hill would be at least as great as at Clarendon—some portion of the Cambrian quartzite being brought up the entire thickness of the Stockbridge limestone and about 250 feet of that of the Berkshire schist.

RÉSUMÉ.

GENERAL STRUCTURE OF THE INTERMEDIATE RANGE.

The foregoing sections establish the general anticlinal structure of this range: it is a complex anticline of the lower Cambrian quartzite and the associated conglomerate "cement rock," sericite-schists, and gneisses of the Vermont formation, overlain by the Cambro-Silurian Stockbridge limestone, followed by a variable thickness of the lower Silurian Berkshire schists, representing a total thickness of at least 2,000 feet and on Dorset mountain probably more than 3,200 feet. This anticline has been faulted in two ways—by a double fracture resulting in letting down a somewhat keystone-shaped block of schist and limestone several hundred feet in width into the anticline, to a depth of about 1,500 feet, and by a reverse fault, which resulted in thrusting some portion of the lower Cambrian quartzite and gneiss westward over the lower Silurian (Berkshire schist), the vertical displacement amounting in this case also to about 1,500 feet.

This fault extends from the Pittsford line south into the town of Wallingford, a distance of at least 12 miles, but not exceeding 18 miles, as it does not reach the town of Danby.

In this town, at a point about 22½ miles south of the north end of

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[1] See his section, op. cit., p. 333, and Fig. 63, herewith.

[2] A rough estimate of the maximum thickness of the Stockbridge limestone at center Rutland gives about 1,250 feet if the structure be a simple anticline.

Pine hill, the ridge is crossed by a zigzag east-to-west reverse fault, by which the Cambrian quartzite is brought up to the level of the Silurian schists, with a vertical displacement of about 1,450 feet. Thus the northern part of the Dorset mountain mass was thrust up to nearly its entire altitude above the next summit of the ridge north of the fault. That this entire range has been subjected to great strain is also manifest from the numerous dikes which traverse it in Rutland, Clarendon, Wallingford, and Danby. It corresponds to a line of both great strain and least resistance. It has also been subjected to such powerful or long erosive influences as to have greatly altered in places its form and its height.

RELATION TO THE VERMONT AND TINMOUTH VALLEYS.

The anticlinal structure of the ridge necessitates a syncline in the Vermont valley, and this is also indicated by Mr. Wolff's observations east of Pine hill and by the structure of the west face of the Green mountain range east of the north end of Dorset mountain (p. 544). For similar reasons a syncline must occur along the west side of the intermediate range in the Tinmouth valley. Indications of this are apparent in Clarendon (sections A, E, F), but farther north this syncline is probably continuous with that in the schist mass forming the west side of Pine hill, for the Center Rutland valley is evidently anticlinal.

AGE OF THE FORMATIONS.

Mr. Wolff and Mr. Foerste have shown the lower Cambrian age of the base of the Stockbridge limestone on the east side of the north end of the ridge (Pine hill section). The Clarendon section shows the lower Cambrian age of the lower 470 feet of the same limestone on the west side of the ridge (section A). Mr. Wing's discoveries showed the lower Silurian age of the upper part of the Stockbridge limestone in the West Rutland valley.[1] Mr. Foerste's discoveries in 1890 and 1891 showed the same to be true in the Center Rutland and Tinmouth valleys and in Wallingford;[2] and, finally, the lower Silurian (Hudson River) age of the overlying Berkshire schists, long ago insisted upon by the geologists of the New York Survey, has been confirmed by various recent investigations.[3]

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[1] J. D. Dana, loc. cit.

[2] Wolff, loc. cit. and Wallingford sections. p. 543.

[3] Thirteenth Annual Report of the U. S. Geological Survey, pp. 332-333. Also Monograph XXIII U. S. Geol. Survey, p. 190.

THE STRUCTURE OF MONUMENT MOUNTAIN IN GREAT BARRINGTON, MASSACHUSETTS.

BY

T. NELSON DALE.

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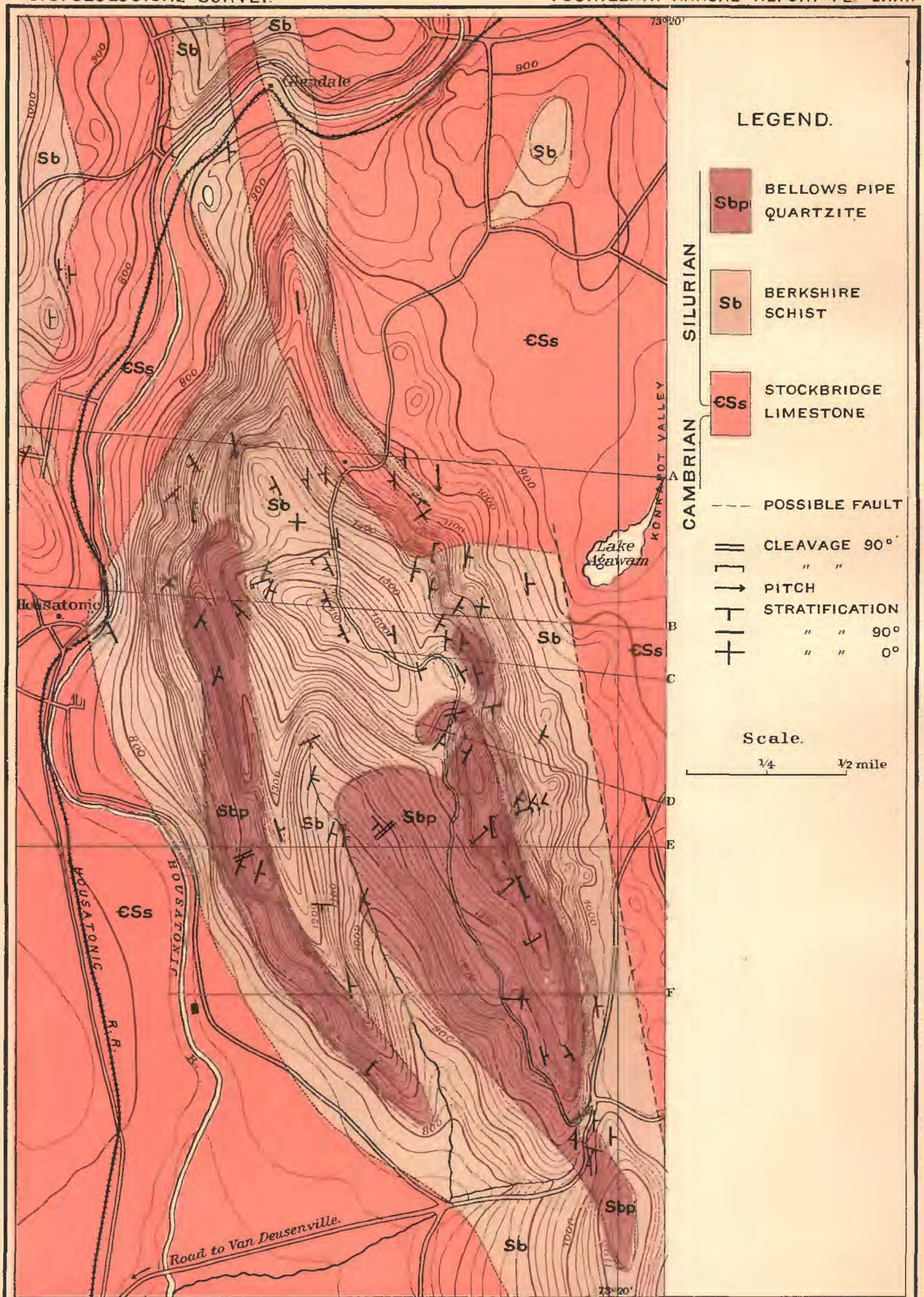
ILLUSTRATIONS.



TOPOGRAPHY BY U. S. GEOL. SURVEY. GEOLOGY BY T. NELSON DALE.

MONUMENT MOUNTAIN BERKSHIRE CO. MASSACHUSETTS

THE STRUCTURE OF MONUMENT MOUNTAIN IN GREAT BARRINGTON, MASS.

By T. Nelson Dale.

PHYSIOGRAPHY.

Monument mountain forms part of a range of hills between the Taconic range (Silurian) on the west and the Hoosac range (Cambrian and pre-Cambrian) on the east, extending from a little south of Pittsfield to the vicinity of the village of Great Barrington, a distance of about 18 miles. It lies in the line of the Greylock synclinorium, from which, however, it is cut off by the broad limestone plain about Pittsfield. Owing to the westward offset in the Hoosac range between Lee

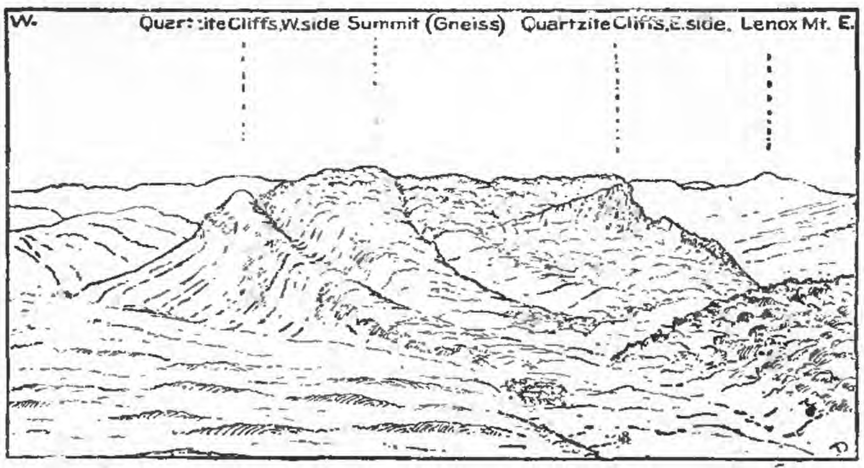


Fig. 65.—Monument mountain, south side, from Mount Keith, in Great Barrington.

and Stockbridge, Monument mountain lies but 2 miles west of the pre-Cambrian gneisses (Beartown mountain). Its area is only about 3 square miles; its higher parts range from 1,640 to 1,710 feet above the sea level and from 740 to 950 feet above the adjoining valleys; its general form is not unlike that of an old-fashioned bootjack, sending out a central spur to the north and two lateral ones to the south. These southern spurs present to the east and west precipitous cliffs of quartzite several hundred feet in height, with considerable talus below. The contour map (Pl. LXXI), in connection with the sketches from the south and the west (Figs. 65 and 66) will serve to complete the description of its general features.

Although of such inconsiderable area and altitude, and, as will be shown, of apparently simple geological structure, Monument mountain offers a structural problem of no little difficulty, as may be gathered from the various hypotheses as to its structure advanced by Prof. Dana.[1] The dip symbols on the map record the structural data obtained by the writer in in 1889.

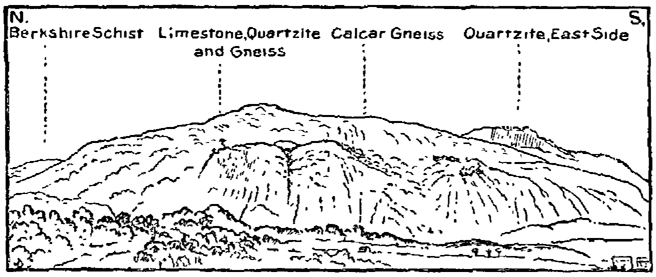


FIG. 66.—Monument mountain, west side, showing the quartzite masses on both sides of the central schist and gneiss mass. North of the top several feet of quartzite are interbedded with some limestone.

PETROGRAPHIC STRATIGRAPHY.

As the petrographic character of the various beds is sufficiently complex to increase the difficulties of structural interpretation, this part of the subject will be first dwelt upon. The petrographic examinations were made by Mr. J. E. Wolff, of this Survey. There is no difficulty in recognizing the Stockbridge limestone from its outcrops north of Housatonic; about Glendale, south of it; and in the Konkapot valley. Its relations to the overlying Berkshire schist are also clear, both from its areal continuity at the north and its structure on both sides of the south end of the small tongue of schist which extends continuously from the West Stockbridge and Lenox mountain mass onto the northeastern flank of Monument mountain.

The Berkshire schist in this tongue and in the schist mass west of it is the usual muscovite (sericite)-chlorite-schist, often graphitic, of northern Berkshire county and Vermont; but along the east and west flanks of the mountains this appears to pass horizontally into or to be overlaid by a very quartzose muscovite-biotite schist with porphyritic feldspars, and resembles the "Buttress type" of the "White gneiss" of Hoosac mountain,[2] which there belongs either below the Stockbridge limestone or represents a transition between the white gneiss and a schist mass which replaces that limestone. A similar schist or gneiss

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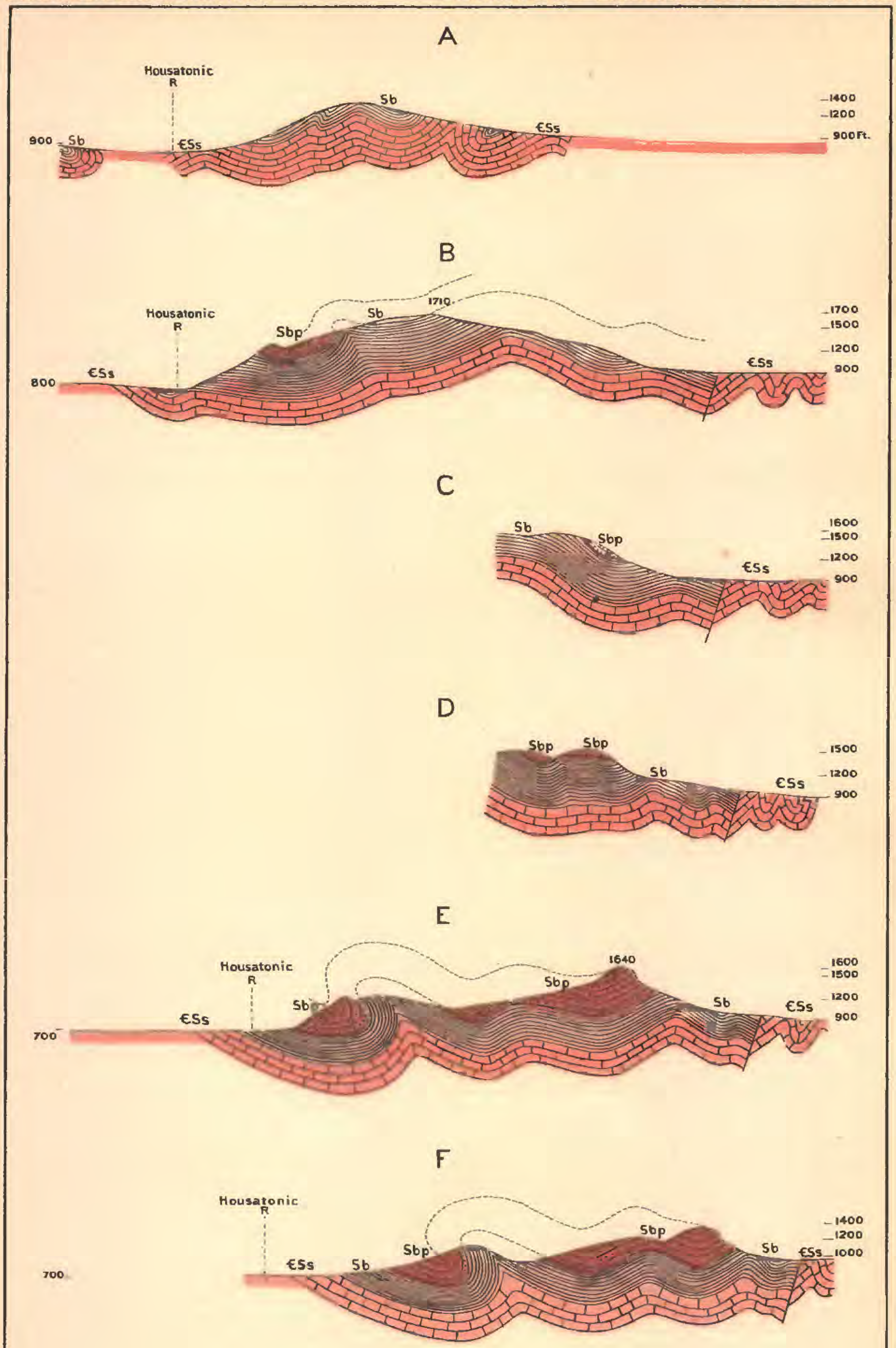
[1] On Taconic Rocks and Stratigraphy; Am Jour. Science, Vol. XXXIII, May 1887, pp. 403-408.
[2] See Monograph XXIII, U. S. Geol. Survey, Part II, by J. E. Wolff, p. 54, Pls. VIIa, VIIIa.



MONUMENT MOUNTAIN

Scale $\frac{1}{30000}$: $\frac{1}{25}$ INCH = 100 FT.

occurs also in the Bellowspipe limestone series on Mount Greylock[1] above the Berkshire schist formation, and again on Rattlesnake hill, between Curtisville and Lee, and north of Stockbridge, where it belongs above or below the Stockbridge limestone. The same muscovite-biotite-schist or gneiss constitutes the central part and the summit of the Monument mountain mass, but passes farther south into a very fine grained calcareous muscovite-biotite schist or gneiss, used for and well adapted to building purposes. A similar rock occurs in Great Barrington village, on the east side of Christian hill, and also forms the center of the ridge east of Tom Ball and Long pond. Whatever may be the exact relations of these various schists to each other on Monument mountain, the relations of the muscovite-biotite schists or gneisses to the quartzite are well shown at several contacts.

Three quartzite areas are shown on the map. The rock is a vitreous quartzite, petrographically identical with that which underlies the Stockbridge limestone, as well as that which overlies it in places, and also with that which occurs on Mount Greylock in the Bellowspipe formation, above the Berkshire schist. On the west side of the smallest quartzite area the muscovite-biotite schist dips conformably under the quartzite. In the hook-shaped part of the larger western mass the schists visibly pass under the quartzite, and here a small brook has perforated its way through the schists under the quartzite, coming out on the other side. These relations are shown in Sections C and D, Pl. LXXII. Along the western edge of the eastern mass of quartzite the schists at one point dip visibly under the quartzite, but about 10 feet of ochraceous schist, with minute layers of limonite and some coarse arborescent forms, dendritic or organic, intervene. (Section E, Pl. LXXII.) Along the western edge of the northern part of the western quartzite a small layer of graphitic schist and one or two of limestone occur near the top of the schist. Along the east side and north end of this quartzite mass a more or less thin-bedded feldspathic quartzite is interbedded with an impure limestone. This appears to occur near the top of the schists, and is also characteristic of the Bellowspipe formation.

The rocks of this mountain may be grouped as follows:

Limestone and marble, 1,000–1,400 feet		Stockbridge limestone.
Muscovite (sericite)-chlorite-schists, often graphitic, 300 ft.		Berkshire schist.
Muscovite-biotite-schist, with porphyritic feldspars	500 ft.	Representing either the Cambrian or the Stockbridge limestone (Cambro-Silurian); or the Berkshire schist (Silurian) or the Bellowspipe formation (Silurian).
A similar finer grained but calcareous rock		
An impure limestone		
Quartzite, 500 to 600 feet		Representing either the Cambrian or the upper part of the Stockbridge limestone (Silurian) or the Bellowspipe formation (Silurian).

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[1] See Monograph XXIII, U. S. Geol. Survey, Part III, by T. Nelson Dale, on Mount Greylock, p. 185.

STRUCTURE.

Dana's hypotheses.—Prof. J. D. Dana[1] offers two hypotheses:

(*a*) The mass is an extremely compressed syncline, so completely overturned to the west as to give the strata a very low inclination to the east. (See Fig. 67.) This makes the Stockbridge limestone pass under the mass, and places the schists above the limestone and the quartzite on the west side, and puts both schist and quartzite in the Silurian. It involves the recurrence of the quartzite along the eastern foot between the limestone and the schist and the absence of the schist along the western foot.

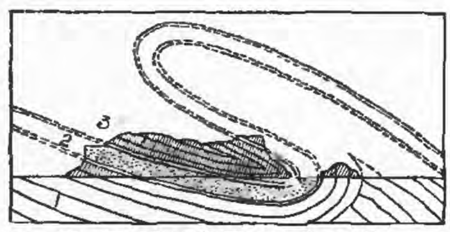

FIG. 67.—Prof. J. D. Dana's hypothesis *a*. 1. Limestone. 2. Quartzite. 3. Gneiss.

(*b*) The mass is an extremely compressed anticline turned over to the west. (See Fig. 68). This places the schists below the quartzite and both below the Stockbridge limestone, i. e., makes them Cambrian. It also involves the recurrence of the quartzite along the eastern foot between the limestone and the schist and the absence of the schist on the west side between the limestone and the quartzite.

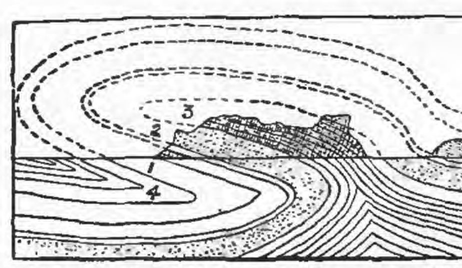

FIG. 68.—Prof. J. D. Dana'shypothesis *b*. 1. Limestone. 2. Quartzite. 3. Gneiss. 4. Schist.

The hypothesis *a* would involve the erosion of twice the thickness of the Stockbridge limestone, 2,000 to 2,800 feet, besides the thickness of the muscovite-biotite-schist, 500 feet, and of the quartzite, 500 to 600 feet, from above the cliffs on the east side. As these are 1,640 feet above sea level, this would make the original altitude of that part of the mass 4,640 to 5,540 feet, from which, however, some deduction should be made for stretching.

Hypothesis *b* would involve the erosion of the thickness of the limestone, 1,000 to 1,400 feet, and of the Berkshire schist, 300 feet, from above the cliffs, making the original altitude of that part from 2,940 to 3,340 feet, with some deduction for stretching.

While the erosion of great loops of rock 1,300 to 3,000 feet thick is quite within scientific possibilities, as shown by modern Alpine geology, it seems safer not to resort to these great loops until simpler theories are shown to be impossible. The chief objection to either of these explanations of Monument mountain lies in the fact of the occurrence of the muscovite-biotite-schist along the western side of the western quartzite and the absence of the quartzite between the limestone and

[1] Loc. cit.

the schist along the eastern foot, although there is a possibility here of its being covered by drift, and this objection has, therefore, not the same weight as the first.

Another theory would explain some of the facts: A fault can be supposed to zigzag from the east to the west, across the north part of the mountain, separating the typical Berkshire schists on the north from the muscovite-biotite-schists on the south. The latter might be regarded as continuous with the similar schists of Cambrian age on the north side of Mount Warner and Mount Keith, near Great Barrington, and the whole mass of Monument mountain conceived as thrust up so as to bring these Cambrian schists in contact with the Berkshire schist (Silurian) coming down from West Stockbridge and Lenox mountains. The quartzite would overlie the muscovite-biotite-schist and, like it, be of Cambrian age. The objection to this theory is that it involves the recurrence of the quartzite along the western as well as along the eastern foot of the mountain, or else the supposition of two longitudinal faults, one on either side, thrusting the limestone down to the level of the schists, neither of which is supported by observation.

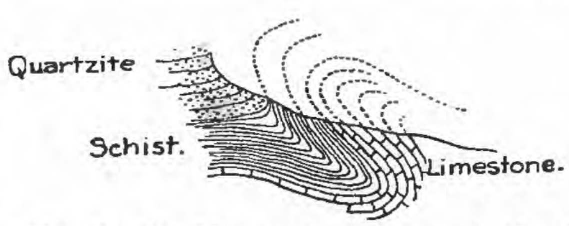

FIG. 69.—Possible structure along east side of Monument mountain.

Another hypothesis would make the central gneiss mass and the lateral quartzites Cambrian, and the graphitic schists on the north side would then represent argillaceous sediments of the age of the Stockbridge limestone. But the quartzite ought then to pitch under them, which it does not.

The structural interpretation shown in Pl. LXXII is advocated on the following grounds: There is a marked parallelism in the features of the mountain (shown on map, Pl. LXXI, and in Fig. 65), the quartzite on the east corresponding to that on the west, pointing to a parallelism of structure. The synclinal structure of the western quartzite appears near its northern end. The presence of an anticline along the east foot of the eastern cliffs is shown by the dips where the road from Muddy brook (Konkapot creek) to Van Deusenville crosses the quartzite. A syncline would naturally follow this anticline on the east, and of this there are also indications in the southern part of the eastern quartzite north of this road. (See map and Section F.) The presence of a gentle syncline and of an anticline east of it, both traversing the central schist mass, and the former traversing also the western part of the eastern quartzite, is also shown on the map. (See Sections B and E.) That two synclines with an intervening anticline enter into the structure of the mountain may be inferred from the two schist synclines which project into it from the schist mountain on the north. (See Section A and map.) The maximum amount of erosion from the surface of the mountain involved in the construction here presented does not exceed 800 feet, and this from the central portion, and abont 500 feet from the summit, making its original height about 2,300 feet. (See Sections B, E, and F.)

The difficulty of this interpretation arises along the east foot, where the schists on a level with the limestone have an easterly dip, in places a low one, with the limestone a thousand feet east of them dipping vertically (section D). The strnctnre here may be regarded either as a very sharp syncline overturned to the west (see Fig. 69), donbling up all the schists along the eastern foot (and overturned folds are very frequent in western Massachusetts), or else, as shown in the sections, Pl. LXXII, as an ordinary syncline resulting in a normal fanlt which brought the Berkshire schist down to the level of the Stockbridge limestone by depressing the eastern side of the mountain 400 to 500 feet.[1] The eastern cliffs, now 1640 feet, would have measnred about

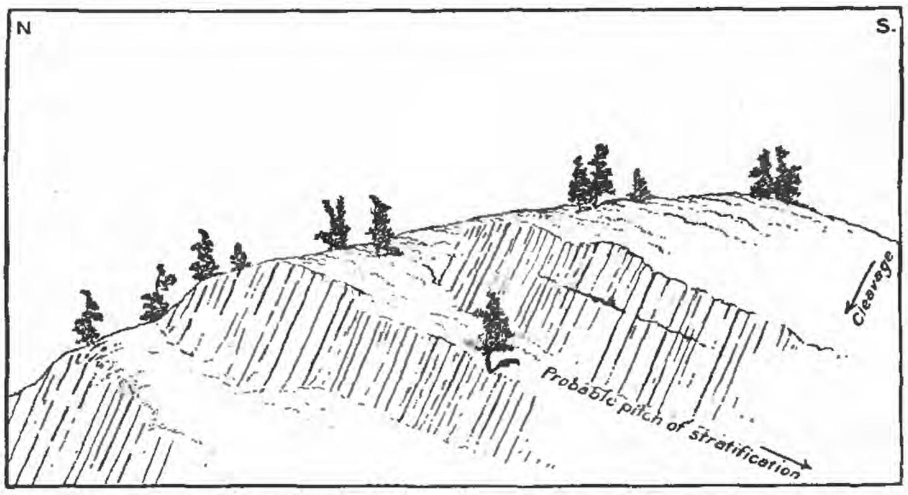

FIG. 70.—The northerly dipping cleavage on the west face of the eastern quartzite of Monument mountain as seen from the west spur.

2200 feet before the fanlting. It is quite possible, however, that the quartzite was originally thicker than 500 feet. The drift along the eastern foot prevents nearly all strnctnral observations. That the top of the Stockbridge limestone is represented in the valley east of the mountain is shown by the occurrence of several masses of the overlying Berkshire schist along its center.

In further support of this general interpretation comes the fact that on Mount Greylock the Berkshire schist, although measuring 1,000 feet, and even more, in thickness, is overlaid by a mass 600 feet thick of more or less impure limestone, quartzite, calcareous sericite-schist and mnscovite-biotite-schist, constituting the Bellowspipe formation, and that the quartzite, calcareons, and noncalcareous muscovite-biotite-schists of Monument mountain correspond to such a series. In the geological coloring of the map, Pl. LXXI, everything but the quartzite

[1] There are some indications of a fracture along the west foot of Beartown mountain, e. g., Ice Glen, in Stockbridge.

and Stockbridge limestone has been thrown into the Berkshire schist formation, owing to the difficulty of defining the boundary between the various schists and the facility of defining the quartzite area. The observed thickness of the sericite-chlorite and graphite schists on Monument mountain is about 300 feet, i. e., 700 feet less than the minimum thickness of the Berkshire schist. All the schists and the quartzite on Monument mountain measure from 1,300 to 1,400 feet. On Greylock the Berkshire schist and Bellowspipe series measure at least 1,600 feet.

Petrographically, such a construction does not offer serious difficulties. As biotite passes by decomposition into chlorite, the difference between a muscovite-biotite-schist and a muscovite-chlorite-schist is not a radical one. Biotite is also a characteristic mineral of the Berkshire schist of a large area in Dutchess county, New York. But the difference between the two schists on Monument mountain is

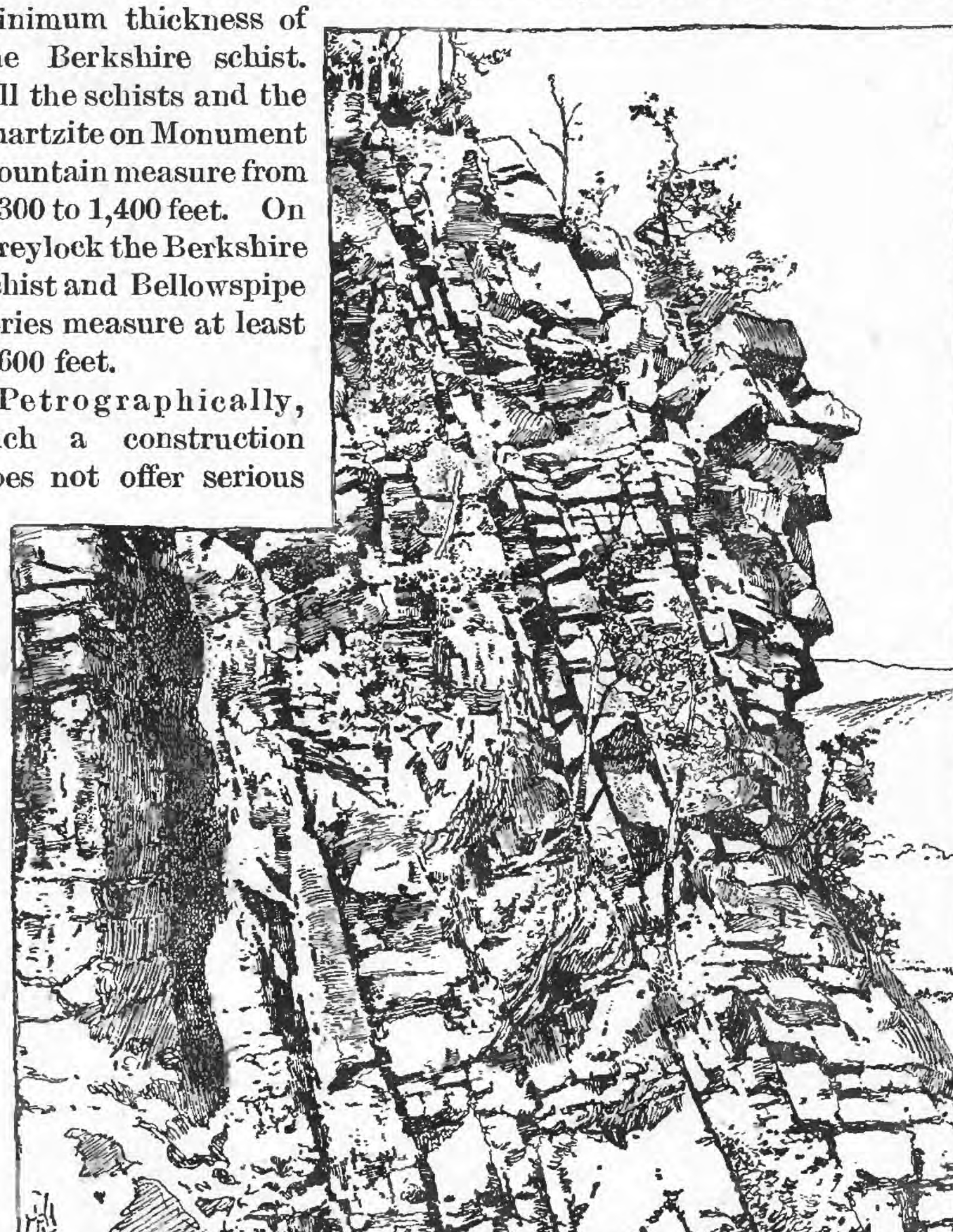

FIG. 71.—Quartzite cliffs, east side of Monument mountain, south face of jog, showing a cleavage dipping north and another dipping east at high angle.

more probably due to a difference of sedimentation, the muscovite-(sericite)-chlorite-schists originating in more argillaceous sediments and the muscovite-biotite and far more quartzose schists, with porphyritic feldspars, in more siliceous sediments. It is also probable that these schists have been subjected to different amounts of pressure and strain, resulting in different metamorphic processes. The fact that the muscovite-biotite-schists are in places calcareous is also true of the Berkshire schists in western Massachusetts and Vermont, and the interbedding of quartzite and impure limestone is quite characteristic of the Bellowspipe formation.

Cleavage and pitch.—Among the marked features of the quartzite of Monument mountain are its various systems of cleavage or jointing. The more general of these coarse foliations are shown on the

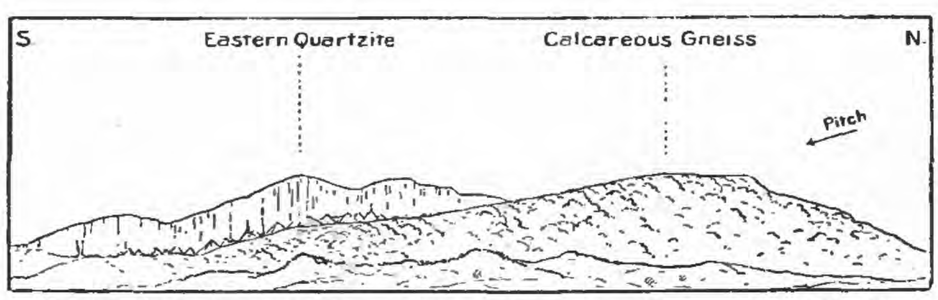

FIG. 72.—The outlines of Monument mountain from the east side of Konkapot valley, showing some of the relations of the gneiss or schist to the quartzite.

map by cleavage symbols. The most conspicuous is that which strikes east-northeast to west-southwest across both the east and west cliffs, and dips either vertically or northerly at a high angle. (See Fig. 70.) Another strikes about north-northwest and dips east at a high angle. (See Fig. 71.) The pressure which in the more pliable schists found relief in minor folds and minute cleavage, produced these sets of fractures in the more coherent and brittle quartzite. In the schist area there is occasionally a southerly dipping cleavage. Sections A and B, taken together, show a marked southerly pitch, the limestone descending with the increasing thickness of the overlying schists, and it is quite possible that the north and south dipping cleavage are related to this southerly pitch and a north to south pressure, while the easterly cleavage is associated with the strike of the folds and an east to west pressure. The southerly pitch of the schists under the quartzite shows itself in the surface features of the east side (see Fig. 72), and the low southerly dipping planes seen in the west face of the eastern quartzite (Fig. 71) are probably due to the pitch of the quartzite.

The southward termination of several schist masses west of Van Deusenville points to a northerly pitch along that latitude, which may extend far enough east to affect the south end of the Monument mountain mass. The termination of the quartzite outcrops on the south, with their decreasing altitude, would add somewhat to this probability.

STRUCTURAL RÉSUMÉ.

The views advanced in this paper may now be summarized:

Monument mountain is a small synclinorium about 30 miles south-southeast of the center of the Greylock synclinorium and similarly situated with reference to the older gneiss mass on the east. It consists of a series of Silurian beds, quartzite 500 to 600 feet, and various metamorphic schists, 800 feet, resting upon the Cambro-Silurian Stockbridge limestone of the Berkshire and Vermont valleys, and finding their stratigraphic parallels in the series of the Greylock synclinorium. These beds constitute a marked syncline on the west side and another on the east side, corresponding to the quartzite bluffs on either side, with intervening minor folds. The difficult relations between the schist and the limestone along the eastern foot of the mass may be explained either by supposing a fault, by which the eastern side of the mass was depressed about 500 feet, or by supposing a sharp compressed syncline overturned to the west. There is a southerly pitch at the north end of the mass, corresponding to the increasing thickness of the beds, and probably a northerly pitch at its south end.

HISTORICAL GEOLOGY AND RELATIONS OF STRUCTURE TO TOPOGRAPHY.

Monument mountain affords a good illustration of the frequent change of sediment, both vertical and horizontal, which characterizes the geology of a large part of western Massachusetts; arenaceous, calcareous, and argillaceous deposits recurred at relatively short intervals of time and space. The great amount of quartz sand implied in beds of quartzite 500 feet in thickness and the close proximity on the east of a mass of pre-Cambrian gneiss, which may have been above water in Silurian time, fall well together.

The bold quartzite cliffs, which attracted the attention of even the Indian aborigines as well as one American poet, may owe their existence partly to their occurring along the axis of a ruptured fold, but more probably to the steep angle of the cleavage (see Fig. 71), which runs along the strike. The divisional planes which traverse them in numerous directions, and the tendency of the quartzite to conchoidal fracture point to these quartzite masses and to the eroded folds which once connected them as the source of many of the numerous quartzite bowlders scattered over the country to the south; and these planes continue to facilitate further degradation by frost.

THE POTOMAC AND ROARING CREEK COAL FIELDS IN WEST VIRGINIA

BY

JOSEPH D WEEKS.

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ILLUSTRATIONS.

THE POTOMAC AND ROARING CREEK COAL FIELDS IN WEST VIRGINIA.

By JOSEPH D. WEEKS.

THE APPALACHIAN COAL FIELD.

The Appalachian coal field, while not the largest in superficial area, is the richest and most important in the United States, and the largest continuous field of any Carboniferous area. Beginning in a few isolated patches at Blossburg, near the northern boundary of Pennsylvania, it extends in a southwesterly direction to Tuscaloosa, Alabama, a distance of nearly 900 miles. Regarding the character and richness of the coals of this great basin, it is only necessary to state that it includes the anthracite beds of Pennsylvania, the steam coals of the Cumberland, Elk Garden, and Pocahontas regions, the gas coals of the Pittsburg and Monongahela river districts, and the coking coals of Connellsville, the Upper Potomac, New river, Flat Top, Sewanee, and Birmingham. Among its noted coal beds, named in descending order, are the Pittsburg of the Upper Coal Measures, the Freeports and Kittannings of the Lower, and the New River group, with its New River and Flat Top beds in the Great Conglomerate or Seral. The commercial importance of its coals may be judged from the fact that of the 148,229,513 short tons of coal mined in the United States in 1889, the census year, 108,517,192 tons, or 73 per cent, were from the Appalachian field, 62,972,222 tons being bituminous and 45,554,970 tons anthracite.

The eastern escarpment of the Alleghany mountains forms the eastern border of this great basin, while the Cincinnati anticline hems it in on the west. The eastern line of the field is quite regular, following the trend of the mountains with a course nearly parallel to the coast line of the Atlantic. Between the eastern edge of the field, as it is now bounded, and the ocean, several detached fields are found, which have been left by the denuding agencies that have cut so deeply, so sharply, and at the same time so destructively into the coal measures of this belt of country. It is a notable fact that some of the most extensively mined coals, as well as some of the best produced, are from these detached basins, chief among which are the anthracites of Pennsylvania and the Cumberland coals of Maryland, the former the type of anthracite coals, the latter of semibituminous steam coals.

It is with the coals of what has been termed the Cumberland region and its extensions and adjacent fields, and chiefly those reached by the West Virginia Central and Pittsburg railway, that we have to deal in this report. We shall consider them especially in their relation to the production of coke, though to do this intelligently and properly it will be necessary to pay some attention to the coal field generally and its coal production.

THE POTOMAC BASIN.

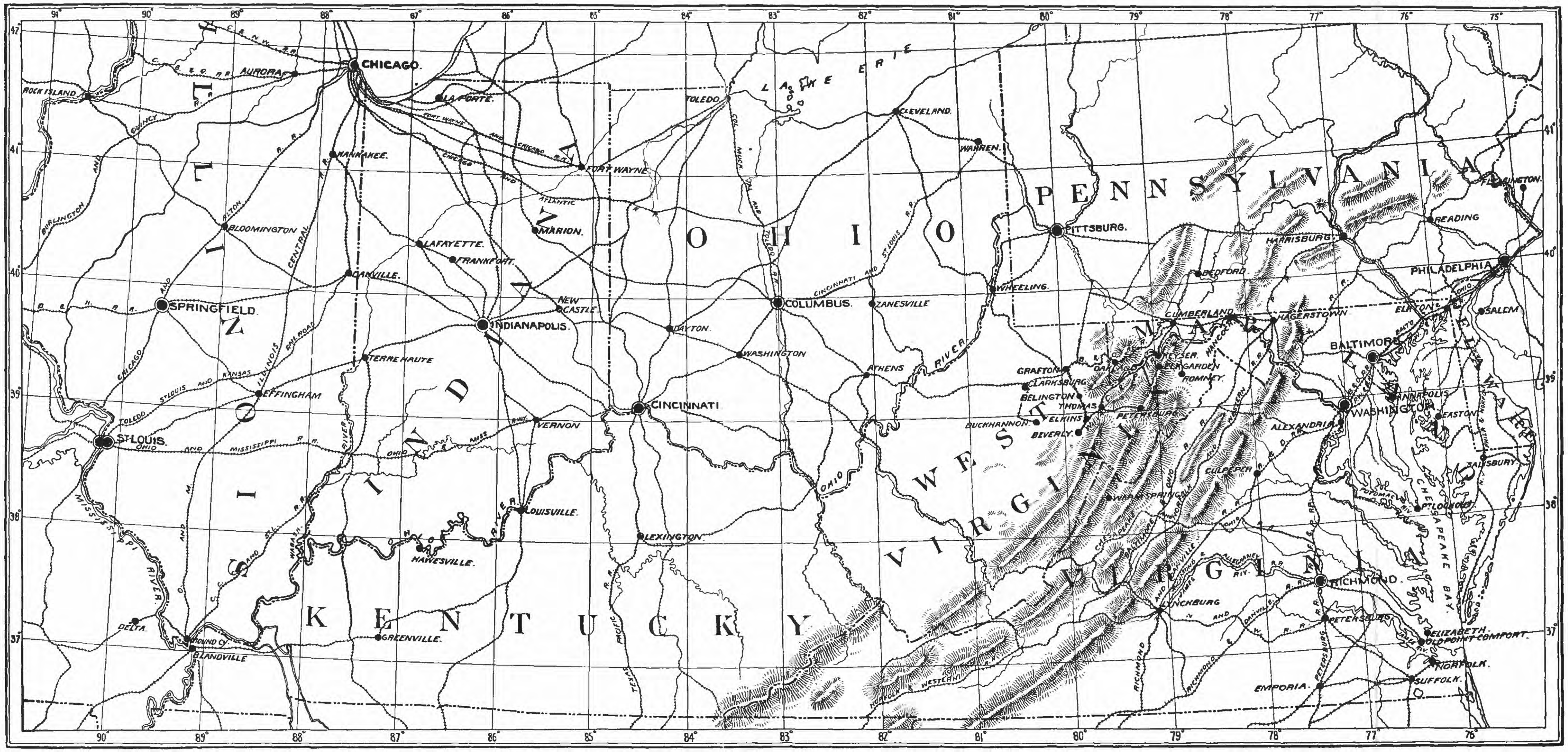
THE NAME.

No name at all descriptive of the great detached coal field we are discussing has yet been adopted. Sometimes the name "Cumberland" is applied to the entire basin, but as the term "Cumberland coal" belongs properly to the coal mined from the Pittsburg seam, and as the Upper Freeport and Lower Kittanning coals are important producers in this basin and will be more so in the near future, this name would seem to be misleading if not a misnomer. In view of the fact that this basin traverses the great watershed of the Potomac, it is suggested that the name "Potomac basin" would be a fairly descriptive title for the field as a whole. The well known and recognized names of the several fields in the basin could be retained and used without confusion.

AREA OF THE BASIN.

This Potomac basin is much the largest of the detached coal fields to which we have referred. It is a narrow basin from 2½ to 16 miles wide, lying on the extreme eastern boundary of the Alleghany plateau, in close proximity to the main coal field, and extending from the extreme southeast corner of Somerset county, Pennsylvania, through Maryland, to near the southern boundary of Randolph county, West Virginia—a distance of some 90 miles. It is not to be understood, however, that the coal fields are continuous through all of this region. At least four, if not five, districts or subbasins, separated from each other by watersheds of greater or less importance, are recognized in this distance.

The region in which this basin is found consists of a series of parallel mountain ranges with deep valleys traversed by rapid running streams, carrying, at certain seasons of the year, large bodies of water which swell the Potomac on the east and the Cheat and Youghiogheny on the west. Many of the ranges exceed 2,000 feet in height, while some reach 3,000 feet and more. The compressive force which raised these mountains acted from the east toward the west, hence the most intense disturbance is always observable on the eastern side of the range, gradually dying away into the central plains. While the result of these forces and subsequent denudation and erosion has been to



GENERAL MAP SHOWING RELATIONS OF ELK GARDEN AND UPPER POTOMAC COAL BASINS TO THE SEABOARD AND THE WEST.

wear away over vast areas certain coal beds (chiefly the Upper Productive Measures in the basin of which we are speaking), it has resulted in at least two compensatory effects:

First, the debituminization of the coal to the east, as pointed out by Rogers, making it less desirable as gas coal but especially valuable as steam and smithing coal.

Second, the exposure of the coal left in these beds (which is still a vast quantity) above the water level, thereby increasing the facility, and greatly reducing the expense, of mining.

SIZE AND DIVISIONS OF THE POTOMAC BASIN.

The general course of this basin, as is seen on the accompanying map (Pl. LXXIII), is northeast and southwest, following the general trend of the Alleghany mountains proper, and hemmed in between the Alleghany Front mountain on the east and the Backbone mountains on the west. The basin cuts the southeast corner of Somerset county, Pennsylvania, and passes through Garrett and Alleghany counties, Maryland, and Mineral, Grant, Tucker, and Randolph counties, West Virginia. In its general shape this field resembles a longitudinal section of a short-handled, long-bowled, pointed spoon—the point of the spoon being at the Pennsylvania end; the bowl at Davis, in the northern part of Tucker county; the extension from just south of Davis, through the lower part of Tucker and through Randolph county, being the handle. From the northernmost point in Pennsylvania this basin gradually widens until it reaches its greatest breadth at Davis, in Tucker county, West Virginia, where it is about 16 miles wide. From this point it suddenly contracts, and does not exceed 3 miles in width south of Bayard. The eastern line of the basin is quite regular and straight, the widening coming from extensions of the basin to the west.

At least four coal-producing districts (five, if the Georges Creek and Cumberland are separated), all well known producers, are included in this field, namely:

(1) The Wellersburg, in Pennsylvania;
(2) The Cumberland or Georges Creek, in Maryland;
(3) The Elk Garden; and,
(4) The Upper Potomac, in West Virginia.

A glance at any good map of this region, especially one locating the mountain ranges, will show that the Potomac, after following from its source the general direction of the mountains—that is, a northeasterly course—turns abruptly to the east at Empire, just west of Piedmont, and, cutting across the coal field as well as the mountains, turns at Keyser to the northeast again, just east of Dans mountain and along its base, wholly outside of the coal basin. The Potomac thus separates this coal field into two distinct divisions, a northern, which includes the Wellersburg, Cumberland, and Georges Creek fields, and a southern, in which are the Elk Garden and Upper Potomac basins. The northern division lies in Pennsylvania and Maryland; the southern in West Virginia and Maryland, chiefly in West Virginia. For the purposes of this report the northern division will require but little attention. It is with the southern we have to deal.

THE COALS OF THE POTOMAC BASIN.

The great coal markets of the United States which draw their supply from a distance lie along the Atlantic seaboard from Maine to Maryland. Into these great markets all the coal fields of the Appalachian basin, from northern Pennsylvania to and including the Flat Top district of Virginia and West Virginia, pour their supplies.

Most of the coal mined for these markets comes from four coal beds: the Pittsburg of the Upper Productive Measures, the Upper Freeport and Lower Kittanning of the Lower Measures, and the New River and Flat Top beds of the Pottsville conglomerate or seral.

The Pittsburg bed, which Prof. I. C. White[1] characterizes as the "most important mineral deposit of the Appalachian field," is the source of much of the fuel for the mills and glasshouses of Pittsburg; it furnishes the gas coals of the Monongahela river and Westmoreland, the coking coals of Connellsville and the Upper Monongahela, some of the anthracite, and is the "Big Vein" of the Cumberland region.

The Upper Freeport and Lower Kittanning belong to the Lower Measures. These beds supply most of the coal mined in Pennsylvania north of the Pennsylvania railroad, the Blossburg, Clearfield, Bradys bend, and Punxatawney coals; they are the 6-foot and 11-foot veins of the Cumberland-Georges Creek region, and the Kanawha splint (Upper Freeport) and gas coals (Lower Kittanning). These beds are much wider spread and are accessible over a larger area than those of the Upper Measures. Prof. White[1] suggests that, "when in the distant future the upper coals and the more easily accessible areas of the lower ones shall have been exhausted there will still remain far down in the trough of the Appalachian fields a great wealth of fuel which can be obtained by deep shafting."

The New River group of coals is not widely distributed as workable beds, but where found they are exceedingly valuable. These beds in Pennsylvania are quite thin, the best example being the Sharon coal of Mercer county, a block coal of great purity. In the New River and Pocahontas Flat Top districts beds 14 feet thick are found at places. It is an unsurpassed steam and coking coal, low in sulphur and ash.

All four of these coals are found in the Potomac basin, and at no point in the entire Appalachian field are the first three exceeded in size, in ease and cheapness of mining, and in purity. The Pittsburg bed is the Big Vein of this region, reaching at times a thickness of 16 feet,

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[1] Bull. U. S. Geol. Survey No. 65, p. 63.

averaging 12 to 14 feet, and carrying 67 to 72 per cent carbon, 19⅓ to 26½ per cent volatile matter, and but 5 to 6¾ per cent ash. The Upper Freeport (Thomas) measures 8 feet and gives 4 to 6 feet of workable coal, while the Lower Kittanning (Davis) bed measures 11 feet and works 6½ feet, and is remarkably low in sulphur.

The New River group has been found in this district, but it is at present of little commercial importance. It is worked in Garrett county, Maryland, where the coal is 3 feet thick, being soft and pure and exhibiting its well-known coking properties, and in the Blackwater section of Tucker county, where the Nuttall coal is 2 feet 6 inches thick.

The Big Vein or Pittsburg seam, though it has the widest reputation, is by no means the most important or valuable coal of this basin. We do not wish to detract from the well established and widely known reputation of this coal, but simply desire to indicate that in this district it is not so important or valuable as other coals. The Big Vein goes into the air just north of Stoney river and shows in but one place to the south of the Elk Garden district. On the top of Fairfax knob, at a height of some 3,200 feet above the sea, some few acres are still left, but the slate partings have thickened greatly, and the bed, instead of being one thick bed with comparatively insignificant partings, is practically three benches.

As has been suggested, the Upper Freeport (Thomas) and the Lower Kittanning (Davis) are the important coals of this district. One or the other, sometimes both, are found throughout the entire length of both the Elk Garden and Upper Potomac districts, except here and there in a locality where they have been cut out. While, therefore, the beds are not as thick as the Big Vein, yet by reason of the great area underlain with these coals the amount remaining in the hills is vastly greater—90,000,000 tons, it is estimated, in the Elk Garden district and 2,000,000,000 tons or more in the Upper Potomac. The range of use of these coals is wide. The Freeport (Thomas) lump is shipped as a domestic fuel, the "run of mine" as steam coal, and the slack is coked, though the coke does not equal in physical structure or purity that from the other bed. The Upper Kittanning coal (Davis), which in this basin is remarkably free from sulphur, is, in the form of "run of mine," shipped as steam coal; the coarse slack has a large market in the West as a smithing coal, while the fine slack makes a strong, bright, porous coke.

THE WEST VIRGINIA CENTRAL AND PITTSBURG RAILWAY.

The West Virginia Central and Pittsburg railway, to whose construction the opening and development of the Elk Garden, Upper Potomac, and Roaring Creek fields is due, and which is their only outlet, extends at present from Cumberland, Maryland, to Belington, in Barbour county, West Virginia, a distance of 131 miles, with branches from Harrison to Elk Garden, from Thomas to Davis, and from Elkins to Beverly. For 74 miles, from Cumberland to Fairfax, at the headwaters of the North Branch of the Potomac, it follows the course of this river, for most of the way in West Virginia, but at times in Maryland. From Fairfax, where it crosses the divide between the Potomac and the Cheat, the latter a tributary to the Monongahela, it skirts the base of the Great Backbone mountain to Parsons, at its southern extremity, and passing around the mountain and entering the valley between the Cheat mountain and Laurel hill, it reaches Elkins on the Tygarts Valley river, where it makes an abrupt turn to the northwest and follows the Tygarts valley to Belington, in the new Roaring Creek coal field.

At Cumberland the West Virginia Central and Pittsburg railway makes connection with the Baltimore and Ohio and Pennsylvania railroad systems and the Chesapeake and Ohio canal, and through these has outlets to tide water and to the great coal-consuming cities of the Atlantic seaboard. Indeed, one of the great advantages of the Cumberland region, and the statement will apply with equal force to the entire Potomac district, is its nearness to tide water. One of the notable physical features of the Atlantic coast line of the United States is the way it is broken by the tidal estuaries and bays which separate Maryland and Virginia and thrust themselves so far inland, bringing tidal water and the head of navigation very far toward the mountains. Not only this, but the existence of these immense bodies of water on the line between the North and South has determined the route of the leading highways of trade between these sections, deflecting them from the ocean border.

As a result of these physical features, the Potomac coal field lies nearest to tide water of any of the important fields that supply the great coal markets of the Atlantic coast. The distance from the Elk Garden region to tide water at Baltimore is 218 miles, while the competing field nearest to tide water is the Clearfield, which is 253 miles from Philadelphia, its nearest tide-water port. By reason of the fact that the Chesapeake has deflected the lines of railroad inland, this region can reach the great Eastern coal markets by rail over remarkably short lines, 312 miles to Philadelphia on the Baltimore and Ohio and 392 miles to New York via the Pennsylvania railroad. When the extension, which has already been begun, is completed to Hagerstown, these distances will be materially shortened.

THE WELLERSBURG BASIN.

The portion of the Potomac field in Pennsylvania belongs to the northern half and is known as the Wellersburg basin, and is some 10 miles long by 3 miles wide at the state line, growing narrower as it goes northward. Coal beds are worked in the Lower Productive Coal Measures, the Barren Measures, and the Upper Productive, but the amount of coal in the Upper Productive, that is, in the Pittsburg seam, is quite small. Its thickness here is said to be not more than from 5 to 9 feet. Most of the coal mined is from the Middle Kittanning. The annual production of this field is from 400,000 to 500,000 short tons.

THE CUMBERLAND AND GEORGES CREEK FIELD.

The Cumberland and Georges Creek field, which may be regarded as one, extends from the Pennsylvania State line through Allegany county, Maryland, into Mineral county, West Virginia. The field is hemmed in by the Great Savage mountain on the west and Dan and Piney mountains on the east, and is some 20 miles long with an average breadth of 4½ miles. The northern part of this field, which is the Cumberland field proper, is drained by Jennings creek, flowing northwest into Wills creek, which joins the Potomac at Cumberland; while the southern slope, which is the Georges Creek field, is drained from Georges Creek, which, after flowing southwest, empties into the Potomac at Piedmont, 28 miles from Cumberland. The important bed of coal in this region, and the one which has given to the coal of the Cumberland field its great reputation, is the Pittsburg, which is here seen at its greatest thickness. Unfortunately, this bed of coal has been swept away from a large part of the territory and appears only on the mountain sides, in detached patches. While the Pittsburg bed, as it is found in the Cumberland region, varies in thickness, its popular name, "14-foot bed," gives a fair idea of its thickness. The production of coal in the field is some 3,000,000 tons a year.

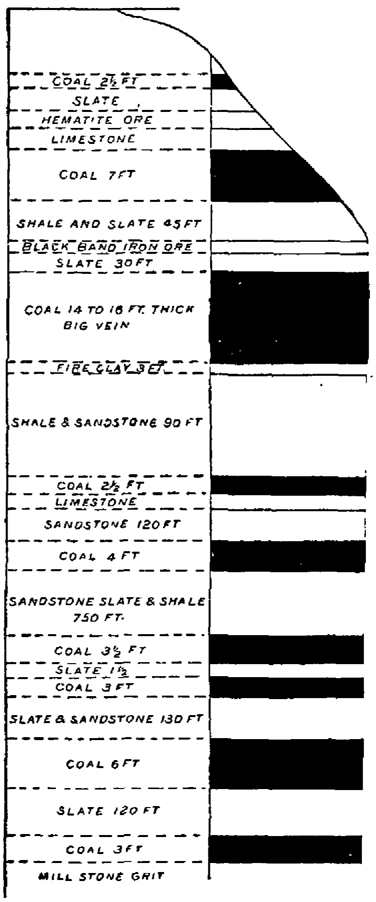

FIG. 73.—Section of Upper and Lower Productive Coal Measures in Upper Potomac basin.

THE ELK GARDEN FIELD.

The Elk Garden district of the Potomac basin extends from near Piedmont, West Virginia, to Stoney river, just south of Schell, West Virginia, a distance of some 20 miles. The field, as will be seen from the accompanying map, has the shape of a truncated wedge, the narrower part at the northern end gradually widening to the south as the mountains draw away from each other. The coal measures, which are both the Upper and Lower Productive, lie on both sides of the Potomac, though what is left of the Upper Productive, the Pittsburg seam, is nearly if not quite all on the right or eastern bank. The coal on the western bank, or Maryland side of the river, is chiefly the lower coal, which is also found abundantly on the West Virginia side. A section of this field is given herewith (Fig. 73).

The Pittsburg vein, which here, as elsewhere in this region, has suffered great loss by the denuding and erosive agencies already referred to, has been mined to a considerable extent and yields a coal that has all the well-known and valuable characteristics of the product of the bed in this section, being a most excellent steam and smithing fuel. The vein varies in thickness, running up in some places to 16 feet and down to 13 feet in others, averaging about 14 feet. It is estimated that there were 15,000,000 tons of this coal in this field when mining began.

While the chief production of coal in this district is from the Big Vein, some of the smaller veins of the Lower Measures are worked—the Freeport (4-foot vein) and Kittanning (6-foot vein). At one place the 7-foot vein above the Pittsburg is mined.

From the section given above, which must not be regarded as typical of the entire district, but only of certain spots where the eroding agencies have not been so active as elsewhere, it will be seen that there are six coal veins below the Big Vein and two above. Of these, four, the 7-foot, 6-foot, 4-foot, and 3½-foot yield a good coal. A section of the Lower Productive Measures in this district, taken from the report of Prof. I. C. White,[1] is as follows:

Section of Lower Productive Coal Measures near Maple Swamp water-tank (between Schell and Harrison), West Virginia Central railroad, Mineral county, West Virginia.

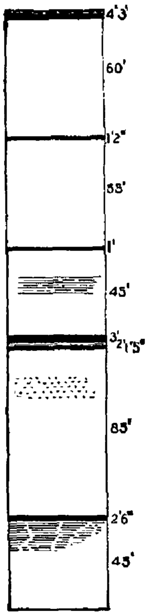

FIG. 74.—Section on north Potomac at Maple Swamp water tank, West Virginia Central railroad.

		Ft.	*in.*
1. Coal, Upper Freeport	Coal 0′ 5″ Bone and slate 1′ 4″ Coal 2′ 6″	4	3
2. Concealed		60	
3. Coal, Lower Freeport		1	2
4. Concealed		55	
5. Coal, Upper Kittanning		1	
6. Concealed, and slate		45	
7. Coal, Lower Kittanning	Coal 3′ 0″ Slate 2′ 0″ Coal 1′ 5″	6	5
8. Concealed, and sandstone		85	
9. Coal, Clarion		2	6
10. Shales, and concealed		45	
11. Massive sandstone, top of No. XII.			
Total		305	4

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[1] Bull. U. S. Geol. Survey No. 65, p. 127.

In these smaller veins, which cover a much larger area than the Big Vein, it is estimated that in the Elk Garden district there are still remaining and available some 90,000,000 tons, making, with the Big Vein, an aggregate in this district of 105,000,000 tons, all above water level.

An analysis of the coal from the Big Vein of this district, made by the U. S. Geological Survey in 1888, is as follows:

Analysis of Elk Garden coal from Pittsburg vein.

Moisture	0·76
Volatile carbon	19·39
Fixed carbon	72·99
Ash	6·86
	100·00
Sulphur	0·880

Mining began in this district in 1881, the first shipment of coal having been made October 20 of that year. The total amount mined and sent to market up to January 1, 1893, has been 4,822,706 tons.

The total shipments of coal from all the mines in the Elk Garden region, on the line of the West Virginia Central and Pittsburg railway, from October 20, 1881, when the first shipment was made, to January 1, 1893, were as follows:

Year.	West Virginia Central.	Big Vein.	Davis & Elkins.	Atlantic.	Virginia.	Hampshire.	Switchback.	Merrills.	Total.
	Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*
1881	11, 372								11, 372
1882	228, 294	28, 774							257, 068
1883	261, 075	68, 942							330, 017
1884	375, 590	83, 170							458, 760
1885	268, 780	65, 792		57, 213					391, 785
1886	211, 852	50, 686		63, 715					326, 253
1887	259, 354	59, 801		107, 605					426, 760
1888	356, 259	30, 407		97, 285					483, 951
1889	353, 216		18, 671	62, 934	1, 737				436 558
1890	414, 547		73, 384	63, 121	5, 926				556, 978
1891	420, 503	538	88, 576	92, 192	193	502	5, 718	1. 872	610, 094
1892	358, 915	3, 876	71, 033	42, 365		17, 326	39, 421	174	533, 110
Total	3, 519, 757	391, 986	251, 664	586, 430	7, 856	17, 828	45, 139	2. 046	4, 822, 706

WAGES PAID IN ELK GARDEN DISTRICT.

Two seams are worked in this district: the Pittsburg, 14 feet, and the Upper Freeport, 4 feet. The wages paid in November, 1893, were as follows:

Mining Big Vein, run of mine....................per ton of 2,240 pounds.. $0.50
(No powder used; smithing, 1 cent a ton; men timber, props being delivered at breast.)
Mining 4-foot vein, lump coal......................per ton of 2,240 pounds.. .75
run of mine..................................do.. .45 to .60
(Powder used; smithing, 1 cent a ton; men timber. About one-half slack when lump is produced. Pay by actual weight.)

Drivers	per day	1.50
Road men, inside	do	2.00
Road men, outside	do	1.50
Inside labor	do	1.50
Tipplemen	do	1.50
Blacksmith	do	2.00
Carpenter	do	2.00
Pit boss	per month	$65.00 to 75.00
Stablemen	do	40.00

At mines visited there is no company store. House rent for a four-room house, $3 a month; five rooms, $4 per month.

THE UPPER POTOMAC FIELD.

The Upper Potomac field of the Potomac basin is at present regarded as extending from Stoney river in Mineral county, where the Elk Garden district ends, through Grant and Tucker counties, to the end of the basin in Randolph county. The headwaters of the Potomac, however, are near Fairfax Summit, where the watershed is crossed. Just beyond this the headwaters of the Cheat are reached. The important coal workings in this region are just beyond Fairfax, at Thomas, Davis, and Douglas, which are on the watershed and on the Cheat river.

In shape this field, up to the southern part of Tucker county, is a continuation of the wedge that begins in Pennsylvania, extending through the Cumberland, Georges Creek, and Elk Garden fields, and reaching its greatest width near the county line in Tucker county, where it abuts on a series of parallel mountain ranges, including Rich, Middle, Shavers, and Cheat mountains. The field here is some 16 miles wide.

The chief coal producers in this district are the beds of the Lower Measures, the Upper Freeport (Thomas), and Lower Kittanning (Davis). At the head of the Potomac a small area of the Pittsburg bed is caught in the summit of Fairfax Knob, 3,250 feet above tide and 20 miles distant from any other outcrop of this coal. The “vein” is here split up into three portions, separated by several feet of shales from the thickening up of the parting shales, as will be seen from the following section at this point, taken from Prof. I. C. White's report[1]:

			Ft.	in.	Ft.
Roof	Shales				8
	Coal		2	0	
	Shale		6	0	
Coal, “breast”	Coal	8′ 2″	9	6	55
	Slate	0′ 2″			
	Coal	1′ 2″			
Shales		5′ 0″	16	0	
Limestone		4′ 0″			
Shales		7′ 0″			
Coal, “brick”			4	6	
Fire clay and shales			18	0	
Coal, “bottom,” slaty			7	0	

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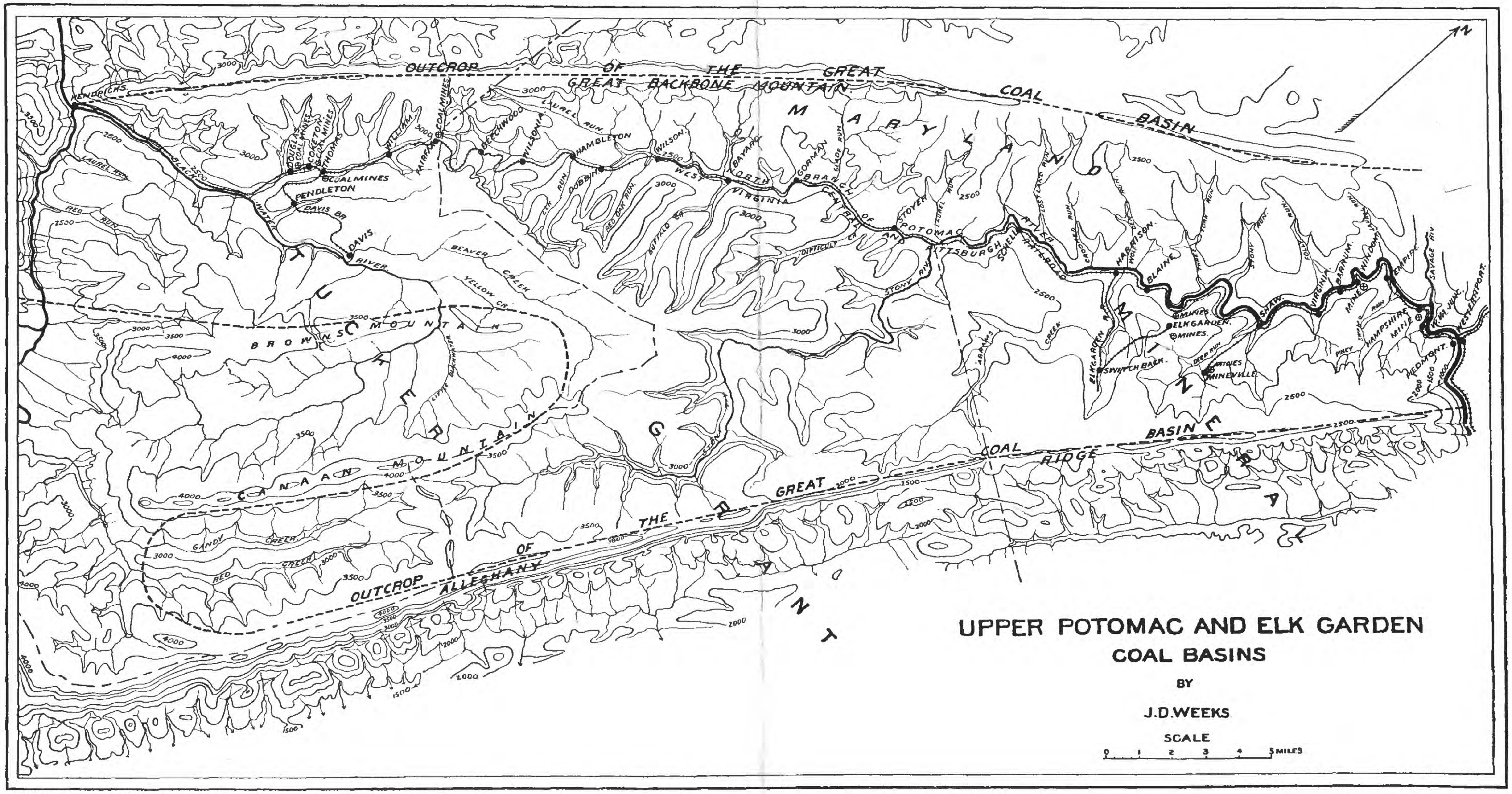
[1] Bull. No. 65, U. S. Geol. Survey, p. 65.


OUTCROP OF THE GREAT BACKBONE MOUNTAIN COAL BASIN
OUTCROP OF THE GREAT ALLEGHANY COAL BASIN
RIDGE
MARYLAND
MINERAL
GRANT
TUCKER
BROWNS MOUNTAIN
CANAAN MOUNTAIN
HENDRICKS
PENDLETON
DAVIS
WILSON
BAYARD
GORMAN
STOYER
HARRISON
BLAINE
SHAW
ELK GARDEN
MINEVILLE
SWITCH BACK
HAMPSHIRE MINE
EMPIRE
PIEDMONT
WESTERNPORT
BLACK WATER
DAVIS RIVER
BEAVER CREEK
YELLOW CR.
LAUREL RUN
RED RUN
STONY RIV.
SAVAGE RIV.
GANDY CREEK
RED CREEK
NORTH BRANCH OF POTOMAC RIVER
WEST VIRGINIA CENTRAL AND PITTSBURGH RAILROAD
UPPER POTOMAC AND ELK GARDEN
COAL BASINS
BY
J.D.WEEKS
SCALE
0 1 2 3 4 5 MILES

Though quite a number of veins of coal have been found here, as will be seen from the sections given below, the veins worked are known locally as the Thomas and Davis veins, so called after the Davis brothers, Henry G. and Thomas B., who were the pioneers in the development of this region. The Thomas vein is the Upper Freeport; the Davis vein the Lower Kittanning. The Upper Freeport or Thomas vein of this region has a thickness of nearly 8 feet, but a bony coal or slate near the center of the bed leaves about 6 feet of merchantable coal. The coal is valuable for both steam and coking purposes. The Lower Kittanning, or Davis vein, has a thickness of nearly 11 feet. With reference to its content of sulphur this is one of the purest coals mined. It is not only used largely for steam, but is especially valuable for blacksmithing purposes. For coking it is a most excellent coal.

At the head of the North Potomac and on the Cheat river side of the great Alleghany watershed, we get a fine exposure of these Lower Coal Measures in the vicinity of Thomas. The exposures have been made by the mining and grading operations of the West Virginia Central Railroad, and there the section reads as follows[1]:

Lower Productive Measures, near Thomas, Tucker county, West Virginia.

		Ft.	Ft.	in.
1. Coal, Upper Freeport	Coal 3′; Bone and bony coal 2′; Coal 3′		8	
2. Sandy shales, weathering reddish			40	
3. Coal, Lower Freeport	Coal 2″; Shale 4″; Coal 12″		1	6
4. Concealed		10	70	
5. Massive, pebbly sandstone, Freeport		60		
6. Coal, streak, Upper Kittanning				
7. Fire clay and shales			35	
8. Coal, Middle and Lower Kittanning	Coal, good 1′ 5″; Slate 0′ 4″; Coal, good 1′ 0″; Slate 0′ 3″; Coal, good 3′ 6″; Shale, gray 1′ 6″; Coal, slaty 3′ 0″		11	
9. Concealed		5	65	
10. Massive, sandstone		20		
11. Shales		2		
12. Iron ore, buhrstone		1		
13. Limestone, ferriferous		2		
14. Shales and sandstone		35		
15. Coal, Clarion			3	
16. Shales			40	
17. Sandstone, top of No. XII.				
Total			273	6

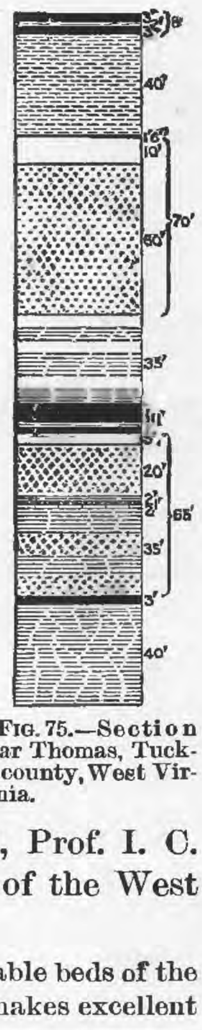


FIG. 75.—Section near Thomas, Tucker county, West Virginia.

Describing these two coals as they occur in this field, Prof. I. C. White, in a report made to Hon. H. G. Davis, president of the West Virginia Central and Pittsburg Railway Company, says:

The Upper Freeport coal is one of the regular, persistent, and valuable beds of the coal measures, and it nearly always furnishes a quality of fuel that makes excellent

[1] Ibid., p. 127.

coke. It has long been coked successfully in the Broad Top, Clearfield, and other regions of Pennsylvania. It has a thickness of nearly 8 feet from roof to floor in the Upper Potomac field, but a bony coal and slate just above the center of the bed render a portion of this thickness unavailable, so that seldom more than 6 feet of merchantable coal can be obtained from this seam. The upper portion of this bed comes out in good sized lumps, and will make a good shipping coal, while the lower bench is softer and will make good coke. This bed goes under the Potomac, near Bayard, and underlies the entire basin from that point to Thomas, a distance of 15 miles, while the width across, from one outcrop to the other, varies from 3 to 4 miles.

At a vertical distance of 170 feet below the floor of the Upper Freeport coal, we come to the roof of the most valuable coal in the basin, the one which has been referred to under the name of Lower Kittanning, or "Davis seam." The entire thickness of this bed is about 11 feet, but as the bottom bench is separated from the middle or main one by a slate of considerable thickness, the lowest ply of coal, which is nearly 3 feet thick, is not usually mined, since there is 6 feet of clean coal above this after it has been freed from all slates, of which there are two streaks in the upper portion of the bed, but they both come out without trouble, taking with them of coal, slate, and all only 8 inches from the thickness of the bed, leaving as just stated, exactly 6 feet of coal, free from impurities.

This Lower Kittanning coal in the Upper Potomac region is one of the purest beds with which the writer is acquainted anywhere in the country, being singularly free from sulphur, so much so in fact, that it already has a great reputation as a smithing coal, being as highly prized for this purpose as the celebrated Blossburg coal of Pennsylvania, with which bed, strange to say, it seems to be exactly identical.

The following are analyses of these coals made by the U. S. Geological Survey from full sections:

Analyses of Thomas and Davis coals, Upper Potomac field, West Virginia.

	Thomas (Upper Freeport).			Davis (Lower Kittanning).	
	Upper.	Middle.	Bottom	No. 1.	No. 2.
Moisture	0 64	0. 68	0 96	0 80	0 70
Volatile matter	22·87	23 88	22 90	26·84	22·03
Fixed carbon	65 60	65 99	72·76	67 18	70 53
Ash	10·89	9 45	3 38	5·18	6·74
Total	100·00	100·00	100 00	100 00	100 00
Sulphur	·64	1 39	59	1·68	·924
Phosphorus	·06	1·02	01	....	....

An analysis of the Davis coal from the mines of the Cumberland Coal Company's Douglas mine, made by the chemist of the Tremont Nail Company at Wareham, Massachusetts, is as follows:

Analysis of Davis coal at Douglas, West Virginia.

Moisture	1·10
Volatile matter	22·65
Fixed carbon	69·68
Ash	6·57
	100·00

This field is of very great extent—how great has not been determined. In 1882, when the explorations were exceedingly limited, Mr.

Raphael Pumpelly, who prepared the report on coal for the Tenth Census, estimated that there were 250 square miles of coal land in the upper Potomac and Stoney river basin after allowing for the erosion of the valleys, and gave 2,000,000,000 tons as the minimum amount of coal in beds of workable thickness, half of which was available, all above drainage, and accessible from the valleys. As the 8-foot vein was the largest he found, it is evident that the amount of coal in the basin was much underestimated.

At Coketon only the Lower Kittanning, or Davis vein, is mined. A section of this coal, known here as the 11-foot vein, is as follows:

Section of Davis vein at Coketon, West Virginia.

	Inches.	
Coal, upper bench	12	Portion worked.
Slate	2	
Coal, middle bench	18	
Slate	2	
Coal, lower bench	44	
	78	
Slate	18	Floor, not mined.
Coal	32	
	128	

Of the 106 inches of coal in the seam, the 32 inches below the 18 inches of slate is left in the floor. All of the vein above this 18 inches of slate is mined, giving in actual work 72 to 78 inches of coal. For this reason the seam is sometimes called the 6-foot or 6½-foot coal. As will be seen from the analyses given elsewhere, the three benches, which constitute the workable seam, differ in quality, the lower bench, 44 inches, being much the purer, showing, as analyzed by the U. S. Geological Survey, but 3.38 per cent of ash and but 0.59 per cent sulphur. The analyses of Prof. Hugo Blanck, of Pittsburg, gives the sulphur very much below this, viz, 0.191 per cent. It is this lower bench that is used for coke.

This coal shows a columnar structure, so typical of all good coking coals; is soft, so much so as to be easily broken by the hand, and breaks flaky and in slivers, even the finest slack showing minute columnar flakes under the microscope. The run of mine is used for steam; the coarse slack is in high repute and good demand in the West for blacksmithing, while the slack of the lower bench is coked.

At Douglas, where the same vein is mined, the conditions are similar.

At Thomas, but a mile north of Coketon, the Davis vein has gone below the surface and the Thomas vein appears in the hillside above the railroad. The distance here between the two veins is 200 feet, though the shaft sunk to the Lower Kittanning is but 184 feet deep.

A section of the Thomas (Upper Freeport) vein, at Thomas, which is an average of thirty sections made by Mr. F. S. Landstreet, the general manager of the Davis Coal and Coke Company, is as follows:

Section of Thomas vein (Upper Freeport) at Thomas mine, West Virginia.

	Inches.
Coal	18
Bone coal	5
Coal	6
Slate and bone	4
Coal	4
Bone coal	3
Coal	6
Slate	3
Coal	37
Total	86
Coal	71
Slate and bone	15

Of the 86 inches shown in the section some 6½ feet are mined, the upper bench, 18 inches, being removed first. The coal is a harder coal than the Davis seam yields, breaks with a cubical fracture, and will stand transportation better. The lump is shipped for domestic purposes, the run of mine for steam purposes, while the slack is coked.

Shipments were begun from this field in 1885, since which time, up to December 31, 1892, the output has been 881,914 tons, as will be seen from the following table:

Total shipments of coal from all the mines in the Upper Potomac region on the line of the West Virginia Central and Pittsburg railway from 1885 to January 1, 1893.

Year.	Davis.	Thomas.	Douglas.	Spring Garden.	Fairfax.	Bayard.	Junior.	Total.
	Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*
1885	8,434	1,131						9,565
1886	17,904	2,772						20,676
1887	18,287	3,774						22,061
1888	69,297	10,350						79,647
1889	99,771	23,320		696				123,787
1890	111,477	30,495		1,290				143. 262
1891	141,142	55,888	15,146	1,247	357			213,780
1892	107,877	95,160	62,860		990	416	1,833	269,136
1893								423. 610
Total	574,189	222,890	78,006	3,233	1,347	416	1,833	1,305,524

The total production of the Elk Garden and Upper Potomac fields, from the beginning of shipments in 1881, have been as follows, in tons of 2,240 pounds:

Total coal production of Elk Garden and Upper Potomac fields.

Year.	Elk Garden.	Upper Potomac.	Total.	Year.	Elk Garden.	Upper Potomac.	Total.
1881	11,372		11,372	1889	436,558	123,787	560,345
1882	257,068		257,068	1890	556,978	143,262	700,240
1883	330,017		330,017	1891	610,094	213,780	823,874
1884	458,760		458,760	1892	533,110	269,136	802,246
1885	391. 785	9,565	401,350	1893	450,394	423. 610	874,004
1886	326,253	20,676	346,929				
1887	426,760	22,061	448,821	Total	5,273,001	1,305,524	6,578,624
1888	483,951	79,647	563,598				

COKE-MAKING IN THE UPPER POTOMAC REGION.

Though all three seams of coal mined in the Elk Garden and Upper Potomac regions are coking coals, only two are coked, the Thomas (Upper Freeport) and Davis (Lower Kittanning), and chiefly the latter. In addition to its being more valuable as a steam than as a coking coal, the Big Vein is lower in volatile matter than either the Thomas or Davis veins, and does not coke as readily. As these seams of coal have been described elsewhere in this report, a description here is unnecessary.

There are three coke plants, with 393 ovens, in this field, all in the Upper Potomac district, no coal being coked at present in the Elk Garden district. Two of these, the plant at Coketon, with 327 ovens, and the one at Douglas, just south of Coketon, with 44 ovens, coke the Davis seam. The plant at Thomas, just north of Coketon, with 22 ovens, uses the Thomas coal.

The ovens used are all beehive, of the standard Connellsville type, 12 feet in diameter by 7 feet high; the batter of the ovens beginning 18 inches above the floor.

Slack or fine coal only is used, experience having shown that the run of mine or lump does not yield as good a coke. The charge is 5½ tons for forty-eight hour coke, and 6½ tons for seventy-two hour. The actual yield of coke by weight at the Coketon plant, using the Davis seam, is over 67 per cent.

The coke is a bright, silvery, porous, hard fuel, and has a most excellent reputation for foundry uses because of its physical characteristics and low sulphur. It is shipped largely for this purpose to South America. It is also an excellent blast-furnace fuel; and, when selected and crushed, has a large sale for domestic purposes.

Analyses of coke made from the Davis seam at Coketon, West Virginia, are as follows:

Analyses of coke made from the Davis seam at Coketon, West Virginia.

	48 hour.	72 hour.	48 hour.	72 hour.	48 hour.	72 hour.	48 hour.	72 hour.	48 hour.	72 hour.
Water	0·25	0·16	Trace	Trace.	Trace.	Trace.	Trace.	Trace.	0·84	1·20
Volatile matter	·86	1·17	1·48	1·36	·310	·320	1·81	2 51	2·02	1·38
Fixed carbon	89·08	92·30	90·19	92·31	90·765	90·835	88·72	90·11	89·00	90·90
Ash	9·81	6·37	8·33	6·33	8·925	8·845	9·47	6·80	9·14	6·52
Total	100.00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Sulphur	·60	·54	·90	·84	·752	·725	·53	·58	·191	·147
Phosphorus	·05	·04	·031	·021	·034	·037	·038	·013	·030	·009
Chemist	U. S. Geol. Sur.		Hunt & Clapp.		Booth & Garrett.		Riverside Iron Co.		Hugo Blanck.	

The average of the above analyses is as follows:

Average of ten analyses of Coketon coke.

	48 hour.	72 hour.
Water	0·218	0·39
Volatile matter	1·296	1·348
Fixed carbon	89·352	91·291
Ash	9·134	6·971
Total	100·00	100·00
Sulphur	·5946	·566
Phosphorus	·0366	·024

The analyses by Dr. Hugo Blanck, of Pittsburg, are quoted from a report of Prof. I. C. White. The sulphur is suspiciously low in these analyses.

The first shipment of coke was made from this region in July, 1887. The total production to January 1, 1893, was 242,205 tons. The shipments by years have been as follows:

Statement showing total shipments of coke from all ovens on the line of the West Virginia Central and Pittsburg railway from July, 1887, when the first coke was made, to January 1, 1893.

Year.	Thomas ovens.	Coketon ovens.	Douglas ovens.	Custer ovens.	Total.
	Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*
1887	2, 211				2, 211
1888	5, 432				5, 432
1889	12, 657				12, 657
1890	7, 409	48, 208			55, 617
1891	8, 901	68, 273	3, 315		80, 489
1892	8, 992	57, 745	18, 429	633	85, 799
1893					84, 186
Total	45, 602	174, 226	21, 744	633	326, 391

It is evident not only from the character of the coke and from its special adaptation to foundry and domestic uses, but from its nearness to tidewater and to markets, that the coke industry in this region is in its infancy. The costs of mining and production of coal and coke in this section are so low that the coke can at all times compete in price with that made in other districts.

THE ROARING CREEK FIELD.

The West Virginia Central and Pittsburg railway, as already stated, after passing out of the Upper Potomac field, around the southern end of the great Backbone mountain, enters the valley between the Cheat mountain and Laurel hill, following it until it reaches Elkins, where it turns abruptly to the northwest and, passing between Laurel hill and Rich mountains, follows the Tygarts Valley river to Belington, in the Roaring Creek field.

This field is a part of the main Appalachian basin and not an outlier, as is the Potomac basin we have been describing. It lies in the northern edge of Randolph county, West Virginia, and the southern portion of Barbour. The field has a basin shape and is bounded on the east by the great Rich mountain and Big Laurel uplift and on the west by Kings mountain. The Tygarts Valley river flows diagonally through the basin, cutting the eastern rim, as already described, near Elkins, thus opening a natural and easy gateway to the field.

Both the Upper Freeport and the Lower Kittanning coals are found in this district, but the latter has not been mined, the former entirely overshadowing it in importance. Near Roaring creek this coal is in veins piled one above the other, but separated by slate, the thickness of the "seam" being 16 to 30 feet. It is hardly correct, however, to call this one vein, and especially misleading to infer that any such thickness can be mined. This thickness is geological, not workable.

A section of this coal at Custer mine, taken by Mr. F. S. Landstreet at a point 150 feet in the main entry, which is a fair sample of the entire mine, is as follows:

Section of the Upper Freeport coal at Custer, Roaring Creek district, West Virginia.

	Inches.
Coal and bone	7
Coal	18
Slate	1
Coal	14
Slate	7
Coal	12
Total	59

At some places the bottom ply is 3 to 4 feet thick, as at Wilson's mine on Roaring creek, where the section is as follows:

Section of the Upper Freeport coal at Wilson's mine, Roaring creek, West Virginia.

	Feet.	Inches.
Coal, slaty, impure	1	6
Slates, dark	2	0
Coal, "upper bench"	2	8
Slate and bony coal	1	3
Coal "breast"	3	1
Slate, gray	0	6
Coal, "mining ply"	1	8
Clay and slate	0	4
Coal, "bottom," slaty	1	0
Total	14	0

The "mining ply" and "breast" layers furnish, as a rule, very good fuel, the "upper bench" being slaty and otherwise impure. A number of sections (thirteen) made at different points shows the merchantable thickness of the bed to be 7 feet, varying from 4 feet 6 inches to 8 feet 5 inches. On this basis, allowing 6 feet of merchantable coal to be mined, the quantity of coal in the seam of this field is estimated by Prof. I. C. White at 30,000,000 tons above drainage and as much below drainage level, the deepest shaft to which would not exceed 125 feet.

The Upper Freeport (Thomas) coal shows somewhat the same characteristics in this field as in the Upper Potomac. It is a bright, excellent steam and coking coal, does not contain an injurious amount of sulphur, and the ash, while higher than that carried by the Davis coal, is not nearly so high as that in a majority of southern coals that are made into cokes used extensively in blast furnaces. We have no authoritative analysis of the coal of this district. An analysis of coke from Custer made by J. Blodgett Britton is as follows:

	48-hour.	72-hour.
Moisture	0·31	0·26
Volatile matter	2·12	2·67
Fixed carbon	85 66	84·74
Ash	11·91	12·33
Total	100.00	100.00
Sulphur	·578	·619

In addition to the Upper Freeport or Thomas vein a second seam, known as the Masontown bed, is mined. This coal is in the Barren Measures, usually the first above the Mahoning sandstone and separated from it by an interval of 5 to 50 inches. It is known locally as the "4-foot coal." It is a good domestic fuel, open burning, rich in carbon, making a hot fire. There are, according to Prof. White, 5,000 acres of this bed in this district, averaging 4 to 5 feet workable thickness, making, taking the average yield at 4,000 tons an acre, 20,000,000 tons in this bed.

This gives the total tonnage of coal in this field above drainage as 50,000,000 tons, 20,000,000 tons in the Masontown bed, and 30,000,000 tons in the Thomas, with 30,000,000 tons more in the latter below river level, to be reached by shafts of a moderate depth.

It is so recently that the railroad has entered this field that as yet the tonnage is very light. For the year ending June 30, 1893, but 3,525 tons were shipped. Poor service on connecting lines was one cause of the low tonnage. Coking operations have begun in this district at Custer, where twenty ovens have been built and some coke of a satisfactory character, as shown by analyses given above, made in 1893.

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