YELLOWSTONE NATIONAL PARK SHEETS.

GENERAL DESCRIPTION.

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GEOGRAPHY.

The area covered by the maps of the Yellowstone National Park folio is represented upon four atlas sheets, known as the Gallatin, Canyon, Lake, and Shoshone sheets, and is embraced between the parallels of 44° and 45° north latitude and the meridians of 110° and 111°. It is situated in the northwest corner of the State of Wyoming, and includes 3,412 square miles.

In 1871 Dr. F. V. Hayden, a United States geologist, explored this region, at that time comparatively unknown, accompanied by a corps of skilled scientific assistants including geologists and topographical engineers. Their explorations were eminently successful, and immediately attracted the attention of the world. It must always redound to the credit of Dr. Hayden that he appreciated the exceptional character of the region and the advisability of its forever being held intact by the General Government. He laid the matter before the Congress of the United States, and upon his earnest solicitation the Yellowstone National Park was established.

By far the greater part of the Yellowstone Park is situated within the area of the four atlas sheets, but a strip of country about 2½ miles in width lies to the northward in Montana, and a still narrower belt extends along the western side in Idaho and Montana. The eastern boundary of the Park, as defined by law, is placed 10 miles east of the most eastern point of the Yellowstone Lake. This eastern line nearly coincides with the meridian of 110°. The southern boundary lies 10 miles south of the lake, and is shown on the maps (Shoshone and Lake sheets).

In the organic act of 1872, defining the purposes and boundaries of the Park, Congress declared that the reservation was "dedicated and set apart as a public park and pleasure ground for the benefit and enjoyment of the people." As defined by law, the area of the Yellowstone National Park includes 3,344 square miles.

All the country situated between the southern line of the Park and the parallel of 44° belongs to what is known as the Yellowstone Park Forest Reservation, set aside by proclamation of President Harrison on March 30, 1891, and therefore may be regarded as practically forming a part of the grand National reservation. The four atlas sheets may therefore be regarded as a unit and described as a single geographical area.

TOPOGRAPHY.

The central portion of the Yellowstone Park may be described as a broad volcanic plateau between 7,200 and 8,300 feet above sea-level, with an average elevation of nearly 8,000 feet. Surrounding this plateau on the south, east, north, and northwest rise mountain ranges with culminating peaks and ridges standing from 2,000 to 4,000 feet above the general level of the inclosed area. The Gallatin Range shuts in the Park on the north and northwest. It is a bold, picturesque range of mountains extending from Mount Holmes, at the southern end, far northward into Montana, where it presents a sharply defined ridge along the west side of Yellowstone Valley. Electric Peak, situated on the northern boundary of the Park, and the highest point of the range, attains an altitude of 11,100 feet. South of Mount Holmes the volcanic lavas which form the Madison Plateau stretch southward beyond the limits of the map. The Teton Range upon the south looms up grandly and forms one of the most prominent geographic features of the northern Rocky Mountains. The eastern wall of this mountain mass rises with unrivaled boldness nearly 7,000 feet above Jackson Lake, which lies immediately at its base in the open valley of Snake River. Northward the ridges of the Tetons fall away abruptly, and only the outlying bold spurs and foothills come within the limits of the forest reservation. To the east of the Tetons, across the broad valley of the Snake, stretches the Gros Ventre and Wind River ranges. The latter forms one of the most prominent orographic features of central Wyoming, and is one of the longest and broadest ranges in the State, extending in a series of high alpine ridges well up toward the Park. An outlying ridge within the area of the map has been designated Big Game Ridge, and the culminating point has long been known as Mount Hancock. This mountain, situated just inside the southern line of the Park, has an altitude of 10,100 feet above sea-level, and commands one of the most picturesque views of the adjacent country.

Along the entire eastern side of the Park stretches the Absaroka Range, so called from the Indian name of the Crow Nation. At its southern end the range is topographically so closely connected with the Wind River Range by the Wind River Plateau that any line of separation between them must be drawn arbitrarily. The Absarokas trend in a north-south direction for more than 80 miles, forming an unbroken barrier along the entire eastern side of the Park. All the western slope of the mountains and many of the higher peaks come within the Park limits, but the great body of the range lies to the eastward, presenting an uncommonly rugged group of peaks and mountain masses, scored by deep canyons. Near the northeastern corner of the Park a confused mass of mountains connects the Absarokas with the Snowy Range. The latter range, high and alpine in character, as its name indicates, shuts in the Park on the north, its western foothills connecting with the outlying eastern spurs of the Gallatin Range. Only the southern end of the Snowy Range falls within the borders of the Park reservation.

Across the elevated plateau inclosed by these mountains lies the continental divide, separating the waters of the Atlantic from those of the Pacific. Entering the Park at the southeast corner, it runs with an irregular course in a northwest direction. Following along the top of Two Ocean Plateau, it skirts the northern escarpment of Flat Mountain, winds among the undulating low ridges lying between Yellowstone and Shoshone lakes, and thence, with a broad sweeping curve around the streams running into the latter lake, crosses the Madison Plateau and leaves the Park a short distance southwest of the Upper Geyser Basin.

Four large rivers drain this region. The Snake carries off all the water on the south and west side of the great divide, and the Yellowstone, Madison, and Gallatin that on the east and north. The Snake River drains somewhat more than one-quarter of the area. Two tributaries of the Snake, Falls and Bechler rivers, run off on the west side of the Tetons, flowing into the main channel beyond the limits of the map. All other tributaries from this region join the main stream before reaching Jackson Basin.

The Yellowstone has its source among the snows of the Absaroka Range and the Wind River Plateau. It enters the Park at the extreme southeast corner, runs northwesterly for 30 miles before flowing into the lake, thence across Hayden Valley and through the far-famed Grand Canyon of the Yellowstone, and finally leaves the Park at its northern boundary. A large part of the central plateau is drained by the Firehole and Gibbon rivers, which unite to make the Madison. The latter river, running nearly due west, cuts a deep gorge through the Madison Plateau, and, after a winding course, pours its waters into the Missouri at Three Forks. Within the Park the Gallatin drains a much smaller region than any other of the large rivers, being restricted to the western slope of the Gallatin Range, with a drainage of less than 80 square miles, and, like the Madison, it empties into the Missouri at Three Forks. Across the Park Plateau and the Absaroka Range the country presents an unbroken mountain mass over 75 miles in width, with an average elevation unsurpassed by any other area of equal extent in the northern Rocky Mountains. From its position it offers exceptional physical conditions for gathering the moisture-laden clouds, which, passing over the arid region, precipitate large quantities of snow and rain upon the cool table-land and adjacent country. The climate is in many ways quite unlike that found in the surrounding low country. As is shown by meteorological records, the amount of precipitation is higher, and the mean annual temperature lower. Rain storms occur frequently throughout the summer, while snow is likely to fall at any time between September and May. Such climatic conditions favor forest development and the growth of luxuriant grasses, together with a varied alpine verdure. These conditions, with numerous mountain torrents, plateaus, lakes, and waterfalls descending from the table-land to the lowland, add much to the scenic attractions of the far-famed Yellowstone Park. Owing to the elevation of the country and consequent severity of its climate, the region is one unfit for agriculture and undesirable for settlement, and as the Park and Forest Reservation are under Government supervision, no person is allowed to reside there permanently or without permit from the Secretary of the Interior. Good roads traverse the country and substantial bridges span the rivers, both being built and maintained by the General Government.

GENERAL GEOLOGY.

Archean rocks.—The oldest rocks in this region are crystalline granites, gneisses, and schists of various kinds, and, like similar occurrences elsewhere, are assigned to the Archean age. They are thought to constitute the earlier rock formations of the crust of the earth. The granites and gneisses are for the most part coarsely crystalline, and the entire series shows the effect of metamorphism by pressure. No exposures of Archean rocks are known in the central region, but they occur in connection with all the great mountain uplifts that encircle the Park plateau. In consequence, they are found only near the borders of the district, where, with the exception of those found in the Gallatin Range, they represent outlying portions of much larger masses. In the Snowy Range they occur along the northern border of the map, and are found on both sides of the Yellowstone for a long distance. Along Big Game Ridge and in the mountain mass of which Wildcat Peak is one of the culminating points, no Archean rocks occur, but southward, in the Wind River Range, as in the Tetons, they form the central body of the mountains.

Algonkian rocks.—In the Rocky Mountains north of the Yellowstone Park there rests unconformably upon the Archean a series of sandstones and slates which have been referred to the Algonkian period, yielding as yet no organic remains. Within the Park, rocks provisionally assigned to the Algonkian period do not occur associated with the older granites and gneisses. They occupy limited and isolated areas, for the most part buried beneath lava flows, preventing their relations with other formations from being studied. The beds consist mainly of massive, dense, bluish-white quartzite. They are recognized only in the southern end of the Park, and are best exposed upon the southern slope of Mount Sheridan. Their assignment to the Algonkian period is based largely upon the fact that similar rocks are unknown in the Paleozoic series, and no sedimentary rocks older than these quartzites are exposed in this region.

Paleozoic and Mesozoic rocks.—Upon the Archean crystalline bodies, which rose as islands or continental areas from a broad open sea, there was deposited unconformably a great thickness of sediments made up of sandstones, limestones, and clays. These overlying sediments present a conformable series of Paleozoic and Mesozoic strata extending from the base of the middle Cambrian, the lowest beds exposed, through the upper Cambrian, Silurian, Devonian, Carboniferous, Juratrias, and Cretaceous, including the Laramie sandstone. They were laid down under varying physical conditions, partly as coarse material in shallow waters as inshore deposits, and in great part as finer sediments carried farther away from land and deposited in relatively deeper and quieter seas.

During the Paleozoic age, from the time of the middle Cambrian to the end of the Carboniferous, the accumulation of sediments attained a thickness, as measured in the Gallatin Range, of 3,250 feet. The basal beds resting directly upon the old continental land surfaces were formed from the detrital material derived from the disintegration of the schists and granites under atmospheric agencies. These earlier sediments everywhere consist of coarse quartz grains and fragmentary material of the underlying rocks. Over this comes somewhat finer and lighter material, carrying mica and clay, the latter derived from the decomposition of the feldspars contained in the crystalline rocks. Overlying these latter beds the first calcareous sediments were deposited, associated with quartz and mica and carrying less and less foreign material, until beds of nearly pure limestone made their appearance. In these beds occur the first remains of a marine fauna, showing a grouping of species characteristic of the middle Cambrian period. From the base of this limestone to the top of the Madison formation—the great limestone body of the Carboniferous period in the northern Rocky Mountains—the beds consist almost wholly of calcareous deposits, varying considerably, however, in the purity of their sedimentation, some of them arenaceous, others more or less argillaceous, while still others are marked by the presence of ferruginous material and belts of cherty and nodular limestones. Differences of color, mode of bedding, and a tendency of certain beds to assume a shaly structure, render it possible to separate this great body of limestone into a series of beds. Many of them are easily recognized and their geological position determined wherever they are exposed. One of these characteristic beds in the Cambrian has been designated the Mottled limestone, so named from the irregular dark-gray and brown lenticular patches scattered through it. It is a persistent horizon, easily traced far beyond the limits of the Park region. No well-preserved organic remains have been found in it, but the fauna found below it has been referred by Mr. C. D. Walcott to the middle Cambrian, while all fossils immediately above this horizon in the Gallatin Range belong to the upper Cambrian. The Cambrian has an estimated thickness of 860 feet.

The beds assigned to the Silurian consist of dark-colored, massive limestones, for the most part sharply defined lithologically, but in the Gallatin Range poorly defined by organic remains. As the Cambrian limestone passes into that of the Silurian without any marked change of deposition, it is natural that conditions favorable to the development of many preexisting species should continue upward into higher horizons, and that there should be a commingling of both the Cambrian and the Silurian species. In many localities only organic forms common to both periods have been obtained in the 160 feet assigned to the Silurian. In the same way, at other localities the species found near the top are such as have a wide range and might occur in both Silurian and Devonian rocks. Again, without any apparent interruption in the continuity of the oceanic sediments other than by occasional more or less shaly beds, the limestones for the next 190 feet are sharply defined by marine fauna carrying such species as *Atrypa reticularis* and *Pachyphyllum woodmani*, characteristic of the Devonian.

Nearly or quite one-half the sediments of the Paleozoic sea in this region consist of Carboniferous limestones. They have been designated the Madison limestone, and present a great thickness of beds laid down under fairly uniform conditions. In the uplifted areas they play a conspicuous part in mountain building, forming the summits of many high peaks. Fossil remains characteristic of the lower Carboniferous occur throughout the limestone, many of the species showing a wide vertical range, as might be expected in such uniform beds. In the Park region the fauna of the Carboniferous is much the same wherever obtained, and several species, among them *Chonetes loganensis* and *Spirifer centronatus*, occur at a number of localities.

At the close of the Madison period the limestone-making epoch of the Paleozoic sea came to an end. Marked changes took place in the sedimentation, and siliceous material began to accumulate. At first the deposited quartz grains were accompanied by calcareous material, which gradually gave way to pure siliceous beds. These have been designated the Quadrant quartzites. Near the top impure beds again came in, showing a mingling of calcareous and arenaceous material, but apparently devoid of life. With the end of the siliceous deposition the great accumulation of sediments deposited in a Paleozoic sea came to a close. In a series of conformable beds unfavorable for the preservation of organic remains, it is difficult to say just where the line of separation between the Paleozoic and Mesoic rocks should be drawn. In some localities in the northern Rocky Mountains the well-recognized Quadrant quartzites are followed by a limestone carrying Carboniferous fossils, but in this region such characteristic limestones are wanting. The beds immediately overlying the quartzites constitute in general a grouping of thinly bedded cherts and argillaceous shales by no means easy to correlate in the different areas, indicating variable conditions of deposition within limited areas. The only fossils yet obtained from these cherty beds are a few specimens of linguloid shells of little value in determining the age of the strata. These cherty and shaly beds are followed by red shales and sandstones forming a very persistent and sharply defined horizon south of the Park. They are overlain by a series of limestones, sandstones, marls, and clays, all of them more or less arenaceous, constituting a group of beds known as the Ellis formation, with a maximum thickness of only 200 feet. These indicate constantly changing conditions of sedimentation, and carry throughout a varied marine fauna of characteristic Jurassic species. Among them may be mentioned *Pleuromya subcompressa*, and *Rhynchonella myrina*.

The Ellis formation is followed by decidedly arenaceous deposits, varying from medium-grained sandstone to coarse conglomerate. They are known as the Dakota sandstone and conglomerate. In this region, as elsewhere, the horizon is regarded as the base of the Cretaceous period. In the Park the conglomerates form the most conspicuous portion of the beds, made up for the most part of smooth waterworn pebbles firmly compacted together. They are evidently shallow-water, in-shore deposits. Associated with the conglomerates in the Gallatin Range occur a few feet of dark-gray limestone, in places filled with fresh-water gasteropods. It is evident that the limestone was deposited in a land-locked area, and as no fresh-water Jurassic fauna has been recognized in this region it indicates the first appearance of fresh-water life.

The middle Cretaceous, or Colorado formation, shows evidences of a deeper sea throughout a long period of alternating ferruginous sandstones and clay shales, the latter greatly predominating. Associated with them are occasional limestone strata. A marine fauna occurs at different horizons from base to summit. Fragmentary plant remains, evidently transported for considerable distances from neighboring land areas, are by no means uncommon in the shales. In distinction to the Colorado, the overlying Montana formation is essentially a sandstone, and, considering its great thickness, was evidently deposited under fairly uniform conditions. This is so marked that on Big Game Ridge and in the region of Huckleberry Mountain it is impossible to differentiate Pierre shales from Fox Hill sandstones. The conditions governing deposition being similar, it is natural to find that life continued much the same, and as a matter of fact it is found difficult to separate by their faunas formations elsewhere clearly defined. There is a decided mingling of a marine fauna throughout the Montana epoch.

The Laramie, essentially a sandstone formation, is far less uniform in its sedimentation than the underlying Montana. The sandy beds are less pure and frequently intercalated with beds of clay and shale. It bears evidence of shallow-water deposits and constantly changing conditions of land to water. In the Laramie occur the great coal-bearing beds which have proved of such importance in the development of the country northward in Montana. In this region occur seams of bituminous clays and impure coals of little economic value, but showing physical conditions favorable to its formation similar to those found elsewhere. The Laramie has furnished a varied flora and a characteristic fauna of brackish-water types. All these conditions foreshadowed marked changes in the geological development of continental areas.

Post-Laramie movement.—With the close of the deposition of the Laramie sandstone the conformable series of Paleozoic and Mesozoic strata came to an end. The entire region was once more elevated above the sea. The strata were plicated and folded. The region became one of profound dynamic action and a center of mountain-building on a grand scale. So far as the age of these mountains encircling the Park is concerned, evidence goes to show that upheaval was contemporaneous in all of them and coincident with dynamic influences which uplifted other north-and-south ranges stretching across Wyoming and Montana. These orographic movements blocked out for the most part the Rocky Mountains after the close of the Laramie epoch. There is evidence, however, to show that in the region of the Park powerful faulting and displacement, accompanied by continental elevation, prolonged the work of mountain-building through the Cretaceous and the greater part of Tertiary time. But such orographic movements must be necessarily greatly obscured by the accumulation of lavas that cover the Park region. For instance, the post-Cretaceous movement which uplifted the Livingston formation northward in Montana can not be recognized as such, although it would seem more than probable that it must have exerted a powerful influence in all adjacent continental areas.

The Gallatin is the only range formed mainly of Paleozoic and Mesozoic rocks that is embraced within the area of the map. Structurally the sedimentary beds present a broad syncline compressed between two grand Archean bodies. Only the northerly dipping beds of this syncline come within the Park, the axis of the fold lying still northward beyond Electric Peak. Along the southern borders of the Snowy Range the sedimentary rocks lie gently inclined toward the Park. In the northern end of the Absaroka Range the strata dip uniformly southward and rapidly pass beneath igneous rocks. Big Game Ridge and the region of country of which Huckleberry Mountain is the culminating peak are formed of compressed and folded Mesozoic strata broken up by profound longitudinal faults. Outbursts of igneous rocks have complicated and in many instances obscured the structure. In the Tetons the entire series of conformable strata lies steeply inclined as a broad anticline curving around the northern end of a massive Archean body which extends far southward into Wyoming.

Volcanic energy, which later played so important a part in the geological development of the region, was probably intimately connected with the post-Laramie movement, and followed closely upon the elevation of the mountains and the accompanying dislocation and compression of sedimentary beds. The eruptive masses forcing their way upward followed lines of least resistance, along planes of faulting or wherever strain had been greatest in the crumpled sediments.

Eocene rocks.—Between the blocking out of the mountains at the close of the Laramie and the pouring out of vast eruptions of igneous rocks there were deposited certain strata, which in the Park region are limited to the southeast corner (Lake sheet). Here are found, resting unconformably upon the tilted and eroded sandstones of the Laramie epoch, a series of nearly horizontal beds which have been designated the Pinyon conglomerate, named from the mountain where they are best exposed, on the divide between Wolverine and Gravel creeks. Nine-tenths of this material consists of waterworn pebbles mingled with sand and gravel. Associated with them are fragmentary pieces of rock derived from the underlying Mesozoic strata, with occasional well-rounded pebbles of volcanic origin, together with granite and gneiss. This material has accumulated to a thickness of nearly 600 feet, and is clearly a shallow-water, in-shore deposit, as it is far too coarse to have been transported to any great distance. As regards their age, these conglomerates have been provisionally referred to the Eocene period, since they were deposited subsequent to the Laramie upheaval and must have preceded the accumulation of volcanic rocks. If not older than the volcanic lavas, they would certainly contain large quantities of the basic breccias of the Absaroka Range and of the acid rhyolites of the Park Plateau. They show no evidences of either, but on the contrary are overlain by both in the neighborhood of Pinyon Peak. These gravels are the northern extension of much larger areas occurring in the Wind River Mountains.

Neocene rocks.—The only other strictly sedimentary formation of Tertiary age in the Park are beds of waterworn conglomerate and friable sands exposed in the walls of the Grand Canyon and in the valley of Lamar River, in both cases overlain by basalt. In the Grand Canyon they are both overlain and underlain by basalt. They were deposited after the outbursts of andesitic breccia, but before the great flows of rhyolite which covered the country were poured out, so that their geological position with reference to the igneous rocks is well determined. They are of slight importance in themselves, seldom exceeding 50 feet in thickness, and they cover limited areas.

Volcanic period.—Throughout post-Cretaceous time the Yellowstone Park region was characterized by great volcanic energy, enormous volumes of eruptive material being poured out during the Eocene and Neocene periods, but probably not extending into Pleistocene time, at least not after the appearance of glacial ice. Active volcanoes surrounded the Park on the east, north, and west, and broke out in the central region. The greater part of the Absaroka Range as seen to-day was built up by vast accumulations of volcanic ejectamenta, and the depressed basin lying between the encircling ranges was filled to its present elevation by flows of rhyolite, forming the present Park Plateau.

Amongst the oldest igneous rocks in the Park are those found in the Gallatin Range, where they occur as intrusive bodies in the form of massive laccoliths, as intercalated sheets forced between sedimentary strata, and as dikes of varying widths cutting older rocks. The intercalated sheets frequently pass from one bed to another, and then resemble normal dikes. All these intrusive bodies penetrate sedimentary beds of all ages from the middle Cambrian to the Laramie. While these early intrusive bodies show considerable variation in mode of occurrence, they possess a chemical composition intermediate between basic and acid magmas, and have been grouped together under the designation of andesite-porphyry. Similar rocks may occur elsewhere in the Park, but if so they are limited in their exposures or else are buried beneath later extrusive flows. Next in order of succession in the Gallatin Range comes the more acid (or siliceous) rock, dacite-porphyry. It occurs as a laccolithic body younger than the andesite-porphyry, as shown both at Mount Holmes and at Echo Peak. Similar masses elsewhere in the Park are too much obscured by later rhyolite flows to present any field evidence of their relations to earlier igneous masses. Electric Peak, situated in the Gallatin Range, lies partly within the area of the map, but in great part beyond its border. It was the center of volcanic energy continued throughout a long period of time. The eruptive material, presenting a great variety of igneous rocks, occurs as intrusive bodies penetrating the shale and sandstone strata of the Colorado and Montana formations. As the area represented by them is small, they have been grouped together under one color and designated the Electric eruptives. The early eruptions are probably closely related to the intrusive masses southward in the Gallatin Range, while the later ones are apparently connected with the extrusive, basic breccias of Sepulchre Mountain.

Extrusive lavas, or those that have been forced out and cooled near the surface, cover by far the greater part of the Park area. From Sepulchre Mountain eastward along the northern boundary of the Park, and in the northern end of the Absaroka Range, occur areas of acid andesitic breccias and flows consisting mainly of hornblende-andesite and hornblende-mica-andesite. They are among the oldest of the extrusive lavas of this region. They occupy relatively small areas, owing to the accumulation of later eruptive material, and in most instances are exposed only by erosion of the overlying lavas. Intimately associated with them, but of later age, occurs a vast accumulation of basic breccias, agglomerates, and mud flows. Interbedded in these later breccias occur flows of compact basalt, varying in extent and of greater or less thickness. This mass of breccias was piled up to a thickness of several thousand feet, and forms a greater part of the northern end of the Absaroka Range, extending eastward far beyond the limits of the Park. Throughout the greater part of this area all earlier rock formations were buried beneath these volcanic accumulations.

Denudation of these early basic breccias has taken place on a grand scale. Deep canyons were trenched and a vast amount of volcanic ejectamenta carried away. With material so varied in texture, erosion has produced many curious rock forms peculiar to the interbedded breccias, agglomerates, and mud flows which make up this group of lavas. Bowlders and irregular masses of dense basic rocks, withstanding erosion better than the more friable cementing material, have protected the underlying rocks and have produced the most fantastic and ever-changing forms of rock sculpture. This rock sculpturing is well exposed in the Hoodoo Basin, at the head of Lamar River, in the Absaroka Range, just east of the Park boundary. These grotesque forms of erosion are strikingly shown in fig. 1, where the so-called hoodoos stand out boldly on the brink of a profound canyon wall.

That the duration of the earlier eruptions of acid and basic breccias and agglomerates continued throughout a long period of time is made evident by plant remains preserved in volcanic ashes and in mud flows associated with the coarser breccias and more or less compacted lavas. Much of this plant material is in an excellent state of preservation, and it is in these beds that the well-known fossil floras occur. In the acid lavas a distinct flora has been discovered in a number of localities upon both sides of the Yellowstone River. In the escarpments along the west side of Lamar Valley the forest and plant-bearing beds are admirably displayed, erosion having cut numerous lateral ravines in the eruptive material of the basic lavas. Many trees are still standing in upright positions, others lie horizontal, firmly imbedded in the layers of volcanic muds and ashes. The section across the beds exposed by the ravines measures nearly 2,000 feet in thickness, with evidence of a fossil flora from base to summit.

Large collections have been made from the extensive fossil floras found in the Park, and all the material has been referred to Prof. F. H. Knowlton for study and identification. From this rich field of research nearly 150 species have been determined, of which more than one-half are new to science. The new species are fairly well divided between the two groups of rocks, and only a few of them, so far as known, are common to both. Of the species found in these lavas previously described as occurring elsewhere, only 5 are common to both the acid and basic breccias. The flora from the acid breccia is so closely allied to that obtained from the Fort Union beds near the mouth of the Yellowstone River in Montana, that they are regarded as identical in age, and are consequently referred to the Eocene period.

At several localities along the contact of the acid and basic breccias between Yanceys Station and Crystal Creek there occurs a flora distinct in its grouping of species from that which is found either in the acid breccia below or the basic breccia above. The flora from this limited area carries 30 species, of which more than one-half are new to science, and of those previously described many have a wide geological distribution. This grouping of trees has been designated the Intermediate flora, and is regarded as belonging to the base of the Neocene period. The flora from the basic breccia which is so characteristically developed at the Fossil Forest is of still later age. It has been named the Lamar flora.

Among other characteristic species found imbedded in the acid breccias at Crescent Hill and along Yellowstone River near Hellroaring Creek are the following: *Sapindus affinis, Cornus acuminata, Populus speciosa, Sequoia couttsiæ.*

From the Intermediate flora the following may be mentioned as characteristic: *Platanus montana, Quercus yanceyi, Laurinoxylon amethystenium, Populoxylon wardii.*

From the abundant collections from the Fossil Forest there may be selected the following species as typical of a much higher horizon: *Platanus guillelmæ, Laurus californica, Magnolia spectabilis, Planera longifolia, Aralia whitneyi.*

The trunks of two well-preserved silicified trees, for the most part laid bare by erosion, but with their roots firmly imbedded in coarse breccia, are shown in fig. 2. Near by stands a bold crag of breccia which conveys a good impression of the easily eroded volcanic material. These trees, with others in the immediate neighborhood, may be easily seen in the bluff which overlooks Lamar

Valley near Crystal Creek on Specimen Ridge.

At Sunset Peak, in the Snowy Range, beyond the limits of the Park, occur one or two outflows of acid lava closely related to the early basic breccias. They have been designated trachytic rhyolite from their resemblance to both these types of rock. Similar bodies occur along the Yellowstone Valley within the Park, where their relations to both the older and the younger rocks are probably much the same, although their geological relations are not always easily made out. In places they are overlain by basalt, but the relative age of the latter is not well determined. In the southern end of the Absaroka Range other bodies of similar mineral composition are recognized, but they occupy very limited areas, and only one occurrence is indicated on the map.

Resting directly upon the early basic breccia comes a series of basalt flows, piled up one upon another till in places they attain a thickness of 1,000 feet. These basalts form the tops of many of the higher summits of the Absaroka Range, appearing as broad, table-like masses with vertical walls. They are remnants of a much larger field. They may be observed on both sides of the Lamar River, where they form the somber escarpments exposed along the west side of Mirror Plateau. From the latter plateau they present a continuous body nearly as far southward as the southern limit of the early basic breccias which terminate in the Signal Hills east of Yellowstone Lake. In determining the relative age of the eruptive masses these early basalt fields play an important part, as they overlie the early series of acid and basic breccias and underlie a somewhat similar series of eruptives designated late acid breccias and flows and late basic breccias and flows. The surface relations of these different eruptive bodies are well shown from Pelican Cone eastward to Lamar Valley (Canyon sheet).

The second series of acid and basic breccias bears the closest resemblance in mode of occurrence to the early series, and Prof. J. P. Iddings has shown that in mineral composition they are much the same. Unlike the early acid breccias, the late acid breccias are not so deeply buried beneath more recent lavas, but form the tops of many high peaks and cover broad areas along the summit of the range, extending from Pelican Cone southward for 30 miles.

The late basic breccias resting upon the more acid outbursts make up the entire southern portion of the Absaroka Range, stretching southward far beyond the limits of the map, and form the top of the Wind River Plateau.

The successive flows and beds of these later basic breccias are nowhere more expressively shown than in the magnificent escarpment found on both sides of the Upper Yellowstone Valley above the Lake. In places these abrupt walls expose a thickness of over 2,000 feet of accumulated volcanic material. The west wall of Table Mountain, with its irregular and turreted edge, is shown in fig. 11, presenting an excellent illustration of this interesting geological structure, which forms a marked physical feature of the Yellowstone Park and the Absaroka Range.

Resting upon the late acid and basic breccias are found numerous flows of dense hornblende-mica-andesite. As this rock withstands erosion better than the underlying breccias, it frequently occurs as the summit rock on several of the higher and isolated peaks of the range. Although covering relatively small areas, these occurrences note a distinct period in the phases of volcanic phenomena in the Absaroka Range, for, so far as can be determined, no breccias followed their outbursts.

Closely related to these andesitic flows are numerous dikes penetrating the breccias. In the region of Sylvan Pass they are especially abundant, representing many types of igneous rocks. While not necessarily contemporaneous, some of them are known to cut the late basic breccias. Owing to the small scale of the map, they are grouped together under the designation Sylvan intrusives.

After the cessation of the volcanic energy which forced to the surface the andesitic and basaltic breccias and flows a long period of erosion followed. Then, with renewed activity, immense volumes of rhyolite were poured out, which converted the depressed basin lying between the surrounding ranges into the Park Plateau. Only a few large vents or centers of eruption of the rhyolite are known, the two principal sources being the grand volcano of which Mount Washburn is now the culminating peak, and the Sheridan volcano, of which Mount Sheridan is the central point. On all sides the long slopes of the preexisting ranges were submerged beneath the rhyolite. It rests against the deeply eroded slopes of the Absaroka Range and buries the outlying low spurs of the Teton Range and Big Game Ridge. On both the east and west sides of the Gallatin Range the rhyolite encircles the sedimentary beds at about the same level. The rhyolites of the Park have been referred to the Neocene period, although no plant remains or invertebrate fossils have as yet been found associated with them. Strong evidence as to their age, however, has been obtained from the Canyon conglomerate exposed in the Grand Canyon of the Yellowstone just north of Tower Creek. Here a few vertebrate remains were collected, which, though fragmentary, were sufficient to enable Prof. O. C. Marsh to determine them as belonging to the skeleton of a fossil horse of Pliocene time. Overlying this conglomerate is a thin flow of basalt, in turn covered by rhyolite, a portion of the great rhyolite field. In the conglomerate careful search failed to find any fragments of rhyolite, proving that none were present in the region when the deposits were laid down. As the basalt, conglomerate, and rhyolite appear in the walls on both sides of the river, it is evident that they were deposited before the canyon was cut.

The Grand Canyon of the Yellowstone is a magnificent and picturesque gorge penetrating deeply into the volcanic rocks of the Park Plateau. An excellent picture of the canyon, reproduced from a large photograph, is shown in fig. 3. It presents on a grand scale a remarkable illustration of recent canyon-cutting, being later than the rhyolites and basalts of Pliocene age. The Yellowstone River, leaving Yellowstone Lake at its broad outlet, flows northward through an open valley for about 15 miles, then suddenly plunges, by two impressive waterfalls, respectively 110 and 312 feet in height, into the Grand Canyon. All that portion of the canyon represented in the picture has been excavated out of the rhyolite, which, however, still forms the underlying rock of the river. The walls of the canyon rise with more or less abruptness 800 to 1,100 feet above the rushing, turbulent stream at the bottom of the gorge, as clearly indicated in the picture.

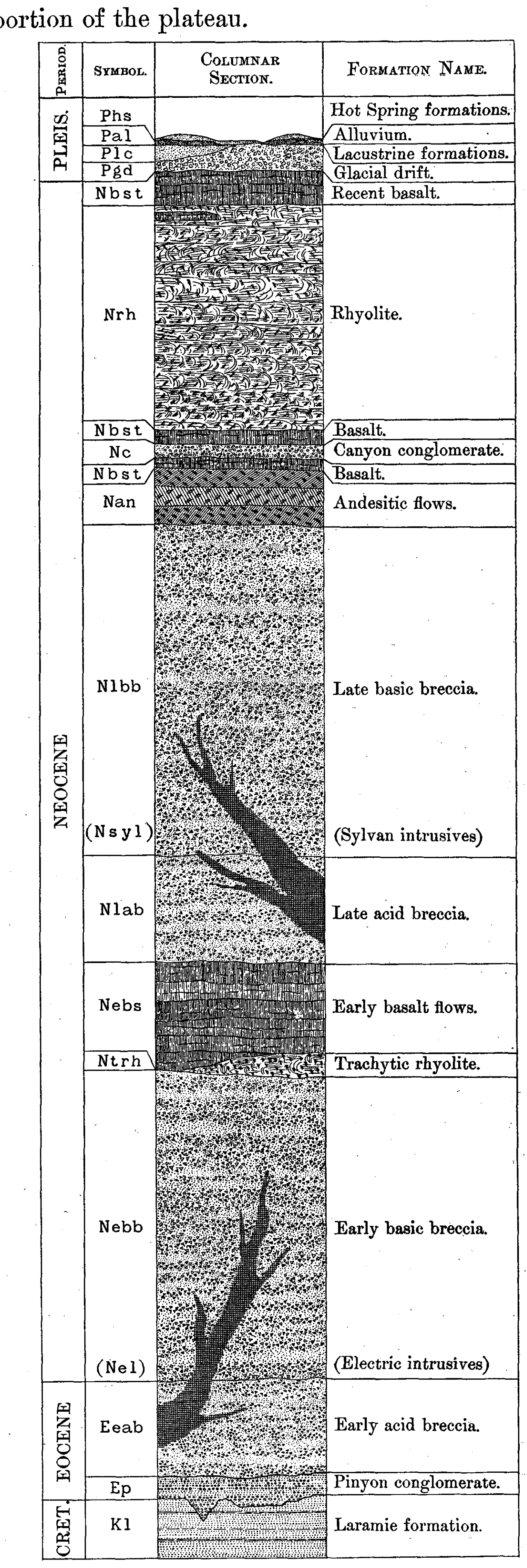
The illustration brings out strongly the relation of the canyon to the Park Plateau, the undulating surface of the rhyolite stretching far southward in a series of monotonous ridges covered with a somber coniferous forest. The vicinity of the canyon has been an active center of hydrothermal energy throughout a long period of time. Much of the exquisite beauty and impressive grandeur of the region comes from the brilliancy of coloring found in the canyon walls. Probably no other area of equal extent in the world affords so varied and vivid a bit of natural color. Hot springs, steam vents, and solfataras are still found along the river bank, remnants of a much earlier and more powerful thermal activity.

The rhyolite walls from the bank of the river to the brink of the canyon have everywhere undergone decomposition by solfataric and thermal agencies. Every product of decomposition may be observed, from nearly fresh rhyolites to rocks completely altered to pure white kaolin. Every shade and tint of red occurs on the canyon walls, from delicate pink and salmon to a vivid Indian red, the prevailing color being a deep orange. Tints of yellow and green are intermingled with those of the prevailing red.

It is this ever-changing condition of rock texture, brought about by these processes of decomposition, that has produced the varied and fantastic forms of rock sculpturing which present so characteristic a feature of the Grand Canyon of the Yellowstone and which have made it so famous throughout the world.

Closely related to the rhyolite, but insignificant in their occurrence, are several small exposures of dacite found on both sides of Snake River, below the mouth of Lewis River (Shoshone sheet). The interest in them consists in the fact that they are slightly more basic than the broad areas of the acid rhyolite, and apparently antedate them in the order of eruption, as on the east side of the river low knobs of dacite are partially concealed beneath the flows of rhyolite forming the slopes of Huckleberry and Wildcat mountains. At one time this dacite was probably completely buried beneath the later rhyolite.

Some thin flows of basalt were forced to the surface before the completion of the rhyolite eruptions, flows of the latter rock overlying the former at several localities, notably along the Grand Canyon of the Yellowstone near Tower Creek. In general the large masses of basaltic lava were poured out after the cessation of rhyolitic activity. These recent basalt bodies occur near the outer edge of the rhyolite plateau, and are well shown about Bunsen Peak and in Falls River Basin. Occasionally they cut the rhyolite in the form of dikes, but in no single instance is there an extrusive flow of basalt in the central portion of the plateau.



GENERALIZED SECTION OF THE IGNEOUS ROCKS OF THE YELLOWSTONE PARK.

In the accompanying illustration there is given a generalized section, in their order of succession, of the extrusive lavas of the Yellowstone Park, from the earliest acid breccias to the top of the recent basalts, as described in detail in the text. At the base of the section the upturned Laramie sandstones are represented in highly inclined ridges, with the Pinyon conglomerate resting horizontally upon them. Over the conglomerate comes the earlier series of acid and basic breccias, followed by the more acid trachytic rhyolite and the monotonously bedded early basalt flows. The latter, which spread over a large area, mark a distinct period in the volcanic history of the region, resting directly upon the early series of breccias, in turn followed by the later acid and basic breccias. The Electric and Sylvan intrusives, which in many ways resemble each other, are represented as penetrating the breccias, the former those of the older series in the neighborhood of Electric Peak, and the latter the later series in the Absaroka Range. The hornblende-mica-andesite flows found capping several of the prominent peaks in the Absarokas are represented as overlying the entire body of breccias. Overlying the andesites come the great accumulations of rhyolite, with the interbedded basalt sheets, both near the top and the bottom, and followed by the more recent basalts, which, as far as can be told, brought to a close the volcanic period in the Park country. The section also brings out the relation of the Pleistocene deposits of still later age to the igneous rocks.

The Glacial epoch.—With the last of the basaltic eruptions volcanic energy came to a close. That it lasted well through the Pliocene period seems probable, but there is slight evidence of its continuation during or after Glacial time. After the dying out of the basalts came the glacial ice. The Park and adjacent mountains constitute such a broad mass of high country favorable to the precipitation of moisture that the entire plateau was in Glacial time buried beneath a heavy capping of ice, constituting one of the largest of the many glacial centers occurring in the Rocky Mountain region south of the continental ice sheet. The ice sheet broadened preexisting drainage channels, opened new waterways, and deepened profound gorges through the rhyolite lavas. Glacial lakes, terminal moraines, kames, and nearly all the phenomena of ice action usually seen in high glaciated regions may be found here.

From the Absaroka Range glaciers were forced down into the Lamar and Yellowstone valleys, thence westward over the top of Mount Everts to the Mammoth Hot Springs Basin. On the opposite side of the Park the ice from the summit of the Gallatin Range moved eastward across Swan Valley, and, passing over the top of Terrace Mountain, joined the ice mass coming from the east. The united ice sheet ploughed its way northward to the lower Yellowstone, where the broad valley may be seen strewn with material transported from both the east and west rims of the Park. This glacier has been named the Yellowstone glacier. Another glacier having its source on the plateau moved southward down the broad valley of the Snake, receiving tributaries from both the Wind River and the Teton ranges. It has been designated the Snake glacier.

An instance of the transporting power and magnitude of these ice fields is shown in the granite bowlder which rests upon the rhyolite near the brink of the Grand Canyon about 3 miles below the Falls of the Yellowstone. This massive block measures 24 feet in length by 20 feet in breadth, and stands 18 feet above its base. It came from the Snowy Range. Fig. 10 is a reproduction from an excellent photograph of this majestic bowlder, which stands alone, hidden in the midst of the coniferous forest, and consequently is rarely seen by travelers, although easily accessible.

In the Teton Range, beyond the limits of the map, small glaciers still exist, remnants of a much larger system, and in the Beartooth Mountains, to the northwest of the Park, névé fields stretch for miles along the more elevated portions.

In the Absaroka Range just east of the Park, but within the forest reservation, a small glacier lies in the amphitheater of the deep canyon of Sulphur Creek, one of the principal tributaries of Sunlight Creek. The glacier flows northward, and is protected from the direct rays of the sun and the warm winds from the south by bold escarpments of volcanic breccia. It has been named the Sunlight glacier, and, although limited in extent, presents all the phenomena of an active glacier.

Since the close of the Glacial period no geological events have brought about any marked changes in the physical features of the Park other than those produced by the active agencies of steam and thermal waters. Although eruptions of lava ceased with the basalt flows, unmistakable evidences of underground heat are clearly visible in the active hot springs, geysers, and solfataras of to-day. These hydrothermal phenomena, which are in a sense evidences of the gradual dying out of volcanic energy, have doubtless been active throughout a long period of time. A proof of the antiquity of the earlier hot-spring deposits may be advanced, based upon the strongest geological reasoning.

At Terrace Mountain, just west of Mammoth Hot Springs, the flat summit is overlain by deposits of travertine, the beds forming the oldest portions of the Mammoth Spring sediments. Lying upon the surface of this travertine on the top of the mountain are found glacial bowlders brought from the summit of the Gallatin Range, 15 miles to the westward, which were transported on an ice sheet across Swan Valley and deposited on the top of the mountain 700 feet above the intervening valley. These bowlders present ample evidence that the travertine is older than the glacier.

Long-continued currents of thermal waters and acid vapors have acted as powerful agents in the decomposition of the igneous rocks. They have produced an indelible impression upon the surface features of the plateau. Large areas of altered rhyolite and extinct solfatara indicate the former existence of still greater thermal activity before historical time. Decomposition of rhyolite by thermal waters and deposition of sediment by siliceous waters are extremely slow processes, judging from what may be seen going on to-day in the different geyser basins. It is evident that to accomplish such changes, even through more intense action than the present, a long period of time was required. This thermal activity is confined almost exclusively to the area of rhyolite eruptions, and it is probable that the few hot-spring localities that lie beyond its limits are closely connected with it by subterranean passages. It is these unrivaled hydrothermal manifestations and their close relations to volcanic eruptions, which are on a far grander scale than those of either New Zealand or Iceland, that have made the Yellowstone Park famous throughout the world.

The thermal waters of the Park may be classed under three heads: first, calcareous waters holding calcium carbonate in solution; second, siliceous waters usually carrying free acid in solution; third, siliceous, alkaline waters rich in dissolved silica.

Calcareous waters, upon reaching the surface, have deposited immense quantities of calcium carbonate, the famous Mammoth Hot Springs being built up almost entirely of travertine. With one or two exceptions, only siliceous waters are found issuing from fissures in the rhyolite. Areas of acid waters may easily be recognized by the whitened and altered appearance of the rhyolite in the region of the vents, and in most instances by efflorescent incrustations of alum and brilliantly colored salts of iron, and not infrequently by the presence of minute crystals of yellow sulphur. These acid waters are characterized by an astringent taste. Alkaline springs present more of general interest than the acid waters, as it is only in connection with the former that the geysers are found. They are the principal waters of all the geyser basins and most of the hot-spring areas. Alkaline waters deposit mainly amorphous silica as siliceous sinter in an endless variety of forms, as shown around the geyser vents and incrustations upon the surface and edges of the hot pools. These sinters form the brilliant white deposits found over large areas in all geyser basins.

While deposits accumulated about the open vents vary greatly in appearance, due to the ever-changing conditions under which they are laid down, it is always easy to distinguish the travertine and sinters from each other by their mode of occurrence. Fig. 5 is a reproduction from a photograph of Minerva Terrace at the Mammoth Hot Springs, and illustrates the building up, one above another, of a series of terraces and shallow basins by the gradual deposition of calcic carbonate. Minerva Terrace is one of the most beautiful of the far-famed travertine deposits, and has for a long period of years poured out a steady flow of calcareous waters.

The Castle Geyser, situated in the Upper Geyser Basin, shown in fig. 4, is a typical example of siliceous sinter deposited about the vent of one of the most characteristic, if not one of the most powerful, geysers in the region. The terrace structure is wanting, the deposition being most irregular, with a tendency to produce botryoidal forms, piled up one upon another in a most confused mass.

After the deposition of the sinter from the siliceous waters, nearly all the remaining mineral constituents, consisting mainly of salts of the alkalies, for the most part very soluble in water, are carried off by running streams. In some instances other mineral substances, such as oxides of iron and manganese, are deposited around orifices of thermal springs, but always in limited quantities. Next to the silica held in solution by these waters arsenic is the most interesting constituent, and is present in sufficient quantity properly to designate them arsenical waters. Arsenic is found in all the geyser waters, in amounts varying from .02 to .25 per cent of the mineral matter in solution. The greater part of this arsenic is probably present in the waters as soluble sodium arseniate. Coating the overflow channels from the hot pools, and incrusting the rocks surrounding the springs, are frequently found arsenical minerals, such as the red and yellow sulphides of arsenic, realgar and orpiment, and scorodite, an arseniate of iron.

The number of thermal springs known in the Yellowstone Park exceeds 4,000. There are about 100 geysers in the Park. Between a geyser and a hot spring no sharp definition can be drawn, although a geyser may be defined as a hot spring throwing with intermittent action a column of water and steam into the air. A hot spring may boil unceasingly without violent eruptive energy; a geyser may lie dormant for years without any explosive action and again break forth with renewed force.

Old Faithful, in the Upper Geyser Basin, may be regarded as typical in many ways of an active geyser. The regularity of its eruptions, the violence of its explosions, and the grace and beauty of its water column, make it one of the most admired of geysers. The illustration given in fig. 6 represents Old Faithful in a state of eruption. The interval between eruptions averages 65 minutes. The period of eruption lasts about 4½ minutes, during which it throws with great power into the air a column of water seldom less than 95 feet and seldom exceeding 130 feet in height. The Giantess Geyser, also in the Upper Geyser Basin, when in action is a far more powerful geyser than Old Faithful, but plays with less regularity, with intervals of nearly three weeks' duration. It has never built up a sinter cone, but, on the contrary, presents a funnel-shaped crater or chasm that gradually fills to the brim, standing for several days with water slightly below the boiling point before explosive action takes place. The crater measures 35 feet across its widest expansion, and is surrounded by a thin crust of laminated sinter, which projects over the sides of the basin. During the most violent eruptions the column of water is thrown to a height of nearly 250 feet. The picture of the Giantess, fig. 7, is a good illustration of a dormant geyser.

Illustrations of both active and dormant thermal springs are well shown in figs. 8 and 9. Chrome Springs, in Hayden Valley, is in a constant state of ebullition, boiling and bubbling with great violence to a height of 2 feet or more. The name is suggested by the color of the water, which is due to finely disseminated sulphur held in suspension by the agitated water. Water slowly flows from the rim of the spring, leaving a thin coating of siliceous sinter around the outside of the pool. Black Sand Spring, in the Upper Geyser Basin, on the contrary, is rarely agitated, and presents the appearance of a quiet pool not unlike a dormant geyser. A thin crust of sinter encircles the edge of the pool in a way seldom seen in other than comparatively still waters. The spring lies at the base of a gravel bench largely made up of black obsidian sands derived from rhyolite rocks.

After the disappearance of the glacial ice sheet the only other geological events which impressed themselves upon the physical features of the Park are the lacustrine deposits and the still later alluvium. The lacustrine sediments attain prominence only on the border of that grand sheet of water, Yellowstone Lake, which at one period, after the melting of the ice, reached its maximum elevation of 160 feet above the present level of the lake. Evidences of such deposits are everywhere to be seen in broad benches encircling the Lake for the 100 miles of its circuitous shore. These lacustrine deposits reach their maximum elevation at about 8,000 feet above sea-level, the present level of Yellowstone Lake being about 7,840 feet above the sea. The alluvium covers most of the river valleys and flood plains, and partially fills the depressions in the undulating surfaces of the rhyolite, as shown by the frequent meadow lands dotted over the plateau. It is mainly derived from the disintegration of the igneous rocks, and consists of gravels, sands, and clays. It is in part older than the hot-spring deposits, and partly younger, when it forms a loose volcanic soil resting directly upon the light-colored sinter.

SEDIMENTARY ROCKS.

BY WALTER HARVEY WEED.

Sedimentary rocks appear in relatively limited areas within the boundaries of the Yellowstone Park, being for the most part buried beneath the lava flows and volcanic accumulations of the region. They present, however, a prominent feature of the geology of the Park, as they form several of the mountain ranges which inclose the Park Plateau, while the small exposures rising above the rhyolite floor give an indication of their former extension over the entire district.

The Paleozoic and Mesozoic rocks of this region embrace representations of all the grand divisions of geologic time from the Cambrian period to the Cretaceous. Leaving out the old Algonkian rocks, whose exact relations to the earliest formations of the Paleozoic age are not known, the conformable series begins at the base with middle Cambrian strata and is capped by beds of the Laramie (Cretaceous) epoch. The total thickness of conformable sedimentary rocks in the Gallatin Range is nearly 9,000 feet, of which less than one-half formed during Paleozoic time. This is the most complete section of the conformable series of the Paleozoic and Mesozoic rocks to be found within the Park borders.

The occurrence of stratified rocks is largely confined to the mountainous regions of the Park. In the northeastern part of the reservation they have been deeply covered by the breccias of the Absaroka Range, recent erosion exposing them in the deeper valleys. In the Gallatin Range, within the Park area the sedimentary rocks dip uniformly to the north and are but slightly disturbed by numerous intrusions of igneous rocks. To the eastward of this range a few exposures are seen, notably at Mount Everts, but to the south no sedimentary rocks outcrop until the Birch Hills are reached. Still farther south they are exposed in the vicinity of Berry Creek, where the great anticlinal uplift of the Teton Range dies out. In the mountainous area about Mount Hancock the Cretaceous rocks attain their most conspicuous development.

STRATA OF THE ALGONKIAN PERIOD.

Sheridan quartzite. — Beds assigned to the Algonkian occupy very limited areas in the Park, and are found at only three localities. They are best exposed upon the slopes of Mount Sheridan, which has furnished the name for the formation. They are made up wholly of siliceous material, and for the most part consist of dense, bluish-white quartzite, weathering with rounded outlines and breaking with a conchoidal fracture. Bowlders of this rock may be seen strewn over a large area, having been transported southward by glacial ice. Similar quartzites outcrop near the shores of the Yellowstone Lake and on Flat Mountain, and at both these localities are overlain unconformably by the Ellis limestone. The third area is an obscure exposure west of Lewis River.

STRATA OF THE CAMBRIAN PERIOD.

Cambrian rocks occur in several of the mountain ranges surrounding the Park and form the prominent terrane at the south end of the Gallatin Range. The strata consist of sandstone, shale, and limestone, the latter constituting the upper member. The basal sandstone rests directly upon the Archean and includes many fragments of gneisses and schists of that age. The system is separable into the divisions known as the Flathead and the Gallatin formations, the two being distinguished by different fossil faunas, a separation that is also defined by lithological differences.

Flathead formation. — This group of beds, which takes its name from exposures in the old Indian pass across the Bridger Range, includes the oldest fossiliferous rocks of the Park and constitutes the base of the Paleozoic section. The lowest bed is a sandstone or quartzite, usually weathering with a reddish or yellow tinge, and is frequently a conglomerate at the base. The shales of the Flathead formation lie above the quartzite, and consist of micaceous and arenaceous material, changing to an alteration of shale and thinly bedded limestone above. The latter are usually glauconitic and frequently conglomeratic with limestone pebbles. These rocks carry fossils of middle Cambrian type. The general lithological character of the formation is quite constant, but the shale and limestone attain somewhat different proportions in the various ranges enclosing the Park. Good exposures occur at the south base of Antler Peak and at several other localities in the Gallatin Range. The beds are also exposed on Berry Creek at the north end of the Teton Range, and in the walls of Slough Creek Canyon in the Absarokas.

Gallatin limestone.—This limestone is named from its typical occurrence in the Gallatin Range, where it forms the upper part of the Cambrian series and has a thickness of 110 feet. It is essentially a series of limestones, more massively bedded than those of the underlying Fathead formation, and forms the first prominent limestone bluff that rises above the Archean areas. The lowest bed is a massive limestone, varying from 50 to 100 feet in thickness, characteristically mottled black and gray, and forming a readily recognizable and persistent horizon. Above this mottled limestone the rocks are more thinly bedded, and carry fossils that are of distinctive upper Cambrian types. Good exposures occur along Soda Butte and Slough creeks in the northwestern corner of the Park, in the Teton Range, as well as in the range from which the limestone takes its name.

STRATA OF THE SILURIAN PERIOD.

The rocks assigned to this period have been recognized in all the Paleozoic areas of the Park, and aggregate about 160 feet of more or less impure and arenaceous limestone. The formation is named from its occurrence in the Jefferson Range west of the Park.

The Jefferson limestone.—This is composed of layers of dark-blue or black limestone alternating with brown granular limestone; the darker rocks possess a strong fetid odor, and are distinctly crystalline. The brown beds are usually markedly arenaceous. Fossils are rare. This horizon is prominent in the mountain ranges of Montana, where the limestone forms bold bluff ledges, and weathers with a peculiarly rough and pitted surface. Good exposures occur in the Gallatin Range at Antler Peak, and in the Teton area in the gorge of Berry Creek.

STRATA OF THE DEVONIAN PERIOD.

The rocks of this period have been recognized in the Park, but are seldom well exposed. The best exposures are in the ranges to the northward, where a typical Devonian fauna has been obtained from the shaly members of the formation.

The Threeforks limestone.—This formation, so named from its fine development near the junction of the three forks of the Missouri River, is in this region generally a massive gray limestone carrying cherty beds, with more thinly bedded limestones that are argillaceous and carry typical Devonian fossils. The Devonian has a thickness of 190 feet.

STRATA OF THE CARBONIFEROUS PERIOD.

The Carboniferous rocks occur in all the mountain ranges of the Park, and form a number of isolated areas that rise above the rhyolite plateau. The series consists of two divisions, lithologically distinct, but characterized by a similar fossil fauna. The rocks constitute the great limestone terrane of the mountains, weathering into rough and rugged peaks that form the most striking scenery of the ranges to the north and west. Contrasted with the softer Mesozoic beds the Carboniferous rocks rise in strong relief, but the separation from the underlying Devonian limestone is not so easily recognized.

The Madison limestone. — This formation is named from the mountain range of the same name west of the Park. It consists of 1,600 feet of limestone of varying color and composition, but characterized throughout by a very uniform fossil fauna of lower Carboniferous types. The formation is separable into two divisions. The lower division, embracing 1,200 feet of beds, consists of bluish, dark-gray, or dove-colored limestones, well bedded, and often weathering in broad flagstones. These rocks are sometimes coarsely crystalline, but normally dense and compact, carrying an abundance of fossils. Impure limestones that might be classed as calcareous shales also occur, but do not form a prominent feature of the series. The limestones are frequently cherty, but this is not an essential feature.

The upper part of the Madison limestone differs quite strongly in general character and appearance from these lower beds. The rocks are cream-colored or white, compact, and quite massively bedded. They weather in rugged and craggy blocks. Near the top the limestones possess a saccharoidal, sandy texture, and are frequently brecciated. These granular limestones carry layers of red or purple earthy magnesian material, which often weather as brilliant red streaks. In the Gallatin Range the reddish beds occur irregularly distributed throughout the limestone, to which they impart a pink color. Fossils from this horizon are all of lower Carboniferous types.

The Madison limestone is the great mountain-forming formation of the sedimentary series, and is the most prominent horizon in all the Paleozoic areas of the Park. The upper valley of the Gallatin River is cut out of these rocks, and they may be seen west of Swan Valley, forming the slopes of Quadrant Mountain. They are also prominent at the northern end of the Absaroka Range, in the spurs of the Teton Range, and east of the fault line that separates the Cretaceous beds of Big Game Ridge from the sedimentary rocks which lie to the westward of Two Ocean Plateau.

The Quadrant quartzite.—This formation consists of white, yellowish, and occasionally pink beds of quartzite, with intercalated beds of drab saccharoidal limestones. The quartzite is generally compact, occurs in beds from 4 to 25 feet in thickness, and weathers in massive blocks. More rarely it breaks into small fragments that form débris slopes, as seen in the Teton Range. The total thickness averages 400 feet in the Gallatin Range. In the southwest corner of the Park it is far less prominent than in the Gallatin, but its resistance to weathering makes it easily recognizable, outcropping beneath the soft red clays of the Juratrias. It takes its name from the Quadrant Mountains in the Gallatin Range, where it is well developed and forms a picturesque bluff encircling the mountain.

STRATA OF THE JURATRIAS PERIOD.

The rocks of the Juratrias period embrace a thickness of several hundred feet of strata whose upper part is characterized by a typical marine Jurassic fauna. The Juratrias is divided into two formations: the underlying Teton formation, and the Ellis formation above. The two are clearly defined upon lithological grounds, the Teton being the probable equivalent of the well-known Red Beds of Wyoming and Colorado.

The Teton formation.—This formation takes its name from the imposing Teton Range. Within the Park it attains its most conspicuous development along Snake River and on Red Creek. At the northern end of the Tetons and in the Gallatin Range, and at other localities, the series is thinner and the beds are very generally concealed by the soft clays into which they so readily weather. The formation consists of the basal sandstone, usually dull-brown in color and more or less calcareous, characterized by rods and rolls of white chert, and carrying interbedded gray limestones containing linguloid shells. Above this basal bed are gray and greenish calcareous shales, often micaceous and capped by a red arenaceous shale that forms a conspicuous part of the formation. This series of beds is capped by a sandstone, generally bright-yellow, with red weathered surface, this rock delimiting the overlying Ellis formation. The thickness is estimated at over 400 feet in the Snake River region and 200 feet in the Gallatin Range.

The Ellis formation.—This formation constitutes a series of fossiliferous beds carrying a Jurassic fauna. The formation consists of two divisions: a lower one, limestone, and an upper one, chiefly sandstone. The formation derives its name from the old military post near Bozeman in the Gallatin Valley.

The limestones of the Ellis formation form its lower part. They are impure, argillaceous, gray limestones and shales, and carry marine fossils at several horizons. Good exposures occur north of Terrace Mountain and at a number of localities in the Gallatin Range.

The sandstone of the Ellis formation overlies the impure limestones just noted. It varies from a coarsely crystalline, quite pure limestone carrying an abundance of fossils—which are, however, generally fragmentary—to a true sandstone, often with conglomerate layers. Owing to its resistance to weathering, this sandstone is often well exposed resting on the slopes above the gray clays of the underlying series.

STRATA OF THE CRETACEOUS PERIOD.

Cretaceous rocks cover large areas along the southern borders of the map. Their aggregate thickness greatly exceeds that of all the Paleozoic strata of this region. The Dakota, Colorado, Montana, and Laramie formations, the four subdivisions of this period, are all recognized, although the distinctions are not always easily defined in the Teton and Wind River ranges. The Livingston rocks of the post-Laramie epoch, which are so greatly developed in the region north of the Park, are not found within its limits. The Cretaceous rocks differ materially from the older sedimentary rocks of the Park, consisting of sandstones and earthy shales with impure limestones, a series whose color, physical characters, and mode of weathering are all in strong contrast to those of the Paleozoic rocks.

The Dakota sandstone.—This formation consists of three members: a basal sandstone that is in part a conglomerate, overlain by sandy clays carrying a thin bed of fossiliferous fresh-water limestone, with a massively bedded quartzite at the top. The conglomerate is the characteristic feature of the Dakota, and wherever exposed throughout the Park region is a readily recognizable horizon. It consists of well-rounded, vari-colored, firmly-cemented, siliceous pebbles, which break with the matrix. This conglomerate forms but a part of the basal sandstone, and its position in the beds varies at different localities. The fossiliferous limestone is filled with fresh-water fossils, and in the Gallatin Range affords a well-determined horizon, but one which has not been recognized in the Teton and Wind River ranges. The quartzite bed capping the formation is a cream-colored, dense rock that breaks into massive blocks in weathering.

The Colorado.—This formation embraces the two subdivisions, Benton shales and Niobrara limestones, aggregating 2,000 feet in thickness in the Gallatin region and exceeding this in the southern ranges. These subdivisions are not recognizable in the Park, as the lithological characters are not sufficiently distinct, and the meager fauna does not warrant separation. The Benton shales consist of finely laminated, carbonaceous shales, seldom well defined, and carrying thin beds of impure sandstones. Good exposures are to be seen on the south face of Electric Peak, at the base of Mount Everts, along the Snake River near Mount Hancock, and on the flanks of the Tetons. Marine fossils and indistinct, vegetable remains characterize the beds. The Niobrara consists of calcareous, argillaceous beds carrying nodules of limestones with occasional thin beds of sandstones. The shales are lighter colored than the Benton, but no line of separation can be established. Moreover, the beds are not well defined from the Pierre shales above.

The Montana.—This subdivision of the Cretaceous includes both the Pierre shales and the Fox Hill sandstones. It covers large areas along the southern part of the map, and occurs also along the northern border at Electric Peak and Mount Everts. The character of the beds varies widely between the northern and southern regions. In the region to the south, drained by the Snake River and its tributaries, the subdivisions of the Montana are poorly defined, the rock consisting mainly of yellowish sandstones. In the northern areas the lower member, Pierre shales, is quite clearly defined lithologically from the overlying Fox Hill sandstones. The Pierre beds consist of leaden-gray argillaceous shales carrying bowlder-like limestone masses. They are distinctly bedded, with well-developed joint planes, producing abrupt cliff faces. The rocks weather readily to plastic clays, and are distinguished by the presence of gypsum scattered through them and covering the outcrops with white efflorescence. Good exposures occur along the Gardiner River and in the bluff face of Mount Everts. In the southern areas these clays are not well exposed and the formation is essentially a sandstone.

The Fox Hill sandstone, the upper member of the Montana, is the predominant stratum of Big Game Ridge. In this area the rocks are yellowish sandstones of varying degrees of hardness. The beds are singularly uniform in character, and carry fossils at several horizons. Along the northern border of the Park the Fox Hill is a series of argillaceous sandy shales and interbedded sandstones. The latter are not persistent beds, but form lenticular bodies, rarely over a few hundred feet in length and from 5 to 25 feet in thickness. This feature may be seen in the face of Mount Everts. In the Gallatin Range the Fox Hill is essentially the same, and usually may be distinguished from the underlying Pierre by its lighter color and greater resistance to erosion.

The Laramie. — This formation consists of light-colored, grayish-yellow sandstones and interbedded shales. The sandstones are often cross bedded, of variable character, and formed essentially of quartzitic material. The shales are argillaceous, and frequently carry considerable carbonaceous material, in places developing into impure coal. In Montana the Laramie contains valuable seams of coal, the formation being the great coal-bearing horizon of the northern Rocky Mountains.

Plant remains occur throughout the formation, and brackish-water fossils have been found at a number of localities. The Laramie forms the summit of Mount Everts and occurs along the northern boundary of the Park, but attains its greatest prominence in Big Game Ridge. The top of the Laramie is probably not exposed in this region, but there is a thickness of at least 600 feet on the summit of Mount Everts, and a still greater development is found to the south.

STRATA OF THE EOCENE PERIOD.

Pinyon conglomerate.—The sedimentary beds referred to this period occupy limited areas and are found only in the southern end of the Park. They have been designated the Pinyon conglomerate from the name of the mountain where they are best exposed. They consist of a series of conglomerate beds with local intercalations of sandstone, the formation resting unconformably upon the upturned Laramie (Cretaceous). The conglomerate is almost wholly made up of pebbles, sometimes as large as 10 inches in diameter, of vari-colored quartzites, carrying occasional fragments of gneiss, and still more rarely a few polished pebbles of porphyry. The quartzite pebbles are mostly light-colored, but are associated with others of widely contrasting shades of red, purple, and green. They are well rounded and polished, and show indentations and sheared surfaces that are the result of pressure and movement. The pebbles are cemented by a matrix of coarse sand, which passes in places into lenticular beds of sandstone. This sandstone is coarse and loosely compacted, and shows strong cross-bedding.

STRATA OF THE NEOCENE PERIOD.

The Canyon conglomerate.—Rocks of the Neocene period occupy still more restricted areas than those of the earlier Tertiary deposits. The Canyon conglomerate is named from its occurrence in the Grand Canyon of the Yellowstone, and consists of thinly bedded conglomerates and gravels, exposed only in stream cuttings along the Lamar River and the Grand Canyon. The beds are light-colored and are composed of well-rounded pebbles of Archean gneisses and andesitic material, derived from the underlying breccias, the latter greatly predominating. At both localities the beds are capped by recent basalt.

DEPOSITS OF THE PLEISTOCENE PERIOD.

Glacial drift.—Glacial drift covers large areas within the Park, but it has been indicated upon the map only in a few conspicuous instances. Gravel, sand, and bowlders of a great variety of crystalline, igneous, and sedimentary rocks are common throughout the glaciated areas. In Hayden and Pelican valleys extensive morainal deposits occur whose clays and loosely cemented sands closely resemble lake beds. The uplands about Yellowstone Lake show extensive accumulations of glacial sands heaped in typical morainal forms. The bowlder moraine at Junction Valley is the most striking example of this variety of drift. The glacial heapings of Swan Valley and the sand hills east of the junction of the Firehole and Gibbon rivers are noteworthy occurrences of drift deposits due to glacial ice.

Lacustrine deposits. — The water-laid and assorted sands, gravels, and clays forming the terraces about Yellowstone Lake are all included under this designation. The beds are not consolidated, and consist of glacial, waterworn material assorted by the lake waters when they stood at much higher levels than they do to-day. These beds are formed of material derived from the adjacent uplands and transported by the outspreading ice sheets of the Glacial period to the shores of the ancient lake.

Alluvium.—The deposits included under this heading embrace the stream gravels, sands, and clays forming the stream bottoms and terrace lands found in all the larger valleys, together with accumulations of débris forming the alluvium cones and fans found at the base of steep mountain slopes. Under this designation there are also found limited areas of diatomaceous earth, generally occurring in connection with centers of thermal waters. These deposits are usually covered by a thin layer of loose soil upon which grasses have grown up more or less luxuriantly.

HOT-SPRING DEPOSITS.

Areas indicated upon the map as hot-spring deposits include calcareous, siliceous, and solfataric areas, both active and extinct. No distinction has been made upon the map between deposits formed by the hot waters and the areas of decomposed and altered rocks brought about by solfataric vapors. The latter are often difficult of precise delimitation, since the altered and unaltered rocks pass into each other by gradual transition. In a few cases solfataric areas which might be indicated on the map have not been discriminated as such; as in the Grand Canyon below the Falls of the Yellowstone a fine example of bleached and decomposed rhyolite, the result of solfataric activity, is colored upon the map as rhyolite. The distribution of these hot-spring areas upon the map of the Park is confined to the rhyolitic areas and their immediate borders.

Calcareous deposits.—These deposits consist of carbonate of lime occurring principally as travertine at several localities in the Park. They attain their greatest magnitude at the Mammoth Hot Springs. Here the hot waters flowing since pre-Glacial time have built up large accumulations of travertine, forming the well-known terraces. The deposits themselves are pure-white, but when freshly formed are often brilliantly colored by the algæ that live in hot waters. This plant life is the principal agent in producing the formation of travertine.

Siliceous sinter.—This is the deposit formed by the hot-spring waters carrying silica in solution. It is a white, opaque mineral occurring in a great variety of forms, consisting of amorphous silica carrying from 3 to 6 per cent of water and small quantities of impurities. It is this sinter that forms the brilliant deposits over large areas in all of the geyser basins of the Park. The geyser cones and the beaded, coral-like incrustations about the springs, as well as the basins of the springs themselves, are built up of this material. The principal sinter deposits of the Park are found at the Norris, Lower and Upper, and Shoshone Geyser basins, and on the shores of Yellowstone and Heart lakes. Siliceous sinter is deposited partly by evaporation, but chiefly through the agency of vegetable (algous) life, whose vivid colors tint the margins of the pools and hot-water streams. Siliceous sinter is not found at the Mammoth Hot Springs, but is very generally present wherever alkaline waters occur. It is also deposited sparingly by evaporation from acid waters carrying free hydrochloric acid, forming spine-covered concretionary pebbles about the borders of the springs and along overflowed channels.

Solfataric areas.—These areas are common throughout the Park. At such places hot vapors rising through the rocks have largely decomposed and altered them. Where the action is complete the hot water charged with sulphuric acid has leached out the soluble constituents and left a white residue of silica. In places where the decomposition is not so complete the rocks are tinted yellow and red by the oxides of iron and their compounds.

The Highland Springs, Crater Hill, Norris Geyser Basin, and other localities furnish striking examples of solfataric rock decomposition. The so-called mud pots and paint pots of the Park belong to this class, as they are formed of clays derived from decomposed rock.

IGNEOUS ROCKS.

BY JOSEPH PAXSON IDDINGS.

By far the larger part of the area covered by the maps of the Yellowstone Park folio consists of igneous rocks. Notwithstanding the broad area thus covered, similar rocks extend far beyond the limits of the Park into Idaho, Montana, and Wyoming, reaching from the highest peaks to the lowest valleys. These erupted masses present marked differences in their field appearance and geological relations, but they all fall readily into one or the other of two groups, extrusive and intrusive rocks, the distinction being based upon their mode of occurrence. The intrusive rocks consolidated beneath the surface; the extrusive rocks reached the surface and formed lava-flows, mud-flows, breccias, and ash-beds. As the extrusive rocks are the most widespread they will be first described.

EXTRUSIVE ROCKS.

The distinctions between the various rocks, indicated by differences of color, are based partly on petrographical characteristics, partly on geological ones, including their order of succession. They might all be treated under the general groupings of andesitic breccias, agglomerates, and lava-flows; basaltic breccias, agglomerates, and lava-flows; rhyolitic lava-flows. They will be described, however, so far as possible, in chronological order, which is also the order followed in the legend on the atlas sheets.

Andesitic and basaltic breccias or agglomerates are subaerial accumulations of rock fragments, dust, and mud-flows. In general they consist of angular fragments of andesite and basalt, of various sizes, cemented together by finer material of the same or of similar composition. In places the petrographical character of fragments and cement is quite uniform through large masses. In most instances the fragments differ considerably in their habit, and somewhat in mineral composition. The breccia for the most part is rudely bedded in slightly inclined layers, and there are few contemporaneous sheets of massive lava. In places intercalated lava streams are more abundant, and sometimes predominate over the breccia. Occasionally the bedding is distinct, especially where volcanic dust prevailed. Thus the more perfect bedding is usually found farther from the centers of eruption. Near these centers the breccia exhibits little or no bedding and the petrographical character is more uniform. In certain localities there are waterworn and well-stratified beds of volcanic material intercalated in the roughly bedded breccia. They are plainly the result of water action, but it is impossible to differentiate them on the map.

Early acid breccia.—The early acid breccia and flows consist of hornblende-andesites and hornblende-mica-andesites for the most part. They are generally light-colored and variegated, less often dark-colored. This oldest breccia frequently contains fragments of gneiss and schist, besides other foreign material that formed the country rock through which the earliest eruptions were forced. This breccia is more or less highly indurated and compacted to a mass which frequently breaks with an even fracture traversing rock-fragments and cement alike. It underlies the early basic breccia, in some cases being clearly delimited from it by strongly contrasted colors and by a chloritization of the ancient surface of the acid breccia. The best localities in which to observe this relationship are: the north base of Sepulchre Mountain, the lower portion of Cache Creek Valley, and a ravine at the south base of Prospect Peak not far from Tower Creek. In places the lower breccia grades into the upper breccia without a noticeable plane of demarcation. Massive contemporaneous flows of acid andesite are seldom observed. The early acid andesitic breccia in the several scattered localities where it is exposed in the valley of Tower Creek and its tributaries consists in part of well-rounded and water-laid pebbles of acid andesite. In places it carries leaf impressions and fragments of wood.

Early basic breccias.—The early basic breccias and flows consist of fragments of pyroxene-andesite, hornblende-pyroxene-andesite, and basalt associated with lava-flows of the same kinds of rock. They are generally dark-colored, mostly chocolate-brown, but sometimes the colors are quite light. They are often distinctly bedded, as in Sepulchre Mountain and in the mountains on both sides of Soda Butte Creek, and in many other localities in the Absaroka Range. The character of the andesite becomes more basic toward the upper portion of the accumulation, where it is often basaltic, passing into the thick layer of basalt sheets directly overlying this breccia. It carries abundant plant remains in some localities, notably those of the Fossil Forest on the eastern side of Lamar Valley. It occurs over a much larger area than the early acid breccia. The greater part of the volcanic mountains in the northeastern portion of the Yellowstone Park is formed of it.

Early basalt sheets.—Early basalt sheets are closely associated with the basic breccia just described and constitute a massive capping to the underlying rocks, in places 1,000 feet in thickness. They are lava-flows that have poured one over another, with an occasional intercalated layer of tuff or breccia. The individual sheets vary in thickness from 5 to 25 feet. The basalt is andesitic in habit, consisting of microlitic groundmass with porphyritic crystals. Its composition varies within narrow limits, the more extreme forms being rather alkaline and carrying leucite with alkaline feldspars. These early basalt sheets form the east wall of Mirror Plateau and cap the high summits of the mountains east of Soda Butte Creek, as well as other heights of the Absaroka Range. There are occasional sheets of basalt in the large body of early basic breccia which are not indicated by a special color on the map. Their petrographical characters resemble those of the more numerous basalt sheets immediately over this breccia. Columnar structure is quite generally developed in these flows.

Trachytic rhyolite.—This occurs in lava-flows intimately associated with the oldest basic breccia immediately north of the boundary of the Yellowstone Park. Within the Park it forms scattered patches of massive lava on both sides of the Yellowstone River. It resembles the rhyolite of the region in general appearance, being lithoidal and glassy, with pronounced flow-structure. It carries phenocrysts of sanidine and plagioclase, but none of quartz. It differs from the rhyolite of the Park in having biotite in small amount. It is also lower in silica. The lithoidal varieties are white to yellowish, reddish, gray, and more or less altered. Chemically and mineralogically the rock is intermediate between trachyte and rhyolite, with the physical aspect of the latter. The rock frequently carries fragments of andesite. The same kind of rock occurs as tuff or breccia associated with the early basalt in several localities, notably at Two Ocean Pass. It is characterized by its light color, abundant sanidines with plagioclase, some biotite, and the absence of quartz. It is mixed with many fragments of andesite and basalt. Its exposures are of very limited extent and are not always indicated on the map.

Late acid breccia.—The late acid breccia and flows resemble the early ones very closely in many particulars. The rocks are light-colored, variegated hornblende-mica-andesites and hornblende-andesite, sometimes with intermingled fragments of basic andesite. In general the late acid breccia is not so highly indurated as the early acid breccia. It directly overlies the early basalt sheets on Mirror Plateau and in the mountains south of Lamar River. Massive lavas are seldom observed, the great body of the formation being subaerial breccia or agglomerate. Its extent is considerable, reaching from Mirror Plateau to Mountain Creek.

Late basic breccia.—The late basic breccia and flows consist of pyroxene-andesites and hornblende-pyroxene-andesites and basaltic andesites, which closely resemble those of the early basic breccia. This breccia directly overlies the late acid breccia just described, grading into it in some places, and in others being separated from it by distinct unconformity. The basic breccia is mostly dark chocolate-brown, and is bedded in almost horizontal layers throughout large areas, notably in the mountains on both sides of the upper Yellowstone River and Thoroughfare Creek. This breccia forms the greater mass of the Absaroka Range in the southern part of the Park, thinning out northward where it caps the summits of the mountains in the vicinity of Mount Chittenden.

Late andesite flows.—The late andesite flows within the Yellowstone Park constitute some of the more prominent peaks in the Absaroka Range: Mount Doane, Mount Stevenson, and Colter Peak. They are light-colored, massive rocks with well-developed columnar structure. They are hornblende-mica-andesite, some having very few ferromagnesian constituents. The light-gray groundmass carries phenocrysts of plagioclase-feldspar, besides those of hornblende and biotite. These andesites appear to have flowed as lava streams over an irregular surface of andesitic breccia. In places they are closely connected with intrusive bodies of similar andesites and have broken up through the breccia.

Basalt.—Basalt in small sheets or flows occurs immediately upon the late basic breccia in a few localities and beneath the great sheets of rhyolite which form the Park Plateau. The basalt sheets are of no great thickness and are frequently columnar. The rock is dark-gray to bluish-black, more or less vesicular to compact, with phenocrysts of feldspar and olivine, and sometimes of augite. Often the phenocrysts are quite small and scarcely noticeable. Its habit is mostly andesitic rather than ophitic. It occurs beneath rhyolite at the southeast end of Mount Everts, at Osprey Falls, and in the neighborhood of Tower Falls and elsewhere. It occurs intercalated with rhyolite in the canyon of the Yellowstone near the mouth of Deep Creek. Larger bodies of similar basalt occur overlying the rhyolite south and east of Bunsen Peak and in Falls River Basin. But no great body of it is found within the Yellowstone Park limits.

Dacite.—Small exposures of dacite occur on both sides of Snake River. Those on the west side are situated along the river bottom, partially concealed by glacial and alluvial deposits. Those on the east side lie several hundred feet up the steep slope of the ridge, near the boundary of the rhyolite flows with the Montana sandstone.

Rhyolite.—Rhyolite constitutes the largest body of igneous rock within the Park. It is almost wholly in the form of massive lava-flows without fragmental breccia, except at Mount Sheridan. A small deposit of rhyolitic tuff underlies it in places, as at Mount Everts and elsewhere. The rock is quite uniform in composition, but varies greatly in physical appearance and habit. It ranges from wholly glassy to a lithoidal or stony texture, and is filled with phenocrysts of quartz, sanidine, and plagioclase in some cases, but is entirely free from them in others. It generally exhibits marked banding or flow-structure, and often carries spheroidal bodies about the size of pebbles, called spherulites, besides hollow ones called lithophysæ. In color it may be any tone of gray, from white to black. The lithoidal varieties are usually light-gray, bluish, yellowish, or purplish. Red, orange, and yellow besides black and white occur in the glassy varieties. Brecciated masses often present a highly variegated appearance. Glassy forms of rhyolite (obsidian, pitchstone, perlite, and pumice) cover a large part of the area of the plateau, forming the upper surface of the rhyolitic lava-flows and sometimes the bottom surface. They often constitute the whole mass of small flows. The most noticeable exposure of obsidian is at Obsidian Cliff. Fragments of black glass are strewn everywhere. Pitchstone Plateau and the plateau west of the Upper Geyser Basin are covered with black and red obsidian. Pumice is much less abundant, and has possibly been carried away in large quantities from the surface by erosion. Lithoidal rhyolite forms the great mass of the rock, constituting the interior portions of the lava-flows, where they were of considerable thickness. It is often highly laminated parallel to the planes of flow, as at Obsidian Cliff. Typical exposures of rhyolite may be seen at the Golden Gate, in the canyon of Gibbon River, and in the lower portion of the Grand Canyon of the Yellowstone. The brilliantly colored part of the Grand Canyon exhibits the effects of alteration and solfataric action within a great body of lithoidal rhyolite which forms the walls of the canyon. Spherulitic rhyolite is widespread, and may be seen at Obsidian Cliff, the Natural Bridge, on the west side of the Yellowstone Lake, at Keppler's Cascade, on the Firehole River, and at many other places. Columnar structure similar to that of basalt is frequent, both in glassy and lithoidal varieties. It is well developed at Obsidian Cliff, in the walls of the Grand Canyon near Deep Creek, in Madison Canyon, and elsewhere.

INTRUSIVE ROCKS.

The intrusive igneous rocks within the Yellowstone Park form a great number of small bodies presenting considerable variation in mode of occurrence and mineral composition.

Outside the limits of the Gallatin Range they are by no means conspicuous, and, because of their restricted areas and wide petrographical range, have not been closely discriminated on the map by differences of color. In other words, rocks of different composition but similar in mode of occurrence have been grouped together. They have been represented in chronological groups, and fall into three periods. The first of these is subdivided petrographically because of the prominence of the intrusive masses belonging to it. The first series embraces porphyries of both acid and intermediate composition, dacite, and andesite.

Andesite-porphyry.—Andesite-porphyry occurs in laccoliths and intrusive sheets and dikes in the sedimentary strata of the Gallatin Mountains. The rocks are light-colored, mostly gray, with lithoidal to finely crystalline groundmass and numerous small phenocrysts of plagioclase-feldspar, hornblende, and biotite. In some cases biotite is wanting. The habit of the rock is andesitic, with phenocrysts varying in amount and size. In composition they range from that of acid andesite to that of intermediate magmas with 61 per cent of silica. Mineralogically they correspond to hornblende-mica-andesite and hornblende-andesite.

Dacite-porphyry.—Dacite-porphry occurs in large laccoliths and as smaller intrusions in the southern end of the Gallatin Mountains, and in two other localities, Bunsen Peak and Birch Hills. It is light-gray to white, with aphanitic to finely crystalline groundmass and few or many phenocrysts. In the Gallatin Mountains the rock has few phenocrysts of biotite and plagioclase, and in places, if non-porphyritic, having the appearance of a felsite-porphyry. At Bunsen Peak it is porphyritic with small phenocrysts of feldspar, biotite, and occasionally quartz. At Birch Hills the phenocrysts are somewhat larger and the porphyry-like habit is more pronounced. In the Gallatin Mountains it is younger than the andesite-porphyry.

Electric intrusives.—The Electric intrusives are situated in the northwest corner of the Park, in the neighborhood of Electric Peak. They occur as dikes and larger vertical bodies, and as a stock or volcanic neck. They possess a wide range in texture and composition, and embrace diorite, diorite-porphyry, and andesite-porphyry, both basic and acid, and also quartz-bearing varieties, besides andesites, dacite, and basalt as intrusive bodies. A detailed description of these rocks has been published as a special paper in the Twelfth Annual Report of the United States Geological Survey, "The eruptive rocks of Electric Peak and Sepulchre Mountain." These rocks are probably in part contemporaneous with, and in part subsequent to, the early basic breccia.

Sylvan intrusives.—The Sylvan intrusives break through the late basic breccias and earlier rocks in the vicinity of Sylvan Pass in the Absaroka Range. Here the rocks form dikes and irregularly shaped bodies. They range from diorite and granite-porphyry to andesite-porphyry and andesite, and vary in composition from basic to acid, from diorite to granite, from basalt to dacite. They are probably contemporaneous with the later outbursts of the late basic breccia and the latest andesitic lava-flows. Owing to the small size of these intrusive bodies and to the great variability in their composition, they are all represented in one color.

Diorite.—On Sulphur Creek south of Dunraven Peak (Canyon sheet) occurs an obscure exposure of fine-grained diorite, composed of plagioclase-feldspar and hornblende. Similar diorites occur elsewhere in the region, notably among the Electric Peak and Sylvan Pass intrusives, but they are too far removed to be correlated with it. The occurrence is of slight importance in itself, the interest lying in the fact that it is the only body of the kind known in the central portion of the Park.

May, 1896.