The Geology and Geography of the Paunsaugunt Region Utah

By HERBERT E. GREGORY

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A survey of parts of Garfield and Kane Counties

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ILLUSTRATIONS

Recent studies have resulted in a revised interpretation of the Tertiary of southern Utah including the Wasatch formation of the Paunsaugunt Plateau. It has been learned that strata described in this paper as "upper Wasatch" or "white beds" in the Wasatch differ from the massive limestone below in origin, make-up and probably age, as well as in color; that the light-colored rocks of Boat Mountain, Whitemans Mesa and prominences along the western rim of the Paunsaugunt are but peripheral remnants of extensive sheets of calcareous-arenaceous-pyroclastic material preserved from erosion by down-faulting and lava caps. For these distinctive beds the name Brian Head formation (Miocene?) has been adopted. (See Gregory, H. E., 1949, Geologic and geographic reconnaissance of eastern Markagunt Plateau, Utah. Geol. Soc. America, Bull. Vol. 60, pp. 969–997.)

THE GEOLOGY AND GEOGRAPHY OF THE PAUNSAUGUNT REGION, UTAH

By Herbert E. Gregory

ABSTRACT

The Paunsaugunt region includes an area of about 930 square miles in Garfield and Kane Counties, south-central Utah. This paper is based on geographic and stratigraphic records compiled in 1922, 1924, 1929, 1932, and 1935–36 and systematic topographic and geologic mapping during 1938, 1939, and 1940. The region described comprises lowlands, highlands, and intermediate slopes that range in altitude from about 6,000 feet to 9,000 feet and are characterized by marked differences in topography, soil, vegetation, water supply, and other factors that affect human occupancy. It is a semiarid country in which the small population is grouped in valleys about the base of the Paunsaugunt Plateau, where water is available for irrigation. Stock raising is the chief industry; some coal is mined, but the exploitation of other mineral resources has proved unprofitable.

Of the sedimentary rock formations the oldest exposed is the Navajo sandstone, of Jurassic (?) age. Above it lie in turn the Carmel, Entrada, Curtis, and Winsor formations, of Upper Jurassic age; the Dakota (?), Tropic, Straight Cliffs, Wahweap, and Kaiparowits formations, of Upper Cretaceous age; the Wasatch formation of Eocene age, the Sevier River (?) formation of Pliocene or Pleistocene age; and strata of Pleistocene and Recent ages. The igneous rocks include basalt, volcanic agglomerate, and ash in craters and lava flows.

Regionally the strata dip northeastward, but their continuity is interrupted by two long faults of large displacement which affect all the sedimentary and igneous rocks and serve to outline the plateaus. Also here and there the beds are broken by faults of small dimensions and bent into low, broad anticlines.

The physiographic history is in general that of the Colorado Plateau, of which the Paunsaugunt region is a part. Two major cycles of erosion are outlined, the later one divided into epicycles. Conspicuous erosion features are the alcoves, pinnacles, and towers developed in the bounding wall of the Paunsaugunt Plateau, the amphitheaters at the heads of the Paria and Kanab Valleys, and the deep, steep-walled canyons within which enormous accumulations of gravel are in process of vigorous removal.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

In their studies of the drainage basins of the upper Sevier River, the upper Kanab Creek, and the upper Paria River, within which the Paunsaugunt (paun-saú-gunt) Plateau is the dominating feature, members of the Wheeler and Powell Surveys in 1872–75 traversed uninhabited country where almost nothing was known of mineral resources, climate, soil, and water supplies. During the 60 years that have elapsed since these original explorations were completed the aspect of the region about the Paunsaugunt Plateau has radically changed. Villages and outlying ranches have been established in the upper parts of the Paria, Kanab, and Sevier Valleys; the possibilities of irrigation, dry farming, stock raising, and lumbering have been thoroughly tested, coal mines have been opened, and prospecting for oil and commercial minerals has proceeded far. The top of the Paunsaugunt Plateau and its forested foothills have been set aside as a national forest and a strip along its rim as a national park. In parts of the region the old-time trails have been converted into highways suitable for automobiles. In the brief time at their disposal, the pioneer geologists outlined the salient geologic features but found no opportunity to examine in detail the sandstones, shales, and limestones that make up a stratigraphic sequence of 4,000 feet, to trace the great faults and minor structural features, or to interpret the erosion forms as stages in geologic history. To supplement the meager geologic information recorded on maps and in texts prepared by the early workers it has seemed desirable to determine the age and physical history of the sedimentary rocks and the lavas and to gain fuller knowledge of the geographic features. Resurveys were especially needed for the correlation of the formations and the crustal movements with those in adjoining regions that have been described. Furthermore, it has seemed appropriate to interpret the geologic and geographic features of a scenic region that each year attracts the interest of thousands of visitors.

THE MAP

The Paunsaugunt region is shown on the reconnaissance topographic maps made by Lt. W. L. Marshall and his assistants, of the Wheeler survey, and by A. H. Thompson and others, of the Powell survey. However, the small scale of these maps (1 inch=4 miles, contour interval, 250 feet) renders them unsuitable for the representation of complex interrelations of canyons, mesas, and cliffs. Likewise the geologic maps resulting from these surveys—the work of Powell, Gilbert, and Dutton—are highly generalized. To depict adequately the drainage pattern, the erosion features, the sequence and distribution of sedimentary and igneous rocks, and the effect of uplift and faulting, more accurate and more detailed maps were needed. For the construction of the present base map (pl. 1) there was available the reconnaissance map of the upper Paria Valley made by Gregory and Moore in 1923, the excellently detailed contour map of Bryce Canyon National Park made by Richard T. Evans in 1928 and 1931–32, and the map of the Powell National Forest made in 1929–30. For areas within the scope of the present report and not covered by existing maps, particularly the lands deeply dissected by the upper tributaries to the Paria River, the Sevier River, and Kanab Creek, new plane-table surveys were made. In combination these topographic maps form the base on which the features of the geologic map (pl. 1) are shown.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the cooperation given by officials of the National Park Service, the Forest Service, and the General Land Office, and by colleagues in the Geological Survey. In providing equipment, supplies, and working quarters and selecting men to operate pack trains, invaluable help was generously given by P. P. Patraw, superintendent, John Davis, assistant superintendent, and Don Jolly, chief ranger, of Zion National Park, and by Frank Rozelle, general supervisor of the Civilian Conservation Corps. The interest shown by the stockmen of Tropic, Cannonville, Henrieville, Hillsdale, Kanab, and Alton, and by such old-time friends as Merle Findley, of the Deer Springs ranch, and Burton McAllister and Malcolm R. Robinson, of the Skutumpah ranch, made it practicable to record geologic details in out-of-the-way places with little loss of time. In particular Maurice Cope, chief ranger of Bryce Canyon National Park, has assisted in planning field work and has given freely of his comprehensive knowledge of local history and geography, supplementing that generously made available by the historian of the Church of Latter Day Saints. The value of my investigations has been greatly enhanced by the resourcefulness and industry of Franz Christiansen, H. B. Wood, Bronson Stringham, J. C. Anderson, and Norman C. Williams, who, serving as field assistants, measured sections and outlined formation boundaries. In addition to their geologic contributions, Mr. Stringham, assisted by Robert Loer, constructed the topographic base map in the Skutumpah-Swallow Park area; Mr. Anderson took many of the photographs here used for illustration; and Mr. Williams rendered skillful service as draftsman.

In preparing the text and maps in the present report full use has been made of the studies relating to the Paunsaugunt and neighboring plateaus by Thompson (1871–1878, 1875), Gilbert (1875), Howell (1875), Dutton (1880), and Richardson (1909). Specific references to these and to papers of wider scope appear at the appropriate places in the text.

GEOGRAPHY

LOCATION, EXTENT, AND ACCESSIBILITY

The area here defined as the Paunsaugunt region is bounded on the east by the upper Paria River and Table Cliffs, on the west by the upper Kanab Creek and the south fork of Sevier River, on the north by a line in the latitude of Red Canyon, and on the south at the crest of the great escarpment described in geologic literature as the White Cliffs. (See fig. 1 and pl. 1.) As thus approximately outlined the region has an average length of 43 miles, a breadth of 24 miles, and an area of about 932 square miles, all in Garfield and Kane Counties, Utah. It includes the top, the bordering cliffs, and the foothills of the Paunsaugunt Plateau—the areas locally known as the "high flats," the "rim," and "below the rim." Essentially the region is a fractional part of more than 5,000 square miles of grazing lands in Utah and Arizona between the High Plateaus and the Colorado River utilized by stockmen and farmers, who make their homes in small villages and isolated ranches where water for irrigation is available. Of this vast area of once unalloted "open range," about 270 square miles on the Paunsaugunt Plateau and its bordering slopes has been reserved as a national forest and 56.6 square miles as Bryce Canyon National Park. The only permanent settlements within or near the Paunsaugunt region are Tropic, Cannonville, and Henrieville, in the Paria Valley; Hillsdale, Hatch, and Panguitch in the Sevier Valley; Alton, in the Kanab Valley; and Ruby's Inn, on top of the plateau. During the tourist season the residences, camps, and hotels in Bryce Canyon National Park are filled to overflowing. The region is remote from population centers in Utah. The three tiny villages in the Paria Valley mark the terminus of a road 90 miles long that reaches the Denver & Rio Grande Western Railway at Marysville; beyond them to the east and south the nearest railheads are in Arizona and Colorado far beyond the Colorado canyons. In the absence of railroads in Garfield and Kane Counties supplies are brought in by trucks, some over roads from Panguitch, 29 miles, and Cedar City, 88 miles from Tropic, but most of them from Salt Lake City, 280 miles distant. In the early days of settlement the remoteness from markets and from social contacts was a serious handicap. For 20 years after their founding the villages at the head of the Paria were reached by a wagon trail from Kanab across the sandflats and gullies at the base of the Vermilion Cliffs and up the bed of the crooked Paria Canyon. Alternative and almost equally difficult routes led from settlements in Sanpete Valley along the Sevier River through Marysvale and Circleville Canyons, across the top of the Paunsaugunt Plateau, and down the precipitous

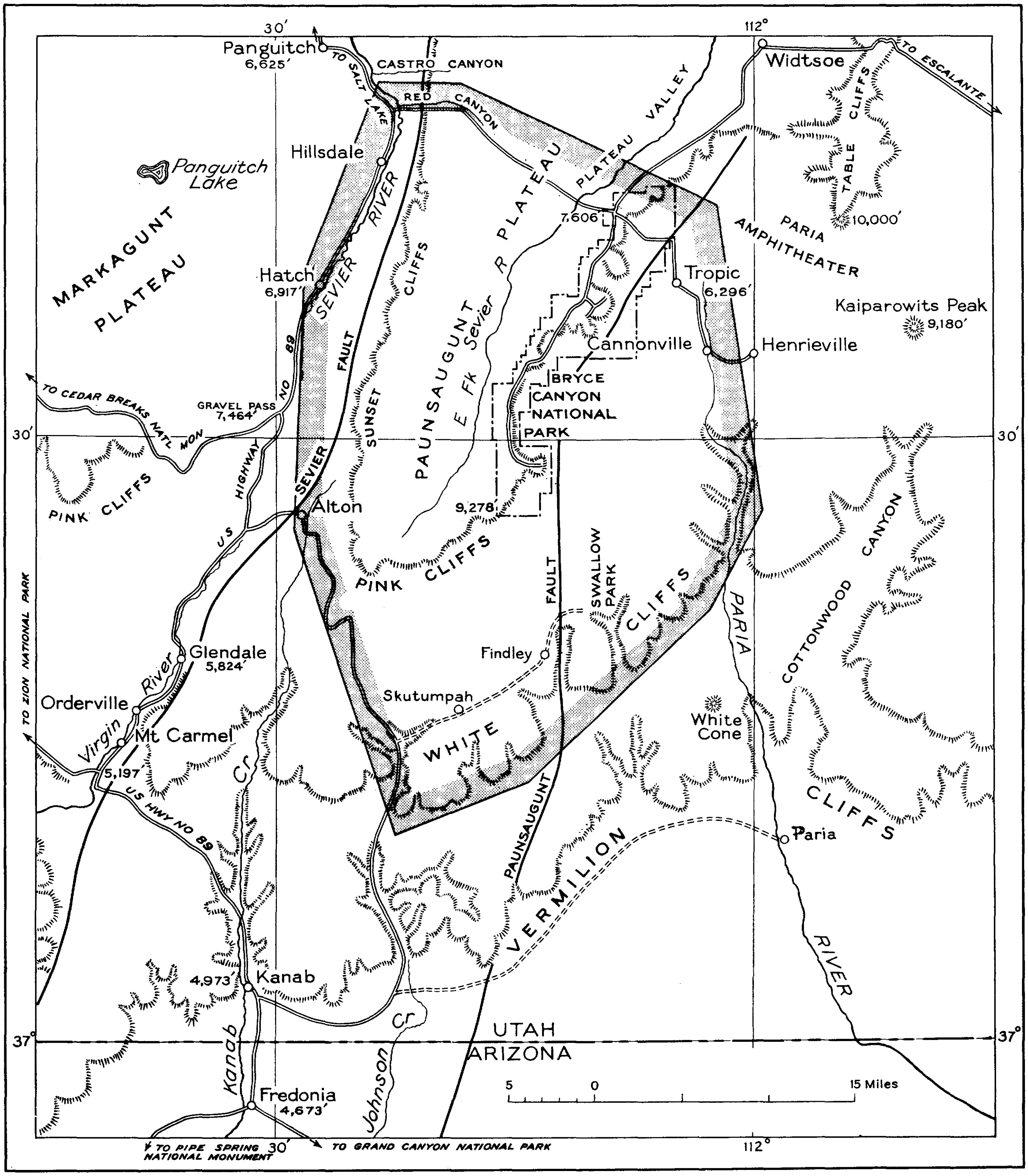


FIGURE 1.—Sketch map of a part of southern Utah, showing roads, settlements, major topographic features, and the location of the Paunsaugunt region.

"dump" over the Pink Cliffs. On the west side of the plateau Hatch, Hillsdale, and the abandoned Asay village were on the rough road that led from central Utah up the Sevier River and over the divide into Kanab and Johnson Canyons. On this road Upper Kanab (Alton) was a "way station." When high water prevented the use of stream beds and when snow blocked the passes the settlements were marooned in some years for weeks at a time. Of late years the handicaps of isolation have been largely removed. The old-time trails and unimproved wagon roads from Panguitch, Cedar City, Kanab, Richfield, and Salt Lake City have been replaced by roads suitable for automobiles, most of them usable even in winter. Federal Highway 89 passes through Hillsdale and Hatch, a branch road reaches Alton and Johnson Valley, and the plateau top is accessible over State Highway 12 through Red Canyon, continued for 18 miles within Bryce Canyon National Park, and a Forest Service road along the East Fork of the Sevier River. A graded highway that replaces the Indian trail and the "dugout" road of early days down the "breaks of the Paria" extends through Tropic and Cannonville to its termination at Henrieville. To reach outlying ranches, the few intermittently cultivated farms, and the temporary stock camps, passable roads from Cannonville have been built to Sheep Creek, Willis Creek, and into Dry Valley and from Alton through Skutumpah to Swallow Park. Elsewhere in the rough lands at the base of the Paunsaugunt Plateau the construction of roads has seemed impracticable. Along the stock trails traverses are necessarily made by saddle horse and pack train. The great cliffs, the towering ridges, and the deep boxlike canyons are accessible only on foot.

HISTORICAL SKETCH

The Paunsaugunt Plateau and bordering lands in Utah are outside the traverses made by the pioneer explorers of the Southwest. The routes of Sitgreaves, 1851–52, of Whipple, 1853–54, and of Ives, 1857–58, lie south of Grand Canyon—that of McComb, 1859, east of Glen Canyon, and those of Frémont, 1842–54, of Gunnison, 1853, and of King, 1867–71 in northern Utah. Of the Spanish missionaries, Escalante in 1776 could have seen the Paunsaugunt Plateau on the skyline 50 miles north of his trail from the Virgin River to Glen Canyon. The routes followed by Jedediah Smith in 1826–27, by Wolfskill in 1830–31, and by other pioneer fur traders and commercial adventurers are far to the west, along the base of the Wasatch and Markagunt Plateaus.

Doubtless adventurous trappers and prospectors visited the upper Paria and the upper Sevier Rivers during the period 1830–50 and in the next decade scouts of the Mormon Church may have reached the south base of the Paunsaugunt Plateau in the course of their "search for fields and pastures." But so far as revealed by written records the Paunsaugunt region remained the undisturbed home of nomadic Utes and Piutes and the hunting ground for Navajos, while in northern, central, and southwestern Utah 86,786 (1870) white immigrants were building homes, pasturing stock, mining ores, and raising crops of grain. For a summary account of the early ecclesiastic, scientific, and commercial exploration of southern Utah west of Glen Canyon see Gregory, H. E. (1945, 1950).

In 1866 Andrus[1] led a military expedition of some 60 men from St. George into Kanab and Johnson Canyons, across the upper tributaries of the Paria, past the Table Cliffs, and on into the valley of the Escalante River. He was in search of the trails by which the marauding bands of Navajos crossed the Colorado River to war with the Utes and Piutes and to rob the weak white settlements of their provisions and livestock. In military fashion, Andrus restricted his report to the task assigned, with scant reference to scenery, natural resources, and possibilities of settlement. A memorial of his expedition is a grave in Everett, Wash., bearing the inscription "Elijah Averett—1866," in memory of one of the few men ever killed by the Indians in southern Utah. That at least the lower Paria Valley was fairly well known in 1866 to the scouts of the Mormon Church is shown by unpublished letters and reports on file in the office of the church historian. For example, a letter from Bishop W. H. Dame, of Parowan, dated August 30, 1866, contains the following:

> On the 22d an exploring party (by order of Gen. Erastus Snow) of 18 men, 4 from Harmony, 2 from Kanarra, 4 from Cedar, 7 from Parowan, 1 from Paragoona, under the command of Adjt. Jos. Fish, left here to pass up Little Creek Canyon [near Paragonah] over onto the Paria, down that stream to Peter Shirt's fort [rock house built in 1865 about 4 miles below the town of Paria], there to join Capt. James Andrus with 44 men, thence to the mouth of Grand River.

It would seem that this party, traversing the valley of the Paria and returning to the settlements west of the great plateaus by a somewhat different route, must have been impressed by the astounding valley landscape about the present Cannonville and the painted walls of the Paunsaugunt Plateau, and as stockmen and farmers they must have made note of the stretches of agricultural land in the Paria amphitheater, of the water available for irrigation, and the vast surrounding lands suitable for grazing. But aside from brief reports on the work assigned, these pioneer explorers seem to have left no records. As one old-timer expressed it, "They were far from home, looking for Indians, not scenery; big cliffs and canyons are everywhere in Utah."

The west and south edges of the Paunsaugunt Plateau seem first to have been explored in 1870. "After the trouble with the Indians had been quieted" an expedition was organized by President Brigham Young to "select suitable places for settlement" in the upper

[1] Andrus, James, manuscript report made available by A. B. Andrus, St. George, Utah.

Sevier Valley, Kanab and Johnson Valleys, and especially to investigate more fully the sites already known on the lower Paria River. Proceeding from Parowan, the party of 43 men including Maj. J. W. Powell, reached Panguitch the first day, Upper Kanab the second, Rock Springs in Johnson Canyon the third, and the Paria River the fourth. On the way they made note of grazing lands and sites for irrigated farms. The report of this expedition as given by A. Milton Musser (1870), is the first published description of the region about Panguitch, Hatch, Alton, Skutumpah, and of the Vermilion Cliffs east of Johnson Canyon. Bishop A. Milton Musser writes:

Sevier Valley, at and below Panguitch Town, is wide, fertile, and beautiful and is capable of sustaining large numbers of industrious people.

On Tuesday p. m. we reached the upper Kanab, where there is an abundance of grazing facilities, also excellent timber and rich soil. From where we nooned on Tuesday (at the last crossing of the Sevier, a most delightful spot) to near the rim of the Great Basin, we passed over and through a paradisaic country, which was very much admired by every member of the party. It is a valley gently undulating, covered with grass, and dotted with springs and "seeps," which form a small stream that courses through the valley and empties into the Sevier River. Timber is abundant and so easy of access that teams can be driven amongst it without roads being made. Near the rim on this side we passed through grassy vales which border the headwaters of one of the principal tributaries of the Rio Virgen.

On Wednesday we passed over a rough unworked road (excepting a few hours' actually needed work done by Bishop Levi Stewart and his brethren of this place) down the upper Kanab Valley over sandy mounds and down through a portion of Scutempah Valley, and stopped for the night by Rock Springs, distant from the mouth of the valley or canyon some 3 miles. The latter part of this day's drive was through canyonlike vales with high walls of white and red sandrock. Here and there, too, we would pass isolated rocks or cliffs of singular castle- and fortification-shaped resemblances.

Except for these meager reports by Andrus and Musser the lands about the Paunsaugunt Plateau were first described not by the men who knew them but by strangers from Washington. Maj. J. W. Powell, the original explorer of the Grand Canyon of the Colorado, initiated the investigation that resulted in maps and descriptive reports covering the valleys and the plateaus of southern and central Utah. In a preliminary reconnaissance Alvin H. Thompson (1871–78), chief geographer of the Powell Survey, made the first scientific traverse of the Paunsaugunt region and of the lands eastward to the Henry Mountains. From his headquarters at Kanab, Thompson in 1872 ascended Johnson Canyon, crossed the many deeply trenched streams that rise in the plateau walls and borders of Bryce Canyon National Park, and reached the Paria River at the mouth of Yellow Creek. Proceeding up "Table Cliff Creek" (Henrieville Fork of the Paria), he continued through Escalante Valley and over the Waterpocket Fold to the Colorado River near Hite. In the reports of this adventurous traverse the salient geographic features of south-central Utah were for the first time described. Thompson outlined the relations of the White Cliffs, the Pink Cliffs, the Paunsaugunt Plateau, and the great northern wall of the Paria amphitheater, which he called "Table Cliffs, 3,000 feet above us, its face a succession of inaccessible precipices and steep, broken tree-clad slopes."

Thompson (1875, pp. 134–136) describes the region along the south base of the Paunsaugunt Plateau in the following terms:

Six miles from camp No. 2 [in Johnson Valley] we entered a narrow canyon, cut through the White Cliffs. At the entrance it is half a mile wide, with vertical walls 1,000 to 1,200 feet high, often beautifully arched in bas-relief. As we ascended, the canyon narrowed to 50 feet, its floor rose rapidly, the walls grew lower, and at the end of 3 miles we came out into the open country, near the Mormon settlement of Skoompa [Skutumpah], having risen 1,098 feet above Kanab settlement. Here we made a camp and established a topographic station on the summit of a near hill.

Toward the south, between Kanab and Skoompa, the country is traversed by two lines of cliffs—the Vermilion and White—having a general trend N. 55° E., and presenting bold, vertical faces from 1,200 to 1,500 feet high. Through these cliffs but three passes were known between the Virgen and the Paria Rivers, a distance of 110 miles—the first, that known as the Long Valley Pass [Gralel Pass]; the second, up the Kanab Creek; the third, the route which we followed. From the very brink or crest of these cliffs, the surface of the country slopes back at an angle of about 2°, so that the general appearance is that of terraces, with escarpments fronting southward and summits sloping toward the north. Scattered over these declivities are fields of loose sand, with continually changing boundaries, in some places burying trees and rocks, in others heaped in huge drifts.

North of our camp, and 8 miles distant, the south end of the tableland known as the Pauns-águnt Plateau rose to an altitude which we determined to be 3,295 feet above our camp, or about 9,200 feet above sea level. The eastern boundary of this plateau is a line of cliffs, having a general trend N. 45° E. These cliffs show in the distance a beautiful pink color and, for the upper 2,000 feet, present bold, perpendicular faces, with here and there steep rocky slopes. From the foot of these slopes and vertical faces long, narrow ridges run out on the plain below. Between these ridges are many beautiful valleys, but probably the whole country is too much elevated for permanent settlement.

From camp No. 3 to camp No. 4 our course was northeast. Camp No. 4 was in a beautiful grassy valley, half a mile wide and 6 miles long, lying between two cedar-covered ridges. At its foot, a small lake [Adair Lake] stands at the entrance of a narrow canyon that drains the valley [Swallow Park] and cuts its way through both the White and Vermilion Cliffs, furnishing, as we determined by exploration, another practicable route through these escarpments to the valley connecting the Kanab and Paria settlements.

From camp No. 4 to camp No. 5 our course was nearly northeast. For 4 miles we passed over low grass-covered ridges, when we came to the brink of a basinlike region, drained by the headwaters of the Paria River. The extension of the White Cliffs to the east forms the southern boundary of this basin, and the Pink Cliffs (forming the eastern face of the Pauns-âgunt Plateau and here swinging in a great curve to the north) the northern.

In the scientific exploration of the Paunsaugunt region, Thompson was followed in 1872 by Lt. W. L. Marshall, Edwin E. Howell, and Grove Karl Gilbert, members of a survey (1870–76) under the direction of Capt. George M. Wheeler, U. S. A. For an account of the work of the Wheeler Survey and its relation to that of the Powell Survey, see Gregory (1945, 1950).

Marshall mapped the "Plateau Valley" along the East Fork of the Sevier River, the rim of the Paunsaugunt Plateau, and the lands about the head of the Paria Valley. Howell, who traversed the Utah plateaus southward for 100 miles, studied the Pink Cliffs as exposed at "Last Bluff" [Table Cliffs, the southern escarpment of the Aquarius Plateau] and examined hurriedly the rock outcrops along the middle Paria River. Gilbert likewise included in his reconnaissance surveys a brief study of the upper Paria Valley. In continuation of the investigation begun by Howell and Gilbert, Capt. C. E. Dutton, U. S. A., extended his investigations of the Utah highlands (1875–77) to include the Paunsaugunt, Aquarius, and Kaiparowits Plateaus.

As shown by their published reports scientists of the Wheeler and Powell Survey gave scant attention to the region that includes the western and southern parts of the Paunsaugunt Plateau and the drainage basin of the Paria River. These regions were difficult of access and seemed to include few features not more fully displayed in parts of Utah already mapped, and the conditions under which their work was done afforded little opportunity for detailed investigation. Thus Dutton (1880) writes: "The Paunsaugunt * * * is exceedingly simple in its structure and presents very little matter for special remark." Regarding the cliffs and canyons tributary to the Paria, he facetiously remarks: "To cross such regions except in specified ways is a feat reserved for creatures endowed with wings."

Gilbert wrote (Gregory and Moore, 1931, p. 132):

The observations that form the basis of these reports were hurried in the extreme. The writer for the most part accompanied field parties which were especially equipped for rapidity of movement and were crowded to the utmost. Moreover, in a country almost unmapped the demand for geographical information was more urgent than for geological, and all plans and routes were accordingly and with propriety shaped to give the topographer the best opportunities consistent with rapidity of movement, while the geologist gleaned what he could by the way. * * * Still I am far from counting my labor lost, for the best presentations that have been given of western geology are not free from error, and I certainly have most honorable company in my imperfection.

Despite their acknowledged limitations, the pioneer surveys of the Paunsaugunt region faithfully outlined the more prominent geographic and geologic features of a region that was previously unknown. As aids in more recent investigations particular value may be assigned to the hachure map by Marshall, the contour map by Thompson, the stratigraphic section at the Table Cliffs measured by Howell, and the diagrams of the Sevier fault by Gilbert. From these early surveys came the first knowledge of the landscapes that give the Paunsaugunt Plateau its high rank among regions famous for their scenery. A pencil drawing by John E. Weyss, reproduced in the reports of the Wheeler Survey, is the first known illustration of the strikingly picturesque erosion remnants of Bryce Canyon National Park, and a characteristically excellent photograph by J. K. Hillers, published in the report by Dutton, is the first known picture of the Pink Cliffs. (See fig. 24.) In his notebook (1872) Gilbert wrote, "up the Sevier [East Fork] a few miles and then to the left a few miles more until we came suddenly on the grandest of views. We stand on a cliff 1,000 feet high, the 'Summit of the Rim.' Just before starting down the slope we caught a glimpse of a perfect wilderness of red pinnacles, the stunningest thing out of a picture."

Dutton's description (1880, p. 254) of the Paria amphitheater and the rock sculpture in Bryce and Campbell Canyons is a recognized classic in geologic literature:

The glory of all this rock work is seen in the Pink Cliffs, the exposed edges of the lower Eocene strata. The resemblances to strict architectural forms are often startling. The upper tier of the vast amphitheater is one mighty colonnade. Standing obelisks, prostrate columns, shattered capitals, panels, niches, buttresses, repetitions of symmetrical forms, all bring vividly before the mind suggestions of the work of giant hands, a race of genii once rearing temples of rock, but now chained up in a spell of enchantment, while their structures are falling in ruins through centuries of decay.

Further geographic knowledge of the Paria Valley was recorded on field plots of the General Land Office as the result of surveys by T. C. Bailey in 1876 and 1877, and beginning with the surveys that resulted in setting aside the top of the Paunsaugunt Plateau as part of the Sevier National Forest (1905) (now the Powell National Forest), members of the Forest Service have compiled topographic maps on which their studies of the water supply and plant life are recorded. Since 1928, when a narrow strip along the rim of the Paunsaugunt Plateau was set aside as the Bryce Canyon National Park, scientists of the National Park Service have continued the biologic studies begun by the Forest Service and for the area included in the park the United States

Geological Survey has constructed a large-scale topographic map (Bryce Canyon National Park, Utah, issued in 1939).

In recent years the investigations of southern Utah made by the Wheeler and the Powell Surveys during the decade 1870–80 have been resumed by the United States Geological Survey. The Jurassic formations of the Parunuweap and Paria Valleys have been studied by Gregory and Noble (1923), and comprehensive reports have been prepared for the Kaiparowits region (Gregory and Moore 1931) and the Zion Park region (Gregory 1950).

The present report is supplementary to these studies and extends geologic mapping of southern Utah to cover the Paunsaugunt Plateau. As basic data for the report geographic observations and stratigraphic sequences were recorded in 1922, 1924, 1929, 1932, and 1935–36, in connection with studies in adjoining areas. Systematic mapping was carried on during 1938 and 1939, and the manuscript was written in 1939–40.

TOPOGRAPHIC OUTLINE

The Paunsaugunt region—the top and the bordering slopes of the Paunsaugunt Plateau—is part of the vast Colorado Plateaus province; its larger topographic features are duplicated many times in the 100,000 square miles of rugged landscape on both sides of the Colorado River. As elsewhere in southern Utah and northern Arizona, the relief is strongly tabular; the region seems made up of terraced plateaus, vertical cliffs, angular mesas, and straight-sided canyons—all impressive alike for magnitude, color, and architectural form. But in contrast to the Kaiparowits region, the San Juan country, and the Navajo country, where the prevailing tabular forms are interrupted by monoclinal ridges, structural domes, and huge masses of igneous rocks, in the Paunsaugunt region folded strata are rare and local and igneous rocks are represented only by small areas of lava in Red Johnson and Tenney Canyons and along the Sevier River and a short ridge of agglomerate at the base of the Sunset Cliffs.

Essentially the Paunsaugunt Plateau is a pile of flat-lying or slightly tilted sedimentary rocks that lies between two faults. Along the west face of the plateau the effects of movements on the Sevier fault are topographically recorded in the Sunset Cliffs. Along the east face, where the cliffs produced by displacement along the Paunsaugunt fault have been largely removed by erosion, a fragment of the upthrown block remains as the spectacular Table Cliffs. Along the south face of the plateau, between the two great faults, the continuous line of lofty cliffs records the vigorous headward erosion of streams tributary to the Paria River and Kanab Creek.

The Paunsaugunt region lies between 6,000 and 8,000 feet above sea level. The average altitude of the plateau top is about 8,200 feet; from an altitude of 7,700 feet on the western approach road to Bryce Canyon National Park, it increases southward to 9,000 feet and attains its culmination of 9,105 feet at Rainbow Point, on the south edge of the plateau. On the south and east flanks of the Paunsaugunt Plateau slopes below the rim begin at about 7,000 feet and with decreased gradient continue downward to about 6,000 feet, where they merge into the flatter surface of stripped beds of rock. On the plateau top changes in altitude are gradual, but below the rim gentle slopes are conspicuously rare; from general levels rock terraces rise step above step, and canyons reach far below. The region comprises two areas of strongly contrasted topography that meet in a line that marks the rim of the Paunsaugunt Plateau and the top of the bordering cliffs. Back from the rim, the plateau surface is generally flat land traversed by broad, shallow valleys. Below the rim, the landscape is a maze of canyons, steep-sided gullies, ridges, mesas, and benches. Because the topographic features have been developed in nearly flat-lying sedimentary rock in a region where erosion is vigorously active, the gentle slopes and sweeping curves that make up the artist's "line of beauty" are conspicuously lacking. In their place are horizontal lines, vertical lines, and oblique lines that meet at angles and along their trends are offset many times. Instead of the rounded hills, the gently inclined valley sides, and the broad, flat river bottoms of more humid regions, are flat tables, vertical walls, and lowlands cut into angular forms that differ from their larger companions only in size. Even the smaller erosion forms are prevailingly angular.

Except for the tiny Adair Lake and a few small meadows and swamps, the region is thoroughly drained by well-defined channels. Water that falls on the top of the Paunsaugunt Plateau is carried northward by the East Fork of the Sevier River; that which falls on the west edge enters canyon branches of the South Fork of the Sevier River, which after receiving supplies from the East Fork and from other streams in central Utah continues westward to Sevier Lake, where it is lost in the arid Great Basin. The streams on the east and south sides of the plateau are tributaries to Kanab Creek and the Paria River, which reach the Colorado River. In their courses through the Paunsaugunt region the Kanab, the Paria, and both forks of the Sevier River are perennial. Likewise the major tributaries to these streams have permanent water in their upper courses, and scores of tributaries of the second and third order flow short distances from their source. In most of the smaller streams water from springs, seeps, and swampy lands is insufficient to maintain permanent flow along the entire valley floor. For long stretches in some valleys and short stretches in most valleys the streams are intermittent: they flow in places where impervious bedrock lies near the surface but disappear in stretches of valley-bottom sands and become through-going only in response to seasonal rains and local showers. In valleys where springs are lacking the streams are ephemeral; for a few hours after heavy flood their channels carry swiftly flowing, muddy water. Between floods "dry valleys" show only sand beds, boulders, and bare rock.

The minor topographic features and the behavior of streams show the influence of the semiarid climate. The soil, native vegetation, and human occupations likewise reflect the control exercised by precipitation and temperature, which range widely in amount, time, and place. There are no large areas of sand dunes, no desert stretches of salt and alkali; thick soil is restricted to valley bottoms. Much of the plateau top is forested, and in favorable places below the rim vegetation is dense, but generally it is sparse and in few places sufficient to conceal the rocks. Many canyon walls, the faces of cliffs and mesas, and square miles of rock benches and terraces are essentially devoid of plant life.

As an area of scenic interest the Paunsaugunt region has few equals. From the southern rim of the Paunsaugunt Plateau the land descends southward in an orderly succession of terraces from the Pink Cliffs across the White Cliffs, the Vermilion Cliffs, and the "Chocolate Cliffs" to the Kanab Plateau and the rim of the Grand Canyon. Westward from the crest of the Sunset Cliffs the broad valley of the upper Sevier River is in view, and beyond it the tilted surface of the Markagunt Plateau, spotted with lava flows and volcanic cones. Eastward near at hand is the Paria amphitheater, walled in by the towering cliffs of the Paunsaugunt and Aquarius Plateaus. Beyond this flat land is a region of extreme ruggedness—an unparalleled array of gorges, plateaus, mesas, and ridges on both sides of Glen Canyon. Everywhere the landscape in view is colored in distinctive shades of red, yellow, brown, and gray, in broad bands that continue around headlands, along cliff faces and canyon walls. Once difficult of access, the marvelous architecture and coloring of the Pink Cliffs may be examined at leisure on walks of a few hundred yards from the highways and hotels in Bryce Canyon National Park.

CLIMATE

GENERAL CONDITIONS

In the upper Paria Valley instrumental records, for some years lacking or incomplete, have been kept by volunteer observers since 1889 at Tropic or the closely neighboring Losee and Cannonville; in the upper Kanab Valley at Alton (including Ranch, 1902–15) since 1902; in the Sevier Valley at Panguitch since 1904; at Hatch for the period 1916–31; at Widtsoe from 1912 to 1930; and on the top of Paunsaugunt Plateau in Bryce Canyon National Park since 1933. The records for these stations are obviously too short and fragmentary for general climatic studies and give no clue to cycles of climate. However, the records for Tropic, Bryce Canyon, Alton, and Panguitch suffice to indicate the nature of the rainfall and temperature in the Paunsaugunt region and when combined with records for other stations in Washington, Garfield, Kane, San Juan, Emery, and Grand Counties present all the climatic factors that determine the extent to which irrigation farming and stock raising may be developed in southern Utah. As discussed somewhat fully elsewhere (Gregory and Moore 1931, pp. 14–23, and Gregory 1938, pp. 15–21), the climate of large areas east and west of the canyon of the Colorado is characterized by such fluctuations in time and place as to produce a group of local climates.

As in other parts of southern Utah, the climate of the Paunsaugunt region is only generally controlled by latitude and prevailing winds. In a broad sense cyclonic storms are favorable for producing rain, and altitude and seasonal changes determine temperature, but as factors that govern the amount and time of rainfall and the degree and range of temperature, these major controls are outranked by the local winds, the daily distribution of the sun's heat, and the position and form of topographic features. Especially is the great diversity in topographic expression reflected in the equally great differences in climate. There is some basis for the popular saying that "Garfield and Kane Counties have no climate, only weather," and it might be further said that the plateau tops, the adjoining lowlands, the opposite sides of plateaus, two adjoining valleys, and even opposing canyon walls may have weather sufficiently different to determine agricultural practice.

Though the stations are less than 30 miles apart, differ little in altitude, and are both on the west side of the Paunsaugunt Plateau, Alton (altitude 7,000 feet), at the head of the Kanab Valley just below the cliffs of the plateau, has an average annual rainfall of over 20 inches—heaviest in January, February, and March—a mean annual temperature of 43.2°, minimum temperature of −20°, a growing season of 84 days, and a prevailing southwest wind; but Panguitch (altitude 6,700 feet), on the flat lands of the Sevier Valley, has an annual rainfall of less than 10 inches—heaviest in July, August, and September—an average annual temperature of 42.2°, a minimum temperature of 32°, a growing season of 80 days, and a prevailing northwest wind. Though at greater altitude, Alton has a climate favorable for fruit trees and specialized garden crops that are not successfully grown at Panguitch or at Hillsdale and Hatch. Because it is situated at the eastern base of the Paunsaugunt Plateau, Tropic (altitude 6,296 feet) has but half the rainfall of Alton, though more than Panguitch, a higher maximum and mean annual temperature than either Alton or Panguitch, but a minimum temperature as low as any other station in southern Utah.

The effect of topographic position in the control of climate is well shown by the records at Tropic (altitude 6,296 feet), near the head of the Paria Valley, and at Bryce Canyon (altitude 8,000 feet), 5 miles distant, on the flat top of the Paunsaugunt Plateau. Generally at Tropic the summers are long and hot and the winters fairly short and cold, and the yearly, monthly, and even daily rainfall varies widely. At this station temperatures of 100° and 101° are recorded for June, July, August, and September, and −9° to −32° for November, December, January, and February; the mean annual rainfall (12.62 inches) is made up of monthly means of 0.00 to 1.85 inches. The prevailing wind is north. At Bryce Canyon an uncomfortably cold season that extends from November to March is followed by months of delightfully cool weather. The mean monthly temperatures range from 8.2° (January) to 64.5° (July); and the daily temperatures from 86° to −20°. The annual precipitation at this station is 18.41 inches and except for the relatively dry months, April and October, is fairly evenly distributed. The prevailing wind is southwest.

Snow falls each year at all stations in the Paunsaugunt region. On the lower lands in the Sevier and Paria Valleys about Hatch and Hillsdale, Tropic and Cannonville, 5 to 20 inches of snow is to be expected during the period November to March. For 25 years at Alton the mean annual amount received during this same period was 75.6 inches. On the plateau tops at Bryce Canyon the measured annual snowfall averages 103 inches and is made up of snows received during all months of the year except July, August, and September. For nearly half a century after settlements had been established in Garfield County the roads over the Paunsaugunt Plateau and across the Gravel Divide were passable only in exceptional years without clearing the drifts from the "jumpoffs" and the "dugways," and during years of heavy snowfall Alton, Tropic, and Cannonville were inaccessible for weeks at a time. On the recently constructed Federal highways snow plows intermittently clear the way for winter automobile traffic. Except for the occasional use of sleds most of the branch roads are abandoned. Because of anticipated snowfalls the hotel at Bryce Canyon National Park receives guests only from June 1 to October 1, and the periods of grazing on the national forest are set at May 21 to October 21 for cattle and June 15 to September 30 for sheep. During December, January, and February of most years the forest rangers and game wardens make their rounds on skis.

To the farmers and stockmen of the Paunsaugunt region these snowfalls are an extremely valuable asset. They supply most of the water that percolates into the soil and feeds the springs that in turn maintain the flow in streams. Because of the snow, tributaries to the Paria, Kanab, and Sevier Rivers provide some water for irrigation in seasons when rain is lacking. On the plateaus and in high-level valleys water from melting snow favors the growth of herbs and grasses. Generally the value of grazing lands is proportional to the amount of snow.

Like other parts of southern Utah the Paunsaugunt region is a "land of open skies." At all stations clear days exceed cloudy days in number. During 7 years Bryce Canyon National Park, on top of the Paunsaugunt Plateau, recorded an annual average of 233 clear days, 67 partly cloudy days, and 65 days with overcast skies. Likewise at most places below the plateau rim clear days are much more numerous than cloudy days, but at Tropic and Alton partly cloudy skies are more common than clear skies. In some years during September clouds fill the canyon.

PRECIPITATION

The precipitation in the Paunsaugunt region is characterized by great annual, seasonal, and daily fluctuations related but slightly to altitude. Tropic (altitude 6,296 feet) receives 11.55 inches of rain each year, and Bryce Canyon (altitude 8,000 feet) 18.82 inches; but because of their topographic setting Alton (altitude 7,000 feet) receives more rain (20.86 inches) than Bryce Canyon, and Panguitch (altitude 6,700 feet) receives less (9.67 inches) than Tropic. (See fig. 2, *a*.) Though lying at nearly the same altitude, Widtsoe, on the plateau top, and Hatch, in the Sevier River Valley, receive about half as much rain as Alton. At these stations the range in annual rainfall, even in successive years, is remarkably great—at Alton 10.77 to 34.85

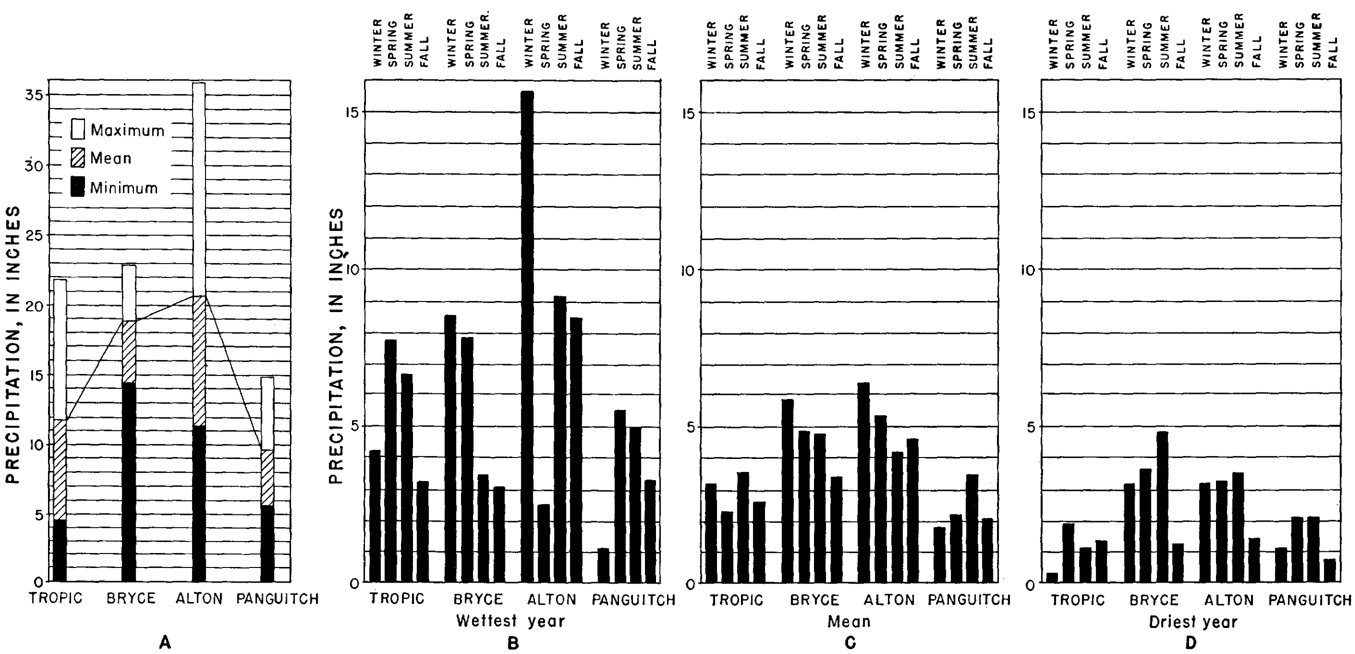


FIGURE 2.—Precipitation at stations in the Paunsaugunt region: a, total and mean annual; b-d, seasonal. The measurements are for the period of record.

inches, at Tropic 4.51 to 21.78 inches, at Bryce Canyon 14.41 to 22.93 inches, at Panguitch 5.97 to 14.93 inches. Of 23 years at Alton the precipitation in 11 years was less than 15 inches and in 12 years more than 20 inches. During 26 years at Tropic the annual rainfall was more than 13 inches for 9 years and less than 7 inches for 6 years. At Tropic 14.97 inches of rain fell in 1905 and 21.78 inches in 1906, as compared with 5.77 inches in 1904 and 6.18 inches in 1903. At this station one of the wettest years (1909, 14.69 inches) was preceded by one of the driest years (7.47 inches). At Alton 28.40 inches of rain fell in 1916 and but 12.22 inches in 1917. At Panguitch the driest year of record (1926) was preceded and followed by years with rainfall considerably above normal. At Bryce Canyon the driest year of record (1934) was followed by the wettest year. The incomplete records show that drought was general in the Paunsaugunt region in 1902–04, 1916, 1918, and 1922–24 and that exceptionally great amounts fell during the years 1905–15, a period that included the wettest years at Tropic, Alton, and Panguitch.

These dry and wet periods were not made up of years that showed corresponding records for all stations. Annual rainfall exceeding 15 inches has been recorded but once at Tropic and Widtsoe, never at Panguitch, and at the wet stations, Alton and Bryce Canyon, excluding snowfalls, is about 13 inches. These low maxima, taken in connection with wide and unpredictable fluctuation from year to year, obviously make ordinary farming impossible and even irrigation farming speculative. Profitable agriculture is further handicapped by the wide variation in the amount of rain received in corresponding seasons and months from year to year. (See fig. 2, *b*.) In the amount of precipitation, the seasons rank winter, spring, summer, fall at Alton and Bryce Canyon; summer, winter, fall, spring at Tropic; and summer, spring, fall, winter at Panguitch, but the order is not maintained from year to year. The wettest months are March at Alton and Bryce Canyon, July at Panguitch, and August at Tropic. The driest month at all stations is June. The other months occupy no persistent places. In different years at Tropic and at Panguitch any one of eight months ranks as the wettest and any one of five months as the driest. For some months the rainfall of the driest year exceeds that of the wettest year. For the period of record, the wettest and next wettest months are, for Panguitch, January and October; for Bryce Canyon, March and February; for Tropic, November and March; and for Alton, March and January. At Tropic in three successive years, rainfall in November was 0.00, 4.87, and 1.90 inches; in December, 0.10 inch, 0.40 inch, and 2.89 inches. At Tropic in 1901 nearly half the annual rainfall was received in February. Of the annual rainfalls in various years, Tropic has received nearly half in February and April, more than one-third in March, and four to seven times the normal in July and November. Corresponding relations are shown in the records for

Panguitch and Alton. During the wettest year at Tropic (1906) only a "trace" was recorded for June and November.

In a region where the maximum rainfall is insufficient for ordinary farming and the vigorous growth of forage plants, these wide fluctuations in annual and seasonal rainfall have an obvious influence on agriculture and stock raising. The influence is especially felt during April, May, and June, the growing season for most crops. For 4 years at Alton, 11 at Tropic, and 10 at Panguitch the combined precipitation for these months was less than 1 inch. The normal precipitation for this period is but 1.63 inches at Tropic, 1.61 inches at Panguitch, and 2.63 inches at Alton, the wettest station in southern Utah. For 9 years at Tropic, Alton, and Panguitch no measurable rainfall was recorded for June. In most years the rains and melting snows of early spring are sufficient to induce plant growth which, in spite of evaporation incident to high temperatures, continues unchecked until soil moisture is depleted, usually in June. To bring most crops to maturity July and August rains are necessary. Fortunately the normal precipitation at Tropic is 1.50 inches for July and 1.75 inches for August; for corresponding months 1.66 and 1.52 inches at Panguitch and 1.75 and 1.88 inches at Alton. However, the average rainfall for these months is made of extremes. The July rainfall at Tropic ranges from a trace to 5.25 inches; for August, 0.00 to 3.77 inches. The corresponding figures for Panguitch are 0.37 inch to 3.97 inches for July and 0.50 inch to 2.80 inches for August, and for Alton 0.06 inch to 3.59 inches for July and a trace to 4.27 inches for August. Under such conditions, the supply of water for irrigation is uncertain and dry farming is speculative.

Much of the great irregularity in the rainfall as recorded at stations in the Paunsaugunt region is due to its distribution in place and time. Gentle rains that continue for as much as a day and cover the plateau and adjoining lowlands are very rare. Most of them cover small areas, last for less than an hour, and occur at infrequent intervals. Incomplete records show that the annual average number of days with as much as 0.1 inch of rain is 72 at Alton, 49 at Bryce Canyon, 50 at Panguitch, and 38 at Tropic. Many monthly rainfalls consist of single showers that supply 1 inch or more of rain. At Bryce Canyon on September 12, 1939, 4.09 inches was recorded—20 percent of the annual total.

Nearly all the heavy downpours are local thundershowers during which the skies are streaked with lightning, and many of them are accompanied by hail that temporarily chills the air and strews a few acres with ice marbles. Lightning is the chief cause of forest fires; particularly on the higher land many trees with split trunks and scorched foliage and partly burned trees uprooted from the ground testify to its prevalence.

TEMPERATURE

The existing records, though for short periods and incomplete, seem sufficient to indicate the seasonal changes and the influence of temperature as a climatic factor in the life and industry of the Paunsaugunt region. They show that the mean annual temperature varies generally with altitude, though Alton (altitude 7,000 feet) is warmer than Panguitch (altitude 6,700 feet). At Bryce Canyon (altitude 8,000 feet) the highest mean monthly temperature and the highest daily temperature are recorded as 48.2° and 86°. The corresponding figures for Alton (altitude 7,000 feet) are 64.6° and 94°; for Panguitch (altitude 6,700 feet), 63.3° and 95°; for Tropic (altitude 6,296 feet), 67.4° and 101°. At Bryce Canyon, Alton, and Panguitch temperatures above 90° are rare; at Tropic those above 100° are common during the summer. The maximum annual range for Bryce Canyon is 111° (86° to −25°), for Alton 114° (94° to −20°), for Panguitch 127° (95° to −32°), and for Tropic 133° (101° to −32°). Thus all stations regardless of altitude experience cold winters, and Tropic has exceptionally hot summers. At all stations, the hottest month is July and the coldest month is January, but the rank of the other months is different at each station. Each year, soil is frozen to a depth of 1 to 4 feet and ice forms on reservoirs and streams. The great monthly ranges are associated with great daily ranges that reflect the influence of topographic setting and the erratic distribution of winds, clouds, and hailstorms. Definitely cold days immediately preceding or following hot days are normal occurrences of most months at all stations. Ranges of 40° to 55° in 24 hours have been recorded for Alton, Panguitch, and Tropic. The coldest period known in southern Utah was January 1937, during which the departure from the normal monthly mean was −14.8° at Alton, −13.5° at Panguitch, and −19.8° at Tropic. However, in 1937 the mean annual temperature was 1.29° above normal at Alton, 2.90° above normal at Tropic, and only 1.08° below normal at Panguitch.

As given in the reports of the United States Weather Bureau the average dates of the last killing frost in spring and the first killing frost in autumn are June 20 and September 8 at Panguitch, May 24 and September 11 at Bryce Canyon, June 20 and September 12 at Alton, and June 4 and September 14 at Tropic. Thus Panguitch has a normal growing season of 80 days, Alton 84 days, Bryce 110 days, and Tropic 102 days.

At all stations killing frosts at later dates in the spring or earlier in the fall have been many times recorded, even for July and August, and in exceptional years the normal period between killing frosts has been reduced as much as one-half. Because of the short growing season, crops suitable for the Paunsaugunt region must be selected with discrimination, and many crop failures are to be expected.

SOIL

In the Paunsaugunt region the great differences in altitude, in form and size of the topographic features, in mineral content of the sedimentary rocks, and in the amount and distribution of rainfall, snowfall, and solar heat are reflected in the depth and quality of the soil. On the high, relatively flat land drained by the East Fork of the Sevier River the soil weathered directly from the underlying rocks lies in shallow valleys, on low slopes, and in places on the rounded ridges between streamways. On the plateau edges where precipitous slopes favor rapid run-off, innumerable rivulets fed by showers carry away the soil about as fast as formed; as agents for the disintegration of rock, the abundant soil moisture supplied in the spring by slowly melting snow is overmatched by the swift streams of summer and fall, which tend to strip the surface of its covering debris and even cut into the solid rock. In patches here and there on these steeply inclined surfaces soil is deep enough to support rather dense shrubbery, but generally the trees find sustenance in cracks and pits inaccessible to the scouring streams. Considerable areas are bare of soil and of vegetation. At the base of the steep slopes, where the stream gradients change from very steep to nearly flat and where springs emerge, considerable soil from local sources remains long in place. In many of the alcoves at the heads of tributaries to the Paria and the Kanab rotted sandstone and shale mingled with talus blocks forms "soil" 3 to 10 feet thick suitable for the vigorous continuous growth of aspens, oaks, and associated plants and, where the temperature permits, for planted crops.

Most of the soil in this region—all of that used for farming—has been brought to its present position by streams, aided at times by wind. On the plateau tops storm water transports the disintegrated rock from local highlands to the floor of nearby swales, and the streams from the plateau rim carry the products of weathering directly into their lower valleys or build them into alluvial fans and terraces. The Paria Valley about Tropic and Cannonville is floored with alluvium, and the upper Sevier Valley is essentially a wide expanse of stream-borne materials in various stages of decomposition. Likewise the valleys of Sheep Creek, Willis Creek, Meadow Creek, Mill Creek, Johnson Creek, Sink Creek, and other tributaries to the Paria and the Kanab are partly filled with sand, gravel, and silt deposited by streams. These valley soils have made possible the development of agriculture and though now in process of destruction they constitute the irrigated farms and the dry farms.

The soil used in this region is derived from rocks well supplied with the mineral matter needed for plant growth. As the lands suitable for farming are at the base of the Paunsaugunt Plateau, where temperatures favor a growing season long enough to permit the crops to mature, they receive the waste from all the sandstones, shales, and limestones exposed on the plateau front. Most of the beds of sandstone and shale are highly quartzose and therefore poorly supplied with plant foods, and the minor beds of gypsum yield deleterious matter. But the enormous quantities of "pink mud" and "gray mud" carried down the slopes by streams from outcrops of decomposed limestones and arkosic rocks form soil of high value. Tests show that the farm lands of the region contain the needed calcium, potash, iron, magnesium, phosphate, and sulfur, and the intermingled plant fragments. In this semiarid climate the soil moisture is insufficient to leach out the soluble constituents, and air and bits of plant food remain in storage for long periods. The fertility of these transported soils is attested by the vigorous natural growth of perennials and annuals when sufficient water is present and by the crops harvested at Tropic, Cannonville, Alton, and such outlying ranches as Skutumpah, Meadow Creek, and Procter Canyon. The deficient soil element is water, and in many places its absence prevents the use of soils of suitable depth and quality. In recent years much good soil has been destroyed by the down-cutting of streams in alluvium-filled valleys.

VEGETATION

As a site for plant growth the Paunsaugunt region consists of a plateau and peculiarly eroded strips of land along its sides and about its base. The plateau itself bears a heavy coniferous forest, principally of pine, spruce, and fir intermixed with aspen. The sides of the plateau, abruptly breaking off into lower levels, mark a transition to a chaparral type, principally oak, which in the foothills yields to a pygmy forest of juniper and piñon.

Between the coniferous and pygmy forest levels lie the extremely rough canyons and ridges of the plateau sides, undergoing rapid erosion. This rough area presents many slope aspects, ranging from exposed bare ridges to protected, heavily vegetated nooks, and contains a great variety of vegetation, including the peculiar fox-tail pine (*Pinus aristata*), which occupies the exposed ridges. In places erosion, undermining the edges of the forested plateau, produces dry slopes so steep that vegetation cannot cover them, and the brilliantly colored underlying rocks are exposed to view. The net effect seems to be that by cutting the flat lands into gullied slopes, thus lowering the ground-water table and preventing the retention of heavy snowfalls, the streams pushing headward into the forested plateau are destroying the coniferous forest and allowing revegetation by plants adjusted to less favorable conditions.

For the Powell National Forest, which includes the Paunsaugunt Plateau and its bordering slopes, 198 genera, comprising 405 species and varieties of plants, have been listed by Jacobs, and for Bryce Canyon National Park, Weight (1933) has given the names and regional distribution of 286 identified flowering plants. Many of the species in these lists have been described by Tidestrom (1923) and a few by other botanists.

In response to climatic conditions, the plants of Bryce Canyon National Park are roughly arranged in three zones within which certain species are dominant—the upper Sonoran zone, piñon-sage-brush belt, altitude 3,000 to 7,000 feet; the transition zone, yellow-pine belt, 7,000 to 8,500 feet; and the Canadian zone, spruce-aspen belt, above 8,500 feet. Such plants as the Joshua-tree and *Covillea* and many cacti characteristic of the lower Sonoran zone and the shrubs and grasses of the Arctic zone have not been recorded.

Weight's list of plants shows 53 species of composites in the aster family, 28 grasses and relatives, 20 members of the pea family, 14 of the mustards, 13 of the rose family, 11 of the figwort family, 10 conifers, 9 each of the lily and phlox families, 8 each of the buckwheat, buttercup, and borage families, 7 each of willows and evening primroses, 6 chenopods, 5 gentians, 4 each of euphorbias and mints, 3 each of the mistletoe, pink, currant, mallow, oleaster (buffalo berry), carrot, and potato families; 2 each of the iris, oak, barberry, flax, primrose, dogbane, and honeysuckle families; and 1 each of the orchid, birch, sandalwood, amaranth, fumitory, caper, apple, plum, geranium, sumac, bittersweet, maple, buckthorn, violet, cactus, dogwood, shinleaf, heath, waterleaf, verbena, and bellflower families.

The principal coniferous trees are blue spruce (*Picea pungens*), Douglas fir (*Pseudotsuga taxifolia*), white fir (*Abies concolor*), yellow pine (*Pinus ponderosa*),

FIGURE 3.—Top of the Paunsaugunt Plateau: View from the approach road from Red Canyon to Bryce Canyon Park, southeast across East Fork of Sevier to Boat Mesa (left sky line).

dwarf juniper (*Juniperus utahensis*), and piñon (*Pinus edulis*). On the Table Cliffs (altitude 10,000 feet) Engelmann spruce is the predominant conifer. With the firs and pines golden aspen (*Populus tremuloides aurea*) grows profusely.

The upper Sonoran zone is the natural habitat of the piñon and the Utah juniper ("cedar")—trees that grow in poor soil and good soil, in canyons, on ridges, and on cliff sides in such abundance as to justify the term "pygmy forest." (See figs. 11–15, 34.) Among these trees where the soil is deep, particularly in valleys, sagebrush grows profusely. (See figs. 3, 30, 35, 57–59.) At canyon heads scrub oak forms dense thickets, and in favorable places such shrubs as cliffrose, service berry, manzanita, mountain-mahogany, squaw bush, clematis, and herbs that include larkspur, nightshade, dogbane, stick weed and snake weed are conspicuous. Some cool canyons and open valleys are lined with cottonwood, willow, water birch, and maple.

The transition zone is dominated by yellow pine. For some 6 miles the highway through Bryce Canyon National Park is lined with big, tall widely spaced pine trees—the east edge of the attractive forest that covers large parts of the Paunsaugunt Plateau. (See figs. 4, 18, 20.) Underneath and in open spaces between them roses, iris, goldenrod, primrose, snow berry, rabbit bush, mustard, Indian paint brush, mariposa lily, sweet clover, flax, tall bright-stemmed grasses, and many species of asters and astragalus make a flower garden of exceptional beauty.

FIGURE 4.—Top of the Paunsaugunt Plateau: Forest of yellow pine, typical of flat areas at altitudes of about 8,000 feet. Photograph by C. C. Presnall.

With increasing altitude, plants of the transition zone gradually give way to those of the Canadian zone. Along the "rim road" west of Bridge Hollow the yellow pine and flowering herbs become fewer and the firs and aspen more abundant until at Rainbow Point the forest consists chiefly of white pine, foxtail pine, white fir, Douglas fir, and aspen, which form compact groves or stand alone (fig. 5). Between the trees grow violets, cranesbill, gentians, blue bonnet, yarrow, cinquefoil, bell

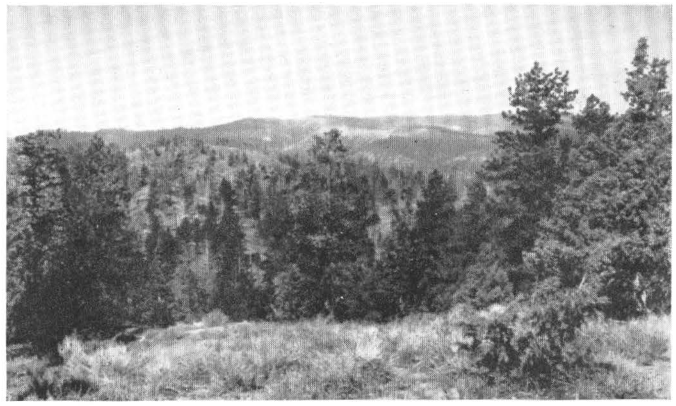


FIGURE 5.—Top of the Paunsaugunt Plateau: Forests of pine, spruce, and fir on rough lands at altitudes between 8,000 and 9,000 feet. Photograph by the Forest Service.

flowers, strawberries, six species of erigeron, and in suitable places many of the grasses and flowering plants found also in the transition zone.

Though in mass the vegetation of the three zones is distinctive, the range in kind of soil, exposure to the sun, and amount of ground water is so great that the zonal boundaries are zigzag lines with upward and downward departures of hundreds of feet. Thus, of the 286 species of plants recorded for Bryce Canyon National Park, 71 are listed in both the upper Sonoran and transition zones, 34 in the transition and Canadian zones, and 29 in all three zones.

With reference to its use as grazing land, vegetation on the "vacant unreserved, unappropriated public domain" in Garfield County—1,969,000 acres of the total 3,350,000 acres—is classified by the Forest Service as follows:

Subalpine.—The highest lands, precipitation more than 18 inches, much of it snow. Principal trees, aspen, lodgepole pine, fir, and spruce. In open parks a scattered growth of sage, snowberry, chokeberry, gooseberry, elderberry, currant, wild rose, various grasses, and annual "weeds." Though the subalpine type of vegetation covers but 8,000 acres, it is sufficient for 15 to 100 animal units to the square mile during the growing season, about June 15 to October 1.

Mountain brush.—Plateau tops and adjoining slopes and foothills. Dominant plant species, oakbrush, sagebrush, service berry, snowberry, squaw apple, generally in association with yellow pine and aspen, and an undergrowth of palatable grasses and weeds like those in the subalpine type. The carrying capacity is 10 to 30 animal units to the square mile.

Woodland.—Foothills about the base of high plateaus. Precipitation 10 to 15 inches. The most conspicuous vegetation is piñon and juniper, scattered yellow pines, and areas of sagebrush. The most abundant plants suitable for forage are bunch grass, rice grass, gramma grass, galleta grass, birch leaf, mahogany brush, and bitter brush. Vegetation of this type has a carrying capacity of 5 to 25 animal units to the square mile during a 6-month season. It is of particular value during the spring and fall.

Sagebrush.—Foothills, plains, and canyon floors. Annual precipitation is 8 to 16 inches. The dominant growth is black sage, which locally is replaced by valley sage, bitterbrush, and buckbrush. Introduced weeds form a fairly dense undergrowth. Vegetation of this type is capable of supporting 5 to 15 animal units to the square mile on the more arid lands and 15 to 35 animal units on land better supplied with soil moisture.

Shadscale.—Arid valleys and bench lands. Estimated annual precipitation is 8 to 12 inches. The most abundant plant is shadscale. Other plants are little rabbitbrush, bud sage, black brush, and winterfat. Vegetation of this type is used for winter grazing when snow supplies stock water. The carrying capacity is 5 to 15 animal units to the square mile.

Greasewood.—Low lands, generally alkaline. The dominant species is greasewood, and, in accord with varying degrees of alkalinity, seepweed, pickleweed, and saltgrass. Most of the greasewood areas provide no palatable forage, but the rare saltgrass meadows have a carrying capacity of 75 to 100 animal units to the square mile.

For Garfield and Kane Counties it is estimated that the woodland and shadscale types of vegetation constitute 82 (42 and 40) percent, sagebrush 3 percent, and the high-level subalpine and mountainbrush type 1 percent. So far as observed in the area defined as the Paunsaugunt region the shadscale and greasewood types of vegetation appear only in small patches in dry valleys where exceptional conditions prevail.

FAUNA

The fauna of the Paunsaugunt region consists largely of the animals that normally inhabit the coniferous and pygmy forests of southern Utah. For Bryce Canyon National Park, which includes the plateau tops and rims (altitudes 7,000 to 9,000 feet) and the piñon-juniper-sagebrush lands below, Presnall (1934, pp. 52–57; 1935, pp. 28–31; 1937) lists 30 species of mammals—9 carnivora, 20 rodents, and 1 ungulate; 85 species and varieties of birds; and 6 reptiles. Chick (1936, pp. 13–17) reports a rich and interesting, in some respects unique, insect fauna that includes 15 species that thrive in the coniferous forests. During the course of field work cougars, foxes, bobcats, lynxes, skunks, and prairie dogs were noted as "scarce"; the mammals most frequently seen were mule deer, porcupines, the rock chucks (or marmots), ground squirrels, pine squirrels, chipmunks, pocket gophers, woodrats, and various kinds of mice. A census taken in 1939 showed 200 mule deer, 25 badgers, 2 red foxes, 30 gray foxes, 30 coyotes, 4 badgers, and 25 bobcats and lynxes.

Bears, once common on the Paunsaugunt Plateau, seem to have been exterminated. No grizzly bear has been reported during the last half century, and only three brown bears are known to have visited the region since 1920. Wolves and coyotes, the bane of the stockman, have been so reduced in numbers as to be no longer a serious menace. Beavers, formerly abundant (the name Paunsaugunt—the transliteration of the Piute term Paincé-ágant—means "beaver country"), have been exterminated by trappers. Of the "great herds" of elk, antelope, and deer that provided food and raiment for the Indians and the Mormon pioneers, only the mule deer remains. Now rigidly protected by law, its numbers are rapidly increasing.

Among the birds, the hawks (10 species), the woodpeckers (6 species), and the owls (2 species) are prominent. Fairly common also are some of the passerine birds recorded in notebooks as flycatchers, swallows, jays, chickadees, wrens, thrushes (5 species), ravens, and at least 10 members of the sparrow family. There is a notable absence of aquatic birds.

Of the reptiles, a very conspicous element in the fauna of Utah, the Paunsaugunt region has but few species, and these are represented by few individuals. Compared with the lower, hotter lands of southwestern Utah, where 25 forms are fairly common, only the sagebrush swift, horned toad, desert whiptail lizard, and 3 snakes (gopher, garter snake, and rattlesnake) have found a habitat in the high, cold, and forested Paunsaugunt Plateau, and reptiles are rare in the foothills.

INHABITANTS

PREHISTORIC TRIBES

Of the pre-Indian population of the Colorado Plateaus both the Basket Makers and the Puebloans inhabited the Paunsaugunt region, especially the canyons tributary to the Paria River south of Bryce Canyon National Park. The Basket Makers, probably the first human beings to live in southern Utah, are represented by their characteristic artifacts and mode of burial. From a large Basket Maker cave in Starlight Canyon Byron Davies, of Cannonville, obtained sandals of yucca and hide, robes of rabbit and deer skin, baskets, ropes, bags, arrow points, drills, unglazed pottery, and other materials, and he reports an abundance of archeologic remains in the unexplored surrounding country. The Puebloans, who succeeded the Basket Makers and in places were contemporaneous, seem to have found the Paunsaugunt Plateau an unfavorable place for large-scale settlement. Here and there on the upper tributaries to the Paria, the Johnson, and the Kanab, their dwelling sites are indicated by stone walls, broken pottery, and stone implements that suggest short-time occupation. Doubtless some of these sites were used only when crops needed attention. South of the White Cliffs along the Paria and its principal tributaries Pueblo ruins are fairly common (fig. 6). In the region between the Vermilion Cliffs, the Kaibab, and the Kaiparowits Plateau centering about the old town of Paria, Davis reports at least 3,000 "rectangular ruins, none of them very high." From cliff caves have been taken many wood and bone artifacts and pottery ware of various forms and styles of ornamentation that permit the recognition of stages in the development of Pueblo culture. From Kitchen Canyon beautiful specimens of pottery, typical of the stage of culture known as Pueblo 3, have gone to museums. Besides the abundant pottery, household utensils, articles of dress and ornamentation, and implements of warfare and hunting are strewn about ruins, in caves, and "open lands." On many canyon walls and under roofs of cliff caves are rock carvings and paintings—angular designs of the Basket Maker and the more general curves of the Puebloans. There is a conspicuous absence of large community houses, well-built smaller structures, and large anciently cultivated fields. Cursory examination of the remains leaves the impression that the Pueblo settlements in the Paria Valley were outposts of the great villages south of the Colorado River, which through a period of a thousand years attained a notable stage of cultural development that reached its peak about A. D. 1150.

PIUTES, UTES, AND NAVAJOS

As the Piute clans built no permanent structures, their early history in Utah must be compiled from scattered archeologic materials and tribal tradition and from the observations of explorers and pioneer settlers. The evidence seems clear that the Piutes entered southern Utah before the Puebloan tribes had entirely disappeared and that unlike the sedentary agricultural Puebloans they had no established house sites but occupied temporary camps at places favorable for hunting, gathering seeds and piñon nuts, and planting small fields of corn. Obviously they were a weak race unskilled in agriculture or in textile and pottery making and unable to cope in warfare with the neighboring

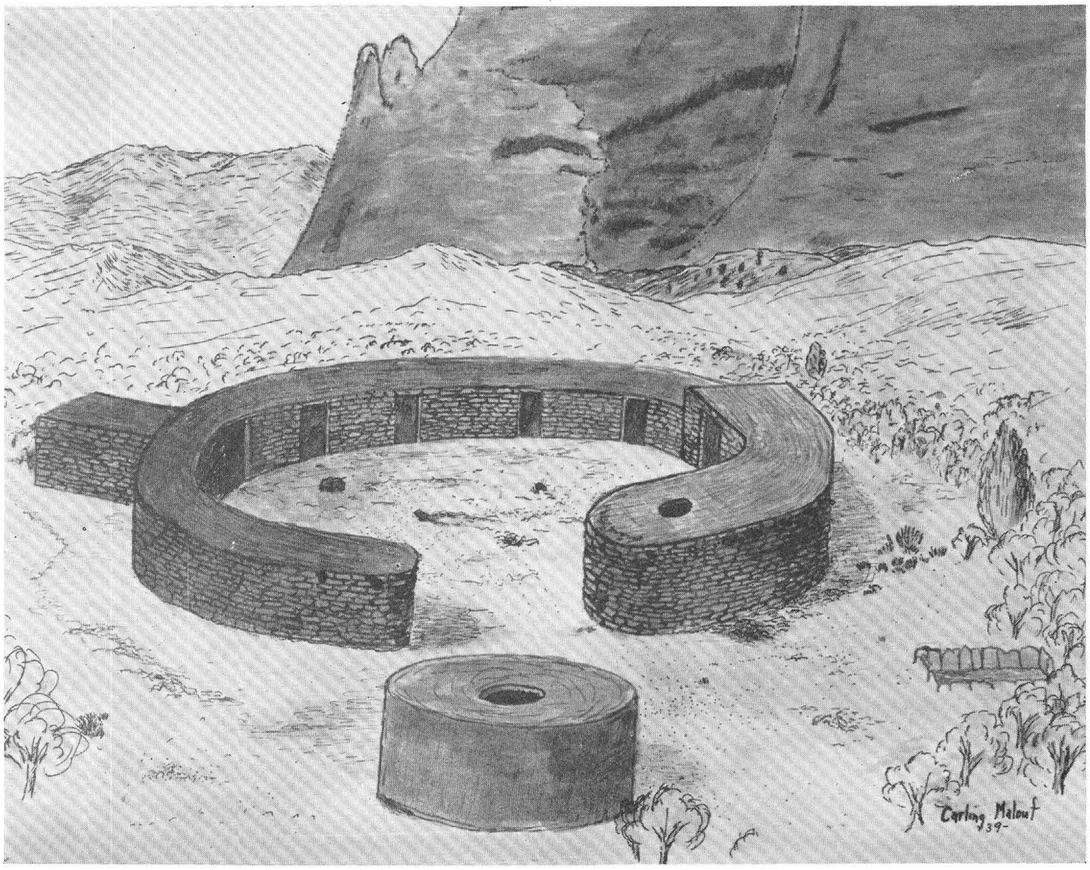


FIGURE 6.—Restoration of a Pueblo community dwelling in Paria Valley. Reproduced from a painting made available by Elmer Smith, anthropologist, University of Utah.

tribes. They seemed content with a standard of living characterized by flimsey dwellings, scanty clothing, and a food supply that included as standard items plant stems, grass seeds, nuts of the pine and piñon, sego lily, wild potato, birds, rodents, snakes, lizards, crickets, and grasshoppers. By skillful methods they trapped rabbits and squirrels by the hundreds, and with their ineffective weapons the plentiful antelope and deer were occasionally killed for food. On this low scale the Piutes were well adjusted to their environment and except as harassed by neighboring tribes maintained a creditable existence for several centuries. In consequence of the changes associated with the advent of white men the tribes have decreased in number to the present unimportant remnants. (See Gregory, 1950.)

That the Piutes were frequent visitors to the Paunsaugunt region is shown by arrowheads, spear heads, stone axes, and grinding tools. In 1872 Thompson found Piutes in camp near Cannonville, and an old-time resident estimated the number of Piutes in the Paria Valley "during the early days" as about 250. Most of them belonged to the clan known as A-vo-ats-in (a-vo-av, "semicircular valley"), who intermittently inhabited the cliff-walled amphitheater at the head of the Paria River (pa-re-a-pa, "elk water," "elk spring"). They recognized the rock walls of Bryce Canyon as the ruins of a great city, buried in red mud and now partly excavated, the work of Shin-awav, a Piute demigod of great power. As told by Indian Dick, an aged Piute now living on the Kaibab Reservation in Arizona, the legend runs:

Before there were any Indians, the To-whon-an-ung-wa lived in that place. There were many of them. They were of many kinds—birds, animals, lizards, and such things—but they looked like people. They were not people; they had power to make themselves look that way. For some reason the people in that place were bad; they did something that was not good. Because they were bad Shin-awav turned them all into rocks. You can see them in that place now, all turned into rocks; some standing in rows, some sitting down, some holding on to others. You can see their faces, with paint on them just as they were before they became rocks. The name of that place is Angka-ku-wass-a-wits. This is the story the people tell.

Indian Johnnie, a member of the Avoav clan, translated Angka-ku-wass-a-wits (or Unka-ka-was-sa-wits) as "red painted faces." Other Piutes use the name Unka-timpe-wa-wince-pock-ich, a term translated by William R. Palmer, of Cedar City, as "red rock standing like men in a bowl-shaped recess."

Bishop A. Milton Musser (1870) saw "a number of 'Piede' (Piutes) in lower Paria Valley." He wrote:

These Indians are the wildest and most untutored I have ever met with in all my travels. They have seldom seen a paleface and in their attire are exceedingly economical, not so much from choice as from necessity. Combs, soap, and all such concomitants of civilization are not known among them. Assisted by a wandering "Mormon," Peter Shurtz [they cultivated] a large field of promising corn.

Musser speaks of an Indian named Naraquats who, on foot, "brought telegrams and papers to Mound Valley from Parowan, 69 miles, from day break to 9 p. m."

The Utes (Utahs), the linguistic relatives of the Piutes and once the dominant tribe of the intermountain region, seem never to have made settlements in the Paria Valley and rarely visited the upper Sevier Valley. During the Black Hawk war, 1866–69, fear of their depredations delayed permanent settlement of Panguitch, Hatch, and Skutumpah. Cannonville, Henrieville, and Tropic were established after peace had been declared (1870). Navajo hunting parties from across the Colorado frequently visited the Paunsaugunt region in search of pelts and doubtless molested the few resident Piutes, but in the absence of white settlements their raids were directed especially against the villages of the Virgin and Parunuweap Valleys and the stock herds south of the Vermilion Cliffs. Since friendly relations were established (1870–71) the Navajo occasionally come to trade blankets for food and horses.

WHITE SETTLEMENTS

PARIA VALLEY

The pioneer white settlers in the upper Paria Valley were the families of David O. Littlefield and Orley D. Bliss, who, on December 24, 1874, laid out farms near the junction of the Paria River and Henrieville Creek. With the arrival of eight additional families in 1875, the original log houses at the base of the red cliffs grew into a small settlement, called Clifton (Cliff town).

One of the new settlers, Ebenezer Bryce, who is said to have come to Clifton in 1875 or 1876, selected a site farther upstream in Henderson Valley (New Clifton), where, in association with Daniel Goulding and others (1878–80), he constructed an irrigation canal 7 miles long, planted orchards, and engaged in stock raising. Some of his cattle grazed in the canyon that now bears his name and gives distinction to Bryce Canyon National Park. Bryce left New Clifton in 1880 and Goulding in 1883, selling their holdings to Isaac H. Losee, Orville S. Cox, and Ephraim (?) Coffall, who renamed the site Losee.

Three years after settlement the little town of Clifton found itself too closely hemmed in between the cliffs and the bank of the Paria and its farm lands in process of destruction by flood water. In 1877 Clifton was abandoned, and most of its settlers went to a new site about a mile upstream and named it Cannonville for George Q. Cannon, a high dignitary of the Mormon Church. Three families from Clifton, led by James L. Thompson, established themselves on Henrieville Creek at the present site of Henrieville, about 5 miles east of Cannonville named in honor of James Henrie, president of Panguitch Stake. In 1886 Seth Johnson, Joseph and Eleazer Asay, Richard C. Pinney, and other ranchmen took up lands on Yellow Creek about 3 miles southwest of Cannonville and thus became the pioneer settlers of Georgetown, now a ranch. In the early eighties Cannonville was "the metropolis of Paria Valley," the home of prosperous stockmen who had available for grazing more than 2,000 square miles of unallotted land and of farmers who cultivated nearby parcels of fertile land watered by means of ditches from the Paria River.

By 1886 the increasing population was using about all the fields that the available water would irrigate, but north of the village there remained a large body of unirrigated land that was otherwise suitable for cultivation. To increase the arable area the people of Cannonville in 1889 revived the scheme outlined by Ebenezer Bryce in 1880 (?) of diverting water from the East Fork of the Sevier River on top of the Paunsaugunt Plateau, through a ditch that would pass over the Pink Cliffs to the lands in the upper Paria Valley. At the instigation of William Lewman the locally financed Cannonville & East Fork Irrigation Co. was organized, a reservoir site selected, and a survey made for a feeding canal 9¾ miles long. Under the energetic leadership of Maurice Cope work was begun May 15, 1890. In anticipation of the successful completion of the project James Ahlstrom, C. W. Snyder, and others began building houses on land that the proposed ditch was intended to water. In 1891 a town site was laid out and, as descriptive of its climate, named Tropic. On May 23, 1892, the new-found water was flowing through the town site and onto the adjoining fields, and the life of a continuous village began.

The reclamation of the upper Paria Valley is an outstanding illustration of cooperative work in which members of a community give the time not required for routine duties. From time to time during the 2 years given to construction more than 50 men, boys, and even women from Cannonville and neighboring settlements wielded axes, picks, crowbars, and spades, hauled gravel, and built rock walls. Like the famous Hurricane Ditch, in Washington County, the East Fork Canal is a home-made structure, and like Hurricane, Tropic is a man-made oasis.

SEVIER VALLEY

Settlement of the upper Sevier Valley dates from the year 1864, when a band of six pioneer families from Beaver and Parowan under the leadership of Bishop Jens Nielson crossed the Markagunt Plateau by way of the lower Bear Valley and on April 17 camped near the mouth of the creek that flows from the lake known to the Piutes as Panguitch ("big fish"). Finding the soil and water suitable for farming, the pioneers selected the present Panguitch (first named Fairview) as a town site, constructed an irrigation ditch, and planted a small crop. During the first winter (1864–65) snow blocked the trails to Parowan, and the isolated community was forced to subsist on boiled grain and flour ground in coffee mills. Fear of the marauding Utes made it necessary to live within a stockade, and continued hostilities forced the abandonment of the village in 1866. Under the leadership of Bishop George W. Sevey the site was reoccupied in March 1871. Since that time Panguitch has experienced uninterrupted growth. Its population has increased from 664 in 1880 to 1,975 in 1940 (about two-fifths the population of Garfield County), its irrigated lands from 300 (?) to approximately 4,000 acres. Its large livestock industry gives it a prominent place among Utah villages, and as a cultural and commercial center it is exceeded in southern Utah only by Cedar City and St. George. Of late years it has assumed increased importance as the gateway to Bryce Canyon National Park.

With the founding of Panguitch began the search for suitable farm lands in the upper Sevier Valley, where water from the Sevier River and its tributaries was available for irrigation. In the summer of 1871, 15 families under the leadership of G. D. Wilson settled at Hillsdale, on the river terrace about half a mile east of the present village. In 1872 three brothers—Jerome, Alazar, and Aaron Asay—established a town, Aaron, near the mouth of Asay Creek, with a population of 10 families, 70 people. During the same year farmers occupied land at the mouth of Mammoth Creek, and soon afterward in Hillsdale, Procter and other canyons tributary to the Sevier River. In 1880 (?) the families at Aaron joined with those scattered along the river in founding Hatchtown (named for Meltiar Hatch), a village of about 100 people, at the junction of the Mammoth and the Sevier. The location, however, proved to be unsuitable for "keeping water in the ditches," and after the town had been flooded by the breaking of the source reservoir, it was moved to its present site (Hatch) in 1900–1902.

KANAB VALLEY

On a scouting trip in 1865 Byron S. Roundy and his brothers, Jared and Lawrence, found the meadow lands and adjoining benches at the head of Kanab Creek "well watered" and "easily cultivated," with "tall grass thick enough to be mowed for hay." In 1872 the site was chosen as a summer range by the Canaan Cooperative Stock Co., whose field of operation included much of southwestern Utah. In 1873–74 some 10 families had taken up farms along Kanab Creek and in the nearby Sink Valley, and during the next 10 years a scattered community named Upper Kanab reached its maximum population, reported as "about 200." As a center for stockmen the settlement was well placed; abundant pasturage of excellent quality was close at hand. Likewise the farm lands produced high yields, but the area between the canyon walls possible to irrigate with inexpensive ditches was small, and suitable dam sites were lacking. To provide "better homes for our children" and "space for schoolhouse and church," the residents of Upper Kanab in 1908 selected the present Alton as a site where a compact village could be built and ranch lands converted into farm lands by the construction of a high-level ditch. The next year the community was organized as Alton, a name suggested by the height above the surrounding settlements. (See fig. 7.)

Because of its abundant water and excellent though small arable area, Skutumpah was early chosen as a village site. Available records show that the place was settled in 1870 by the families of John Clark, James Clark, and Emma Lee, Willard Lee, and William Lee, wife and sons of John D. Lee. The population in 1875 is estimated to have been 25. In 1879 the farm lands and buildings came into the possession of James Andrus, representing the Kanab Cattle Co. Since that date its population has varied from about 15 to none, and ownership has changed many times. At present it is a successful ranch of irrigated grain fields and adjoining pasture lands.[2]

North of Skutumpah ranches in Tenney and Mill Creek Canyons are occupied during the summer season, and east of the settlement in Deer Spring Valley the well-known Findley ranch, parts of it irrigated, is the controlling center of a large sheep industry.

Ranch homes once occupied in Swallow Park, in Podunk, Bullrush, Lick, Willis, Sheep, and other valleys along the south base of the Paunsaugunt Plateau are now abandoned or used only during the grazing season.

DISTRIBUTION

The distribution of the population in the Paunsaugunt region and its fluctuation by decades is shown in the accompanying table.

[2] Skutumpah (spelled in various diaries, manuscripts, and maps as Skuimpah, Skimpah, Skoompah, Skutempah, Skoon Pa, and Skutompah) is the translation generally accepted by students of Indian languages for the Piute word sukoompah, sakoompah, or scukoompug, meaning rabbit brush. The pah or puh in this word has a significance different from pah as applied to streams—for example, Pah-rea (Paria). On the maps of the Powell Survey the place is recorded as Clarkston.

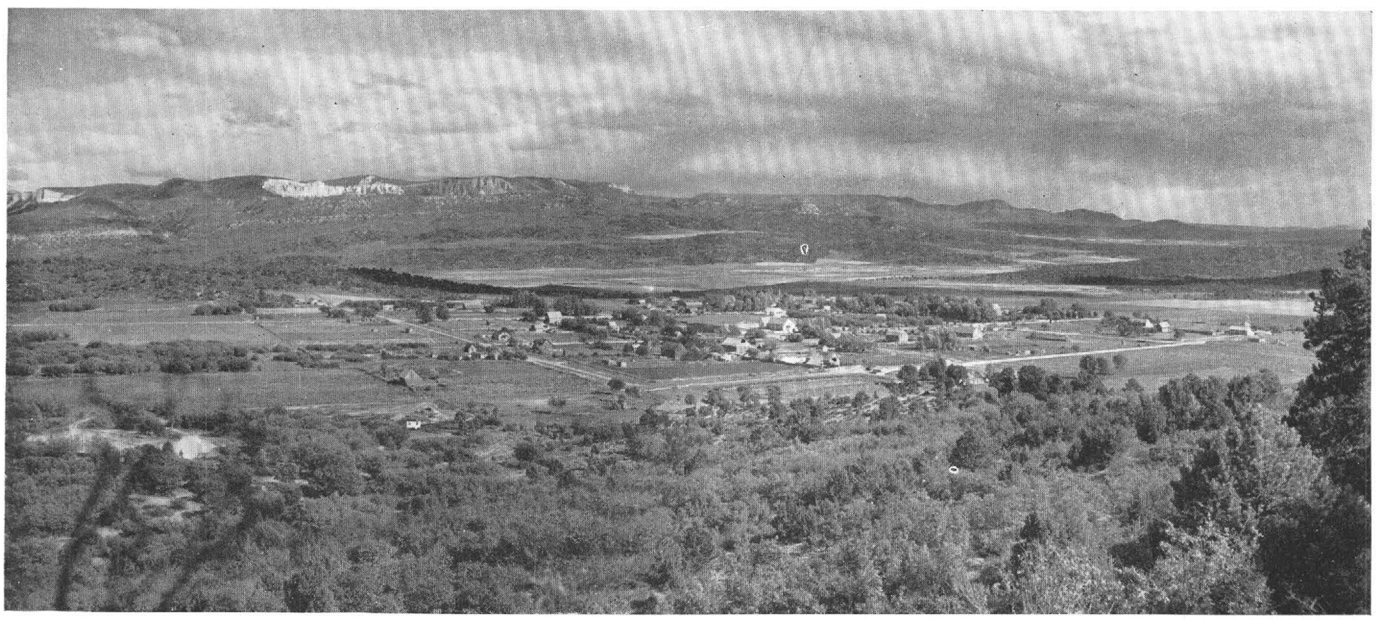


FIGURE 7.—View of the Alton Amphitheater looking east over the village of Alton in upper Kanab Valley. From a floor eroded in Cretaceous shales the land rises by steps to the wall-like rim of the Paunsaugunt Plateau (upper left).

Population of the Paunsaugunt region

Settlement	1870	1880	1890	1900	1910	1920	1930	1940
Clifton 1874	60 (1877)	----	----	----	----	----	----	----
New Clifton / Losee (1875)	----	12	7	6	----	----	----	----
Cannonville (1877)	----	137 (1882)	242	211	219	311	227	255
Henrieville (1883)	----	33(?)	145	181	158	170	207	240
Tropic (1891)	----	----	194 (1894)	379	404	474	447	514
Georgetown (1886)	----	----	22	14	6	----	----	----
Panguitch (1871)	72 (1872)	664	700(?)	883	1, 338	1, 473	1, 541	1, 975
Aaron (1872) / Hatchtown (1880) / Hatch (1900)	----	----	----	----	----	----	274	294
Hillsdale (1871)	----	[1] 179	333	267	180	250	22	6
Upper Kanab (1872) / Alton (1908)	----	106	111	91	98	169	193	227
Kane County (1864)	1, 513	3, 085	1, 685	1, 118	1, 652	2, 054	2, 235	2, 557
Garfield County (1882)	----	[2]	2, 457	3, 400	3, 660	4, 768	4, 642	5, 253

[1] For the census years 1880–1920 inclusive the figures for Hillsdale are recorded as including Hatch. [2] Population for 1883 recorded in Sloanes Gazette as 4,520.

INDUSTRIES

FARMING

In their pioneer explorations James Andrus (1866) reported "plenty of water" and a "good deal" of arable land in the upper Paria Valley, and Bishop Musser (1870) called attention to "rich soil" in the Sevier River Valley and near the head of Kanab Creek. These scouts of the Mormon Church and those who followed them during the period 1870–80 reached the disappointing conclusion that most of the lands about the Paunsaugunt Plateau were unfavorable for agriculture without irrigation. As expressed by Alvin H. Thompson in 1872, "In this portion of Utah irrigation is essential to agriculture. If all the single acres it is possible to cultivate without artificial irrigation were aggregated, I do not believe the sum would reach one-fourth of 1 square mile." Experience of more than 60 years has demonstrated that of the considerable acreage once thought reclaimable only a small part could be profitably cultivated. On the fertile flat land along the larger streams the irrigation farmer has to contend with unpredictable variation in water supply from year to year and month to month and finds difficulty in maintaining ditches in the easily crumbled alluvium. At the heads of valleys and canyon floors, where perennial water supply is ample for many farms, the arable lands are of small extent, and to convey the water to more suitably placed lands is uneconomical. Furthermore, some well-watered lands are too cold for crops. Powell (1879, p. 132) long ago described "lands along the upper portions of the forks of the Sevier which can be irrigated easily enough, but which are not cultivable for grain on account of the shortness of the summer and of the danger of frosts during the growth and ripening of the grain." In recent years much excellent farm land has been destroyed by gullying. (See pp. 91, 103.)

Agriculture in the Paunsaugunt region has appropriately been called "a secondary industry." Though the pioneer settlements "raised their own food," the produce now harvested from the small area suitable for crops is insufficient for local needs; even in "good years" considerable flour and other vegetable food is imported. As the result of persistent skilled attention about 1,500 acres of irrigated land has been made available for tillage in the Paria Valley adjoining the close-spaced villages of Tropic, Cannonville, and Henrieville. In the upper Sevier Valley the land considered feasible for irrigation by the existing systems of canals comprises 700 acres at Hatch, 160 acres at Hillsdale, and about 100 acres in detached farms along Hillsdale, Proctor, Castle, and Asay Creeks. In the upper Kanab Valley about 300 acres is under irrigation at Alton and in the nearby Sink Valley. Along the south base of the Paunsaugunt Plateau 75 acres of irrigated land and 50 acres of dry farms are under cultivation at Skutumpah; 100 acres irrigated and 200 acres of dry farms at the Findley ranch; and 3 to 15 acres at each of several smaller ranches.

In both Garfield and Kane Counties unirrigated farms are more numerous than those supplied with water artificially. Some of them, particularly those about Alton, where the ground-water table is near the surface, have been profitably cultivated for as much as 50 years. Scores of others, intermittently operated, have yielded "fair returns" in "good years," especially when markets were inflated. On the whole, however, experience with dry farming has been disappointing; the failures outnumber the successes. Abandoned farms, many of them improved with fences, houses, barns, and corrals and equipped with cultivating and harvesting machinery, are conspicuously numerous. It is estimated by long-time residents that in Garfield and Kane Counties more than half of the dry farms of 1880 are no longer in use.

On the scattered farms of the Paunsaugunt region the principal grain crops are oats, wheat, barley, and rye. Particularly on the higher lands the climate is too cold for corn. Apples, plums, and peaches thrive in the warm upper Paria Valley. Apples grow well at Alton, but local climates are unfavorable for the growth of fruit at Hatch and Panguitch, at altitudes lower than Alton. Except in the lowest valleys potatoes are an important crop, and excellent garden vegetables, especially lettuce, cabbage, turnips, and carrots, grow profusely.

STOCK RAISING

As listed by the United States Bureau of the Census, the land area of Garfield County (3,349,760 acres), includes 1,969,000 acres of vacant public land available for grazing and areas totaling 899,131 acres in National forests are reserved chiefly for that use. In Kane County 2,685,000 acres, including national forests is potential grazing land. Of the irrigated lands, fully half is given to forage crops. Thus in 1935, the latest year of available record, the 22,848 acres of cultivated land in Garfield County included 10,630 acres of alfalfa, 1,830 acres of oats, and 1,025 acres of corn. The figures for Kane County are comparable. It would seem from these statistics that the Paunsaugunt region is particularly favorable for stock raising. It once ranked high among the western range lands. For several years after 1872 stock owned by the great Canaan Cattle Co. found abundant forage in the foothills of the Paunsaugunt Plateau about Upper Kanab. Beginning in 1873 the plateau top was utilized for grazing by the Kanarra Cattle Co., which claimed also the tributaries to the Paria as its "herd grounds." Sheep were introduced in 1877. The cowboys of the company, who seem to have been the first to explore the plateau thoroughly, have left their records on initialed aspen trees and in the names of such geographic features as Dave's Hallow (David Littlefield), Davis Cave (John Davis), Sevy Flats, John L. Sevy), and Whiteman Mesa. Two shallow wells near Bryce Canyon Lodge date from 1880. The "thousands of cattle" that in the decade 1870–80 found ample forage on the plateaus and foothills and along canyons and washes of Garfield and Kane Counties are now represented by small herds; the present sparseness of native palatable vegetation and the decreased acreage of land suitable for raising forage make a large stock population impossible.

The Paunsaugunt Plateau and the forested slopes along its south base, which are parts of the Powell National Forest, provide excellent summer pasturage for a restricted number of cattle and sheep. But when snow covers the highlands the flocks and herds must be taken to distant lower lands on the Kanab and Uinkaret Plateaus and along Glen Canyon of the Colorado. Outside the forest the pasturage is nowhere abundant or of high grade, and its amount and quality depend on the unpredictable time and amount of snow and rainfall. For large parts of the region utilized by the stockmen of Tropic, Alton, and Hatch, it is estimated that under average climatic conditions 1 square mile is needed to provide forage for 5 head of cattle or 20 head of sheep.[3]

OTHER INDUSTRIES

Since the early days of settlement lumbering has been an important industry in this region. Sawmills have been operated since 1871 in Hillsdale Canyon and from time to time in Big Hollow and elsewhere along streams that issue from the Sunset Cliffs near the source of supply. The mill in Red Canyon was a well-known landmark until it was removed in 1939. On top of the Paunsaugunt Plateau mills were operated near the present Ruby's Inn, in Dave's Hollow (1896), and on the East Fork of the Sevier River and its tributaries. A mill at the mouth of Water Canyon (1890) supplied rough lumber for Tropic and Cannonville, and mills on the upper Kanab Creek supplied Alton. At present sawmills on Red Creek and at Hatch manufacture rough lumber for local use and provide work for about 50 men. A few other men are employed in the intermittently operated coal mines at Tropic and Alton (see p. 108). In recent years the income derived from the entertainment of tourists has been added to that from crops and livestock. In payments for labor, accommodations, and supplies the National Park Service, the Bureau of Public Roads, and other Federal and State agencies, also transportation companies, hotels, and wayside cabins have contributed much to the new prosperity that has come to Garfield County, especially to Panguitch, Hatch, and Tropic. The accommodations for visitors to the scenic area about Bryce Canyon first provided by Ruben Syrett in 1920 were greatly expanded by the Utah Parks Co. after the establishment of the Utah National Park in 1924, renamed Bryce Canyon National Park in 1928. The construction of excellent approach roads (1932–38) has made the park readily accessible. In 1939 the number of visitors was 101,500—about 20 times the normal population of Garfield County.

[3] For a history of the stock industry in the Paunsaugunt region, see Gregory, H. E., and Woodbury, K. M.: The Mormon Southland. [Report in preparation.]

SEDIMENTARY ROCKS

GENERAL STRATIGRAPHIC RELATIONS

The consolidated sedimentary rocks in the Paunsaugunt region are of Mesozoic and Cenozoic age. The surface of the Paunsaugunt Plateau is developed in Eocene strata; its foothills and slopes that extend outward to the crest of the White Cliffs, in Upper Cretaceous and Upper Jurassic beds. The White Cliffs, the southern boundary of the area here described, are built of Middle (?) Jurassic rocks; from their base strata of Lower (?) Jurassic, Upper Triassic, and Lower Triassic age follow downward in orderly sequence to the Permian formations of the Kanab and Kaibab Plateaus and on to the Paleozoic and Proterozoic beds in the Grand Canyon of the Colorado. None of the formations mapped are restricted to the Paunsaugunt region; many are widely displayed in southern Utah, and some are approximately coextensive with the Colorado Plateaus. The chief local departures from the regional stratigraphic arrangement are the absence of the Morrison and the Summerville formations; the modified content of the Cretaceous Straight Cliffs and Wahweap formations; and the prominence of the newly recognized Winsor formation.

The predominant rocks all about the Paunsaugunt Plateau are marine and terrestrial sandstones, much alike in mass composition but widely variant in bedding and texture. Fresh-water limestone constitutes about half of the Wasatch formation, and marine limestone most of the Carmel and part of the Curtis formations. Conglomerate and gypsum, though conspicuous, are much less common, and typical clay shale is rare. To a remarkable degree the stratigraphic units as exposed by erosion are also topographic units.

The unconformities that separate the groups of strata assigned to different ages conform to the pattern common to the Mesozoic rocks of the plateau country. In

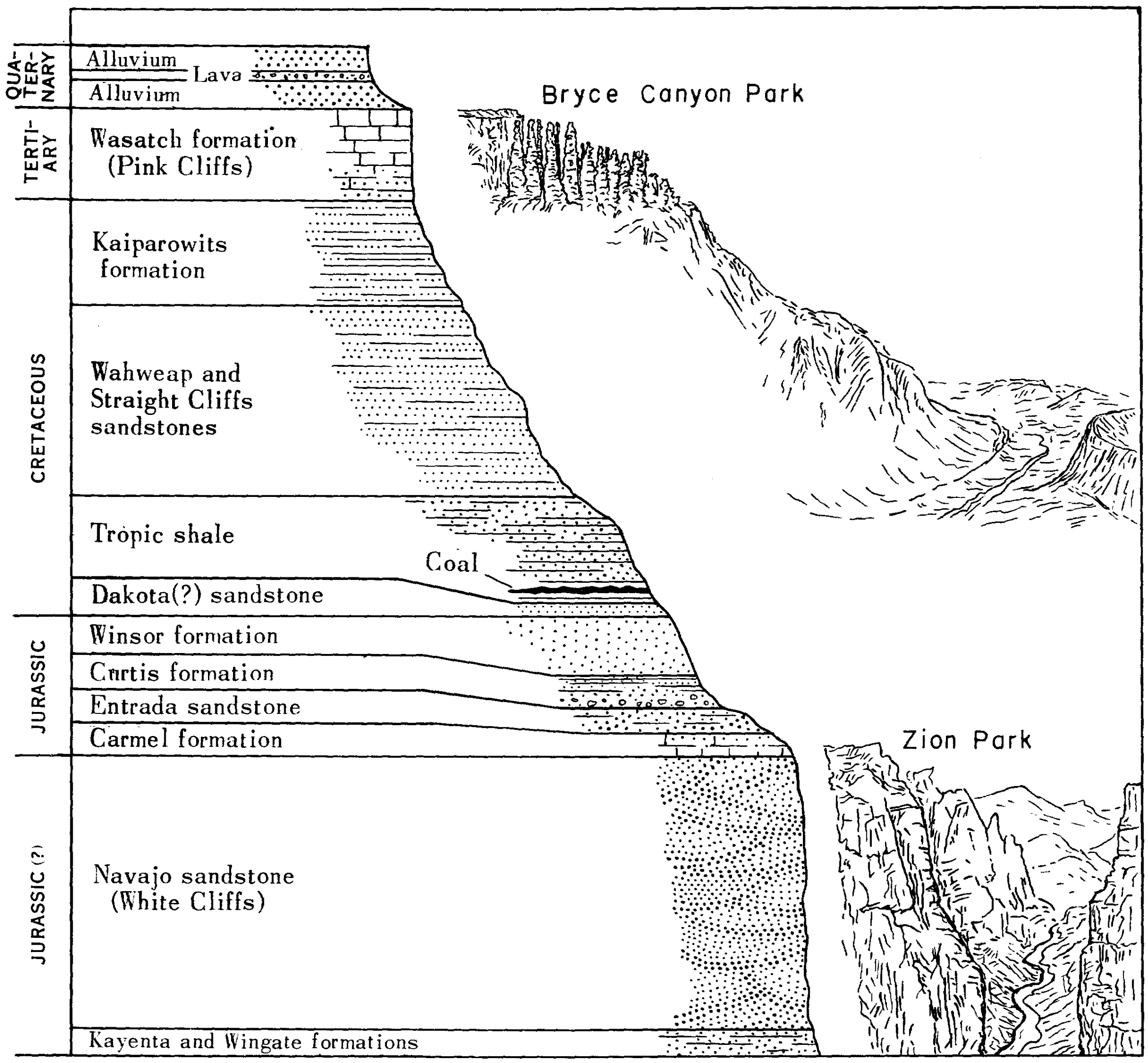


FIGURE 8.—Generalized cross section of the geological formations in the Paunsaugunt region (Navajo sandstone and younger rocks).

some of them a lapse of time is clearly shown by buried surfaces of erosion or by abrupt changes in fauna; in others by weathering and feeble stream scour; but in most merely by change in type of sedimentation. Generally the beds above the unconformities and those below have the same attitude and the record of interruption in deposition is further confused by the presence of many local unconformities, some of which may prove to be regional.

The general stratigraphic features of the Paunsaugunt region are summarized in the accompanying tables. (See also pl. 3 and fig 8.)

Generalized section of the rock formations in the Paunsaugunt Region, Utah

System	Series	Group and formation	Character	Thickness (feet)
Quaternary.	Recent.		Sand, gravel, and silt eroded into terraces in valleys.	10–60
	Pleistocene.		Fluviatile and lacustrine deposits.	10+
Tertiary.	Pleistocene or Pliocene.	Sevier River (?) formation.	Volcanic conglomerate sandstone and calcareous shales; rarely exposed.	8–60
	Eocene.	Wasatch formation.	Limestone pink, white, and varicolored; calcareous sandstone and shales; conglomerate of exotic pebbles.	0–1, 300
		–Unconformity–		
Cretaceous.	Upper Cretaceous.	Kaiparowits formation.	Dark-gray and gray-green, moderately coarse-grained, arkosic sandstone in irregular beds; contains vertebrate bones, fossil wood, and fresh or brackish water invertebrates; weak calcareous cement; forms slopes and bad lands.	265–700
		Wahweap sandstone.	Tan and gray sandstone and highly arenaceous shales generally lenticular on a broad scale and very irregular in detail; few beds of clay shale and conglomerate of quartz, quartzite, and bones; forms broken slopes. Contact with the Straight Cliffs sandstone undefined.	535–1, 620
		Straight Cliffs sandstone.	Sandstone in thin beds and thick massive beds; calcareous, argillaceous, and carbonaceous shales (5 percent); manner of bedding and texture changes in short distances horizontally and vertically; contains marine and terrestrial fossils; forms sheer walls, benches, and slopes.	
		Tropic shale.	Bluish drab, argillaceous to sandy shale; irregularly bedded sandstones; coal at several levels; abundantly fossiliferous; forms broken slopes and bad lands.	630–1, 475
		Dakota (?) sandstone.	Dark-gray to nearly white sandstone; conglomeratic in part; irregularly bedded; contains thin beds of coal and silicified wood.	6–80
		–Unconformity–		
Jurassic.	Upper Jurassic.	Winsor formation.	Thin-bedded, arkosic sandstone conspicuously banded red and white; lower part thickly irregularly bedded; forms prominent steep slopes below the Dakota (?) sandstone.	400–800
		–Unconformity (?)–		
		Curtis formation.	Massive gypsum and dense, thin-bedded limestone; some calcareous shales; weathers into low cliffs and benches.	110–180
		–Unconformity–		
		Entrada sandstone.	Thin stratified friable sandstones, red, brown, gray; subordinate calcareous and gypsiferous shales, gypsum, and limestone; in places includes massive bed of yellow sandstone 60 to 90 feet thick; forms cliffs and talus-strewn slopes.	170–240
		Carmel formation.	Dense, very thin-bedded, ripple-marked tan and blue-gray limestone; calcareous shale; impure sandstone; some gypsum; forms benches on top of the Navajo sandstone.	0(?)–165
		–Unconformity–		
Jurassic(?).		Navajo sandstone.	Light creamy-yellow, white and buff, highly cross-bedded sandstone; weathers in escarpments and innumerable cones, towers, and domes; forms the White Cliffs.	1,200–1,800

HISTORICAL SKETCH

Knowledge of the stratigraphy of the Paunsaugunt and the adjoining Aquarius Plateau dates from the studies by Howell (1875, Atlas, sheet 59) in the Paria Valley. Howell's section of Tertiary and Mesozoic strata "from the Last Bluff [Table Cliffs] south-southwest 36 miles to a point a little west of Paria Settlement," made in 1872, is a classic of the pioneer surveys. Supported by names of fossils and by discriminating lithologic definitions, this section was treated by Gilbert and Dutton as the standard of comparison for the rock formations of the plateau country and found expression on the geologic atlases issued by the Wheeler and Powell Surveys. In the Triassic Howell included 2,250 feet of strata readily recognizable as upper Moenkopi, Shinarump conglomerate, Chinle, and part of the Glen Canyon Group. The Jurassic he described as 500 feet of unfossiliferous sandstones and shales of various composition and texture, including 175 feet of "variegated gypsiferous shales" which he correlated with the fossiliferous marine Jurassic limestone along the Dirty Devil River. Howell expressed difficulty in attempting to separate the Cretaceous from the Jurassic in view of the fact that "the division between the two is not a marked and constant one" and no fossils were found in the 1,000 feet of strata between the "buff, massive buff cross-bedded sandstone" (Navajo) and "the coal bearing beds" (Tropic shale).

In these pioneer studies Howell gave much attention to the prominent Tertiary beds, which he traced from Price River to Table Cliffs along the Wasatch, Awapa, and Aquarius Plateaus. In his measured sections, descriptions, and lists of fossils he presents the evidence for the "fresh or fresh and brackish water" origin of the deposits and for their Eocene age, and has much to say regarding the difficulty of subdivision into stratigraphic groups that might be correlated with the Tertiary as known elsewhere. In particular he found the boundary between the Tertiary and the Cretaceous difficult to place. His type section of the Tertiary at Last Bluff includes 1,200–1,500 feet of fossiliferous shales here classed as Cretaceous (Kaiparowits formation).

In his brief study of the rocks exposed outward from the base of the Paunsaugunt Plateau, Gilbert (1875, pp. 159–160, 172–175) recognized Triassic, Jurassic, Cretaceous, and Tertiary strata in orderly succession. He lists as "the upper division" of the Triassic "two massive sandstones, 900 and 800 feet thick," usually parted by soft layers near the middle, that "form two lines of cliffs, terraces of the great south facing escarpment" (White Cliffs; Navajo sandstone). As Jurassic, Gilbert recognized near the Paria River "several hundred feet of highly colored gypsiferous beds, ranging from sandstone to clay in texture and usually including a thick bed of solid gypsum," and in upper Kanab Valley found a cream colored limestone containing Jurassic fossils. As basal Cretaceous he lists "300 feet of cream shale, with occasional filets of red shale and of sandstone."

Regarding the Tertiary Gilbert (1875, pp. 172–173) remarks:

> These Tertiary beds are so extremely variable in lithological character and thickness that it is difficult to correlate sections, even when taken only a few miles apart, save in a very general way. This is especially noticeable in comparing sections near the western boundary of the system with each other, or with sections to the east, while the eastern sections show more uniformity in character. These facts are consistent with what might be expected, when we consider that the Basin Range system was the ancient continent which furnished the sediments for these beds, and we find their variability such as is usually noted in off-shore deposits. To the north these beds are mostly soft calcareous shale and marls, with only a few sandstones and hard limestones. Southward there is an increase in the limestone, and at the most southeastern exposure, the Last Bluff, there are over 1,200 feet of more or less compact limestone. The fossils from this series have not yet been carefully studied. However, the major part of it, if not the whole, may be referred with considerable confidence to the Eocene, and perhaps the lower Eocene, and it is by no means impossible that the Cretaceous may eventually be moved up so as to include the lowest member.

Confirming the observations of Gilbert in Kanab Valley Walcott (1905, pp. 484–485) assigned to the Jurassic 960 feet of strata above the "White Cliffs sandstone" (Navajo sandstone).

These pioneer geologists restricted the Jurassic to the miscellaneous assemblage of beds between the fossiliferous coal-bearing Cretaceous shales (Tropic) and the massive cross-bedded sandstone (Navajo—at that time classed as Triassic). Their view is summarized by Dutton (1882, p. 35) as follows:

> The Jurassic, as thus separated, consists of a series of bright-red fossiliferous shales resting upon a very massive bed of white sandstone nearly a thousand feet thick. The shales, which are from 300 to 500 feet in thickness, consist of beds which vary much in quality, some being calcareous, some gypsiferous, and others thinly bedded sandstones. Their interest is chiefly palaeontological, since the calcareous layers abound in typical Jurassic fossils, which fix their horizons with certainty.

JURASSIC FORMATIONS

PREVIOUS STUDIES

After a lapse of 50 years the rocks classed by the Wheeler and Powell Surveys as "Triassic and Jurassic" have been reexamined by geologists of the United States Geological Survey. Gregory and Noble (1923, pp. 229–238) found that the Upper Jurassic fossiliferous limestone in contact with Navajo sandstone near Mount

Carmel, Utah, increases in thickness and purity westward but decreases eastward along the base of the Paunsaugunt Plateau and disappears as a definable unit in the cliffs overlooking the Glen Canyon of the Colorado; and that throughout its extent this sequence of calcareous rocks constitutes the "lower part of an assemblage of beds which includes gypsum, sandstone, consolidated variegated muds, and lenses of conglomerate," and extends upward to "coal bearing fossiliferous Cretaceous." Other geologic studies (Gilluly and Reeside 1928, Gregory and Moore 1931, Dake 1919) showed that the "Jurassic" rocks noted by Howell, Gilbert, Dutton, and Walcott in the Parunuweap, Kanab, and Paria Valleys are widely exposed in east-central and southern Utah, where they comprise groups of strata strongly contrasted in composition and origin and are represented in the topography of distinctive forms. As these groups maintain their characteristic features over hundreds of square miles, names applied in local descriptions were gradually abandoned in favor of a comprehensive terminology; by agreement among field workers the Jurassic beds above the Navajo sandstone were subdivided into five formations—Carmel (at the base), Entrada, Curtis, Summerville, and Morrison. In this revised nomenclature the Carmel, Entrada, Curtis, and Summerville formations constitute the San Rafael group, and the Navajo sandstone found its place as the youngest member of the Glen Canyon group, which includes also the Kayenta (Todilto) formation and the Wingate sandstone below. The San Rafael group is assigned to the Upper Jurassic with confidence; the faunal evidence is adequate. The age of the Glen Canyon group has not been satisfactorily determined; diagnostic fossils are lacking. However, as its basal member rests on strata of Upper Triassic age (Chinle formation) and its highest member lies directly beneath strata of early Upper Jurassic age (Carmel formation), it seems reasonable to assign the group to the Lower (?) and Middle Jurassic.

In constructing a stratigraphic column for the Kaiparowits region Gregory and Moore (1931) found that all three members of the Glen Canyon group, also the recognized subdivisions of the Triassic, readily could be correlated with their counterparts east of Glen Canyon, and that southwestward from the Waterpocket fold where its component formations are typically exposed the Upper Jurassic undergoes noteworthy changes. Especially in the Paria River drainage basin, difficulty was encoutered in attempting to define stratigraphic units that reasonably might be correlated with the Upper Jurassic formations established farther east. In fact, the arrangement of beds more closely resembles that to the west—in Johnson, Kanab, and Virgin River Valleys. The Carmel formation was identified with assurance, the Entrada with some doubt, and with great doubt some strata which superficially resembled the Summerville and Morrison were assigned to those formations. Fuller knowledge of the Jurassic of southern Utah permits a re-interpretation of the stratigraphic sequence as originally outlined for the western Kaiparowits and eastern Paunsaugunt regions. In particular it appears that the Summerville and Morrison formations are not represented in the Paria River Valley; that the Curtis formation is present; and that the topmost Jurassic beds are physically so unlike their time equivalents as to justify the recognition of a new formation—the Winsor. Therefore, as treated in the present report the Jurassic comprises five subdivisions: Navajo sandstone, Carmel formation, Entrada sandstone, Curtis formation, and Winsor formation. However, it seems pertinent to express some doubt regarding the validity of this classification. Regional studies and certain physical and faunal features of the formations suggest the possibility expressed by W. L. Stokes (personal communication) that in the Paria Valley the "Entrada" and "Curtis" are facies of the widely spread, well established Carmel formation, and that locally the Upper Jurassic comprises only the well established Carmel formation and the Winsor formation, which probably is the equivalent of the Upper San Rafael group and the Morrison formation.

As represented in the Paunsaugunt region the Carmel, the Entrada, and the Curtis depart from their typical expression sufficiently to justify detailed description. The Navajo sandstone seems to need no special attention; the features of this remarkable bed have been fully described elsewhere (Gregory 1917, 1950). In composition, texture, thickness, and topographic form the outcrops of the Navajo along the Paria River and its many tributaries are but characteristic parts of the massive cross-bedded sandstone that wall in Glen Canyon, form the White Cliffs, and give grandeur to the landscape of the Navajo country and Zion National Park. (See figs. 30, 33, 35, 39.)

CARMEL FORMATION

In the Paunsaugunt region the Carmel formation is almost continuously exposed between Paria Valley and Kanab Valley. Though in few places more than 100 feet thick, it is relatively resistant to erosion, and therefore appears in the topography as a steep slope marked by tiny cliffs whose height measures the thicknes of the harder beds. Along the streamways the Carmel forms the walls and floors of many narrow, sharply cut gulches, and on inter-canyon spaces it is the cap rock of cliffs and mesas, and the surface of broad terraces from which the younger rocks have been stripped.

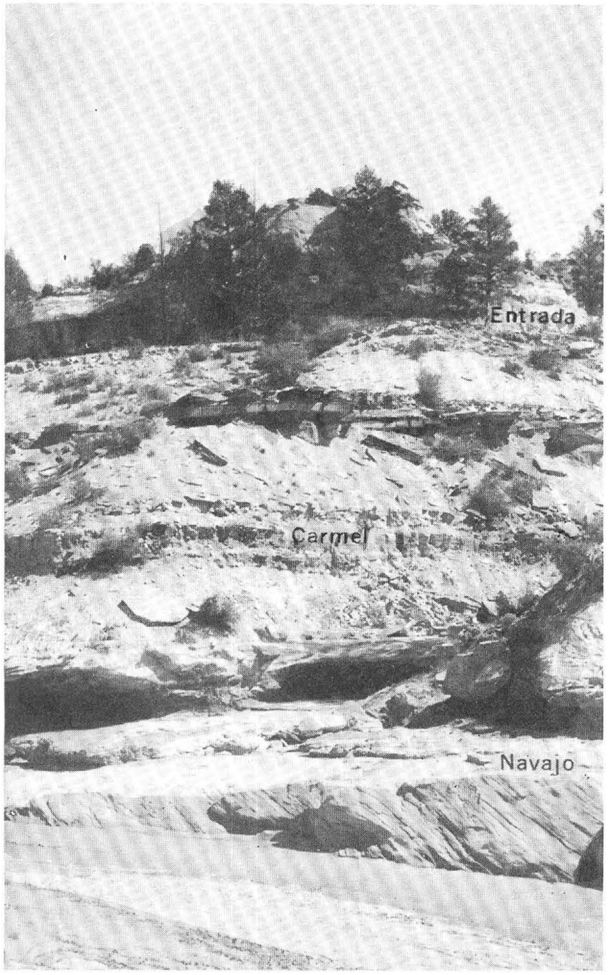


FIGURE 9.—Sheep Creek Valley, showing Navajo sandstone (base), Carmel formation (middle), Entrada sandstone (top).

Wherever observed the Carmel formation rests unconformably on the Navajo sandstone. Commonly the contact is a plane of low relief, in places grooved and channeled, along which the truncated cross-bedded structures of the Navajo sandstone directly underlie horizontal beds of calcareous shale. The upper limit of the formation is not clearly defined. Where the topmost fossiliferous blue-gray limestones of the Carmel are unevenly worn or strewn with fragments of hardened clay and green shale, and the beds immediately above are red gypsiferous friable sandstones, the plane of separation is unmistakable; generally, however, the beds of the two formations are accordant in attitude and where gypsiferous sandy shales of the Carmel directly underlie similar beds the contact is not recognizable. For these reasons, areas mapped as Carmel (pl. 1) include much weathered, indefinitely bounded exposures of Entrada in shallow valleys and among sand hills on interstream spaces.

At all outcrops examined the Carmel consists of shale, limestone, and sandstone—regularly interstratified—and smaller amounts of gypsum and conglomerate in thin and thick lenticular beds. Tracing of the formation from the Paria Valley westward along the base of the Paunsaugunt Plateau shows somewhat systematic changes. Though at all outcrops along this course the Carmel includes argillaceous, calcareous, and arenaceous beds, the sequence of strata varies considerably. Just east of Paria River three thin beds of crystalline limestone lie within 6 feet of the top of a measured section; a series of green and gray ripple-marked shales occupy the middle; and sandstone lies at the base. In the Paria Canyon one group of thin limestone beds near the base and two near the top comprise about one-tenth of a section in which sandstone and variegated ripple-marked calcareous and argillaceous shale are dominant. In Sheep Creek Canyon the lower two-thirds of the formation consists of limestone in exceptionally even, persistent beds about one-sixteenth of an inch thick, and the upper third chiefly of irregularly stratified calcareous sandstone, red at the base. On the divide between Sheep Creek and Everitt Creek thin basal limestone is overlain or replaced by bedded gypsum. In Bull Valley, where the formation is 134 feet

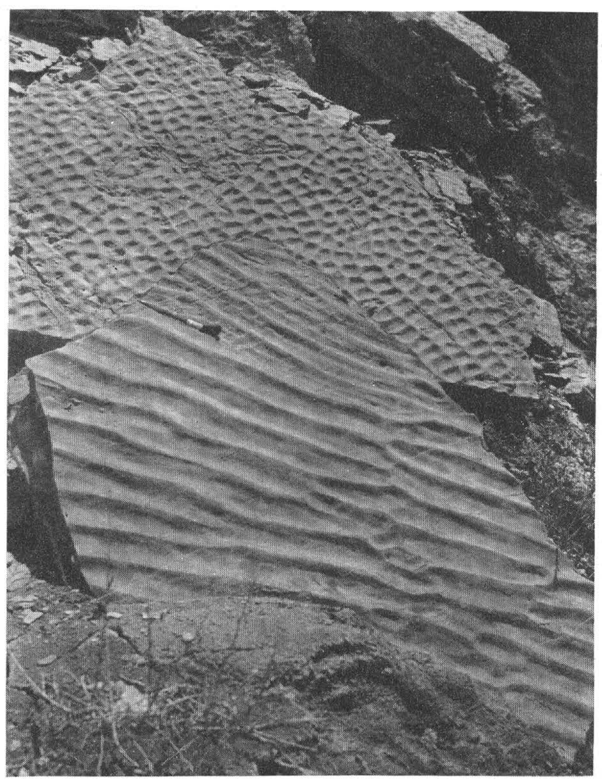


FIGURE 10.—Ripple marks and tadpole holes in limestone of Carmel formation, branch of Paria Valley. Photograph by C. C. Presnall.

thick, 4 feet of gray porous calcareous sandstone is succeeded upward by 6 feet of dense blue thin-bedded limestone, 32 feet of sandy calcareous shale, 3 feet of gray and white bedded gypsum, and 86 feet of regularly bedded sandstone and shale, much of it but slightly calcareous. Between Bullrush Hollow and Swallow Park the arrangement is 0 to 6 feet of greenish imbricated shales (at the base), 40 feet of blue-gray paper-thin sandy limestone, and 80+ feet of red, crumbly, unevenly bedded shaly sandstone. In Swallow Park the lowermost 20 feet is thick bedded limestone. In Johnson Canyon the dominant beds are calcareous shales and the limestones are more abundant than the sandstones.

As commonly exposed in the Paunsaugunt region, the individual limestone beds in the Carmel are less than an inch thick; they are dense, compact, and so hard and brittle as to break into sharp-edged chips that lie on talus slopes and appear in stream beds several miles from their source. They consist almost wholly of calcite or calcite and dolomite; as viewed under the microscope only two thin sections show as much as 5 percent of cloudy quartz and clay substances. The beds recorded in notebooks as "arenaceous limestones" are made of beautifully rounded, glistening quartz grains (5 to 30 percent of the rock) and crystalline calcite tightly cemented with lime. Many of them show symmetrical ripple marks. (See fig. 10.) The soft variegated argillaceous shales that in places lie at the base of the Carmel reveal to the microscope grains of quartz and calcite, hardened mud, also tiny lenses of stratified clay and impure sandstone. A thin section of a local hard bed consists almost wholly of oolitic grains of chertlike quartz and silicified calcite. The sandstones consist generally of spherical grains of quartz, cemented weakly with calcite, rarely with gypsum.

So far as observed, the Carmel of the Paunsaugunt region is devoid of identifiable fossils. Its position in the time scale is fixed by regional relations. It everywhere overlies Navajo sandstone and has been traced into its type exposures at Mount Carmel, where a rich fauna has been identified as lower Upper Jurassic (Callovian)—the age of the Ellis, of the lower part of the Twin Creek formation, and perhaps part of the Sundance formation of Wyoming.

The materials that make up the Carmel may have come from the hypothetical land mass, Jurosephynea, in Montana and Idaho, as postulated by Crickmay (1931). More likely their source was nearer; probably the lands east of Glen Canyon, where terrestrial rocks are known to have been exposed to erosion in Carmel time.

ENTRADA SANDSTONE

DISTRIBUTION AND GENERAL FEATURES

In the Paunsaugunt region the dominantly calcareous Carmel formation is overlain by a series of dominantly arenaceous beds classed as Entrada sandstone, which in the mass is readily distinguished by its mode of weathering and by its red or yellowish-red color, contrasted with the tan and bluish-gray limestones below and more strongly with the beds of white gypsum above. (See fig. 11.) Considered as a whole

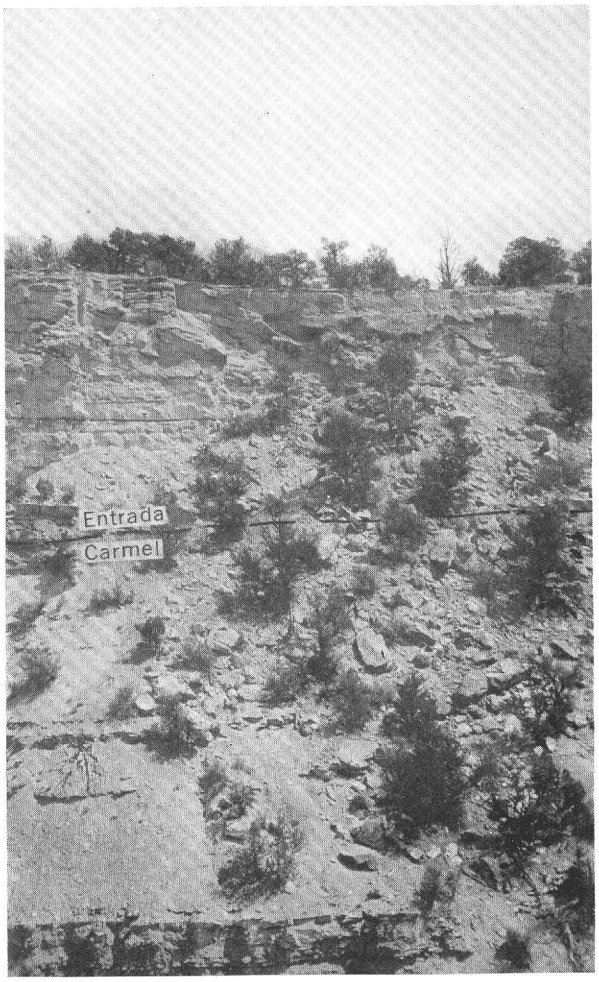


FIGURE 11.—Thin bedded, friable Entrada sandstone (upper third of view) above calcareous shales of the Carmel formation, near the mouth of Everett Wash.

the Entrada is a series of fairly thin regular strata of sandstone interbedded with thicker sandstones and subordinate layers of calcareous and gypsiferous shale, gypsum, and limestone; the cementing material is gypsum and lime, very rarely iron. As shown in the stratigraphic sections (pp. 57–68), an outstanding feature of the formation in the Paria Valley is a massive cross-bedded yellowish sandstone stratum, 60 to 90 feet thick, displayed as a strong cliff, that westward thins to extinction. Along strike this big, compact stratum is replaced by two strata of smaller dimensions, and in places by sandstones 1 to 4 feet thick which occupy different stratigraphic positions, or by arenaceous shales that crumble into mounds of sand. In Sheep Canyon the thickest individual sandstone bed measures 28 feet; at Swallow Park, 18 feet; in tributaries to Johnson Canyon, 10 feet; and farther west in Kanab and Parunuweap Valleys, beds of this type are unrecognizable.

The exact base of the Entrada sandstone is difficult to determine; it is generally concealed by a cover of sandlike talus. In places it is marked by a surface of incipient erosion, but commonly the limestones, or highly calcareous shales of the Carmel, grade upward into slightly gypsiferous and calcareous sandstones of the Entrada, and their contact is shown chiefly by contrast in color and degree of friability. At its top the Entrada is generally unconformable with the Curtis formation. In places small lenticular masses of iron-cemented conglomeratic sandstone that includes bits of variegated clay and concretionary limestone form an irregularly wavy surface beneath thick beds of gypsum. But at the outcrops where gypsiferous sandstones of the Entrada are not clearly distinguishable except in color from the more richly gypsiferous shales above, the actual contact is obscure. The bedding of the Entrada is substantially accordant with that of the Carmel and Curtis, and the erosional unconformities probably express brief halts in sedimentation.

As measured in sections where its limits are clearly recognizable, the Entrada of the Paunsaugunt region is 102 to 255 feet thick, and farther west, in the Zion Park region, 160 to 240 feet. To the east, in the Kaiparowits region, measurements of 400 to 606 feet are listed, and in the San Rafael Swell, the type locality, 312 to 844 feet. It is worthy of note that Baker, Dane, and Reeside (1936, p. 23, pl. 4) assigned to the Entrada in the Paria Valley all the Jurassic above the Curtis formation—included by them in the Carmel—thus making the thickness approximately 750 feet. It has been observed that across southern Utah west of Glen Canyon the thickness of the Entrada varies inversely with the thickness of the Carmel. Thus at the southeastern edge of the Kaiparowits Plateau, where the Entrada is 660 feet thick, the Carmel measures 50 feet. Maintaining this relation across an intervening stretch of about 125 miles, the thickness of the Entrada near the Hurricane Cliffs averages about 100 feet, and of the Carmel 300 feet. Still farther west in the Santa Clara Valley only the Carmel seems to be present.

PHYSICAL FEATURES

In its physical aspects the Entrada of southern Utah may be said to comprise a massive phase and a bedded phase that regionally intergrade but where fully developed are distinctive in bedding and composition and give rise to distinctive erosion forms. The massive phase is most prominent along Glen Canyon and eastward in Grand County, Utah, where the entire Entrada is displayed as huge red cliffs of uniformly fine-grained cross-bedded sandstone that in bulk rivals the Navajo sandstone. (See Gregory and Moore, 1931, pp. 77, 78; Baker 1933 pp. 49–50.) Progressively westward along the bases of the Kaiparowits and Paunsaugunt Plateaus the massive phase constitutes a decreasing portion of the Entrada, becomes roughly bedded, less uniform in composition, changes its color and incorporates materials other than sandstone. In places the Entrada is entirely massive and strongly cross-bedded, in others obscurely stratified, and in still others subdivided by persistent bedding planes. Selected specimens from ledges in Paria Valley contain grains of clear quartz (±95%), clouded feldspar, magnetite, biotite, and calcite. About half of the grains are spherical and half subangular; 90 percent of them average about 0.07 millimeter in diameter, and the smaller grains make a powderlike silt. A representative sample of the massive Entrada sandstone in a branch of Willis Creek is described by C. S. Ross of the United States Geological Survey as "White fine-grained sandstone, grains average 0.15 millimeter in diameter, subangular. Grain quartz with a little feldspar. Very minute calcite grains between sand grains. Yellow grains average 0.2 millimeter in diameter. Well rounded. Very fine calcite between grains. Color due to slightly more hydrous iron oxide." Most of the widely scattered large grains (0.15–0.50 millimeter in diameter) are angular and many are frosted or wind etched. The finest grains fill local pockets with powderlike silt. The cementing material is calcite and ferric iron, rarely mingled with a little gypsum. The iron is sufficient to give the rock a conspicuous yellowish white to lemon yellow tone; to sheep herders the "yellow ledge" is a landmark. In the mottled rock the range in color from nearly white through yellow to red records chiefly the amount and state of oxidation of the iron.

In the bedded phase of the Entrada the predominant rock is deep red, fine-grained, earthy sandstone; the subordinate materials are gypsiferous shales, calcareous shales, and conglomerates. Near the Paria River the bedding is irregular, much of it lenticular, and on weathered surfaces it develops knobs, benches, and irregularly placed steps that record the thickness and extent of the individual strata. Toward the west the beds become thinner and more uniformly spaced until evenly foliated strata a few inches to a few feet in thickness make up the entire sequence. Generally the regularity of bedding is emphasized by horizontal white bands, more numerous near the top. In composition the bedded phase, like the massive phase, consists chiefly of round and subangular grains of quartz, associated with a little feldspar, biotite, calcite, and chert, but the quartz grains are smaller (0.12 to 0.20 millimeter in diameter) and more of them are frosted, and iron and calcite grains are fewer. Another feature characteristic only of the bedded phase is the abundance of gypsum, which not only serves as the chief cement but constitutes large parts, in places all, of some disk-shaped shaly masses. As secondary deposits it fills joint cracks and lines cavities produced by water seepage. Selenite crystals are conspicuous on the talus.

AGE AND CORRELATION

In the absence of fossils the age of the Entrada sandstone is fixed by its stratigraphic position; along the base of the Paunsaugunt Plateau and westward to Mount Carmel, Utah, the formation occupies the interval between the fossiliferous Carmel and Curtis formations, believed to be respectively early Upper Jurassic and middle Upper Jurassic in age. Correlation of beds assigned to the Entrada in the Paunsaugunt region with those that make up the formation in adjacent regions is established by tracing. Outside of Utah the upper part of the "Nugget" sandstone and the lower part of the Beckwith formation of Wyoming appear to be equivalents. (See Gilluly and Reeside, 1928, p. 62.)

CURTIS FORMATION

In stratigraphic sequence the Entrada sandstone is succeeded by the Curtis formation, which, like the Entrada and Carmel, may be almost continuously traced through the foothills of the Paunsaugunt Plateau and on westward across the Skutumpah and Kolob Terraces to the Hurricane Cliffs. Generally in the topography it is conspicuous: a low white cliff above a steep dark red slope, and rounded ledges devoid of superficial debris. At all outcrops examined the formation comprises gypsum, limestone, calcareous sandstone, and gypsiferous, strongly arenaceous shale. (See fig. 12.) The gypsum, though varied in thickness, is a persistent stratigraphic marker, easy to follow. Generally in measured sections the more massive beds are at the base. In the Dry Valley branch of the Paria Canyon, beds of gypsum, the thickest 13 feet, lie at the top, in the middle, and at the base of the formation. Along Sheep and Willis Creeks and in Everett Hollow beds respectively 3, 9, and 16 feet thick, lie directly on the eroded surface of the Entrada sandstone. At Swallow Park, at Skutumpah, in branches of Johnson Creek, and in Kanab Valley, the basal Curtis is a huge bed of nearly pure gypsum that in some exposures constitutes nearly all the formation. Commonly the gypsum is a solid mass, white or green white, rarely pink in color. In places it is a sequence of wavy or contorted beds that include dense knots and fibrous bundles; in other places it consists of white amorphous gypsum (largely anhydrite) interlaminated with green highly gypsiferous shale in crumbled layers less than an inch thick.

FIGURE 12.—Curtis formation in Everett Wash. The formation consists of a massive gypsum ledge (center) and friable gypsiferous shale (top).

The calcareous beds in the Curtis formation range from nearly pure limestone (or dolomite ?) to strata composed of overlapping beds of limestone, calcareous shales and gypsiferous earthy sandstones richly impregnated with lime. At many exposures the limestones, 3 to 25 feet thick, consist of evenly foliated beds as thin as cardboard and resistant enough to form local cliffs that protect from erosion the gypsum below. Fragments remain in the talus as hard, sharply angular chips. Commonly the beds are ripple marked and in other respects resemble the limestones in the Carmel formation. In turn, above the prevalent gypsum and limestone the Curtis formation includes thin quartz sandstones, many broad thin sheets and lense-shaped groups of brown, pink, or red, closely laminated calcareous and gypsiferous sandstone, also layers and knobby aggregates of flaky mud shales. In places massive, compact, richly fossiliferous limestone—essentially coquina—form lenticular beds as much as 5 feet thick.

The division plane between the Curtis formation and the underlying Entrada sandstone is generally marked by an abrupt change in character of materials: iron-stained quartz sands immediately below gypsum or calcareous shales. In places the contact is a surface of erosion. The upper limit of the formation is much less clearly definable. Commonly the dense gray limestone or calareous and gypsiferous shales characteristic of the Curtis are directly overlain by the color banded, thinly laminated sandstones of the Winsor formation, and where these rocks have been stripped away, the exposed Curtis appears as a platform of hard rock roughened by broad low mounds and shallow depressions which suggest erosion but show no definite evidence of stream work. In places the Curtis meets the Winsor across a sequence of beds that present features of both formations. A rather careful study of the contacts leaves the impression that no great length of time elapsed between the deposition of the Entrada and of the Curtis and that perhaps the Curtis and the Winsor record uninterrupted sedimentation.

In the Paunsaugunt region marine fossils have been found in the Curtis formation at several places, in beds 50 to 250 feet above the base. Regarding a collection from Everett Hollow, Ralph W. Imlay [4] remarks:

The fossils from the Curtis formation at Everett Hollow, Kane County, Utah, consist of molds of *Ostrea*, *Volsella*, *Eumicrotis?*, *Camptonectes?*, and a large undetermined pelecypod resembling *Cardinia*. The state of preservation does not permit very close identification, even generically, and an age determination on the basis of the fossils is not possible.

The fossiliferous beds extend westward into the Parunuweap Valley, where such fossils as *Ostrea* sp., *Dosinia jurassica*, *Ostracoda trigonia* and *Pentacrinus* sp. fix their age as middle Late Jurassic, and serve to establish correlation with the type Curtis formation in San Rafael Swell, Utah. It would appear that the Curtis of the Paunsaugunt region, as of other parts of southwestern Utah, marks the limits of a narrow bay that in Late Jurassic time expanded northeastward into a sea. However, in a regional sense, the outlines of this hypothetical water body are obscure and a continuity of its deposits has not been demonstrated. It may be conjectured that before its final disappearance a fairly long-lived Late Jurassic sea twice overran its southern margin: in Carmel times and again in Curtis times.

[4] Personal communication, Oct. 14, 1946.

WINSOR FORMATION

In their survey of the Kaiparowits region Gregory and Moore (1931, pp. 83–86) found in Paria Valley a sequence of Jurassic strata within which could be recognized modified representatives of the Carmel formation and the Entrada sandstone; and higher up, just below the Dakota, 654 feet of brightly banded sandstones unlike any studied previously in southeastern Utah and northeastern Arizona. Because of their prominence these rocks have received considerable attention, but in the absence of fossils attempts to establish their stratigraphic relations have led to diverse conclusions. Howell (1875) and Gilbert (1875) assigned them to the Cretaceous; Gregory and Moore treated the lower part as possibly a modified expression of the Curtis-Summerville sequence and the topmost 45 feet as highly doubtful Morrison; and Baker, Dane and Reeside (1936, pp. 21–23) classed the entire series as the Entrada formation. More recent studies have shown that these tentative correlations are inadequately supported by field evidence; that the Morrison, as known in eastern Utah, loses its identity before reaching the Paria River; and that no rocks clearly characteristic of the Summerville formation are represented in the Paunsaugunt region. On the other hand, continuous or closely spaced outcrops in the foothills of the Paunsaugunt Plateau and westward into and beyond the Virgin River Valley reveal a stratigraphic sequence in the position of the Morrison but radically unlike that formation, in fact unlike any other Jurassic formation in southern Utah. Along a 50-mile stretch this topmost group of Jurassic strata lies unconformably below the Dakota sandstone and above the Curtis formation, and as determined by measured sections and petrographic analyses, its composition, texture, mode of stratification, and color tones are everywhere substantially the same. For this distinctive sequence of beds the term

Winsor formation has been adopted. (See Gregory, 1950.)

The Winsor formation is conspicuous in the topography; and even at a distance it is readily distinguished. (See figs. 13–16.) Especially near the mouth of Yellow Creek the formation is beautifully displayed as bare, brightly colored walls that extend upward to the dull-colored rims of broad mesas; it borders the

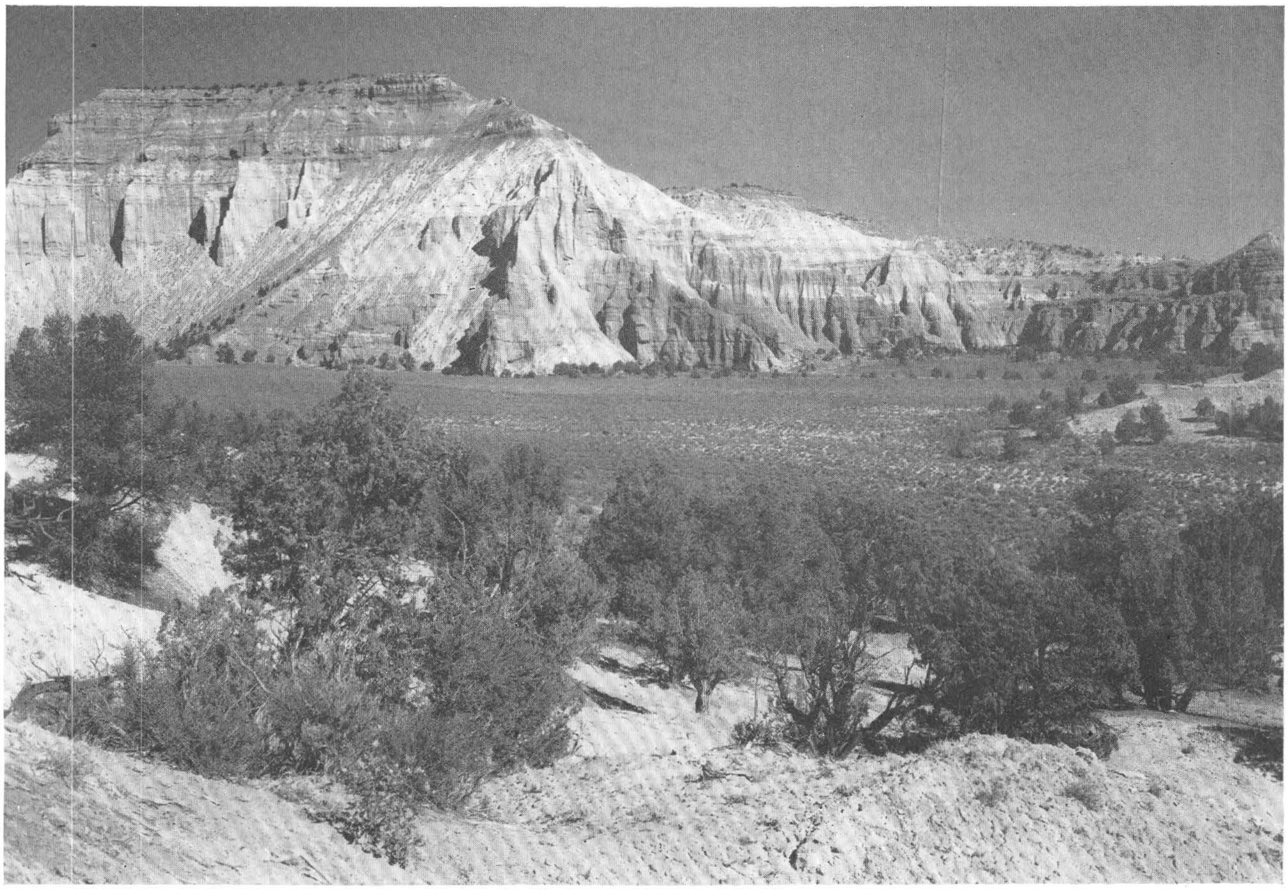


FIGURE 13.—Winsor formation in wall of Yellow Creek Canyon. Dakota (?) sandstone at top.

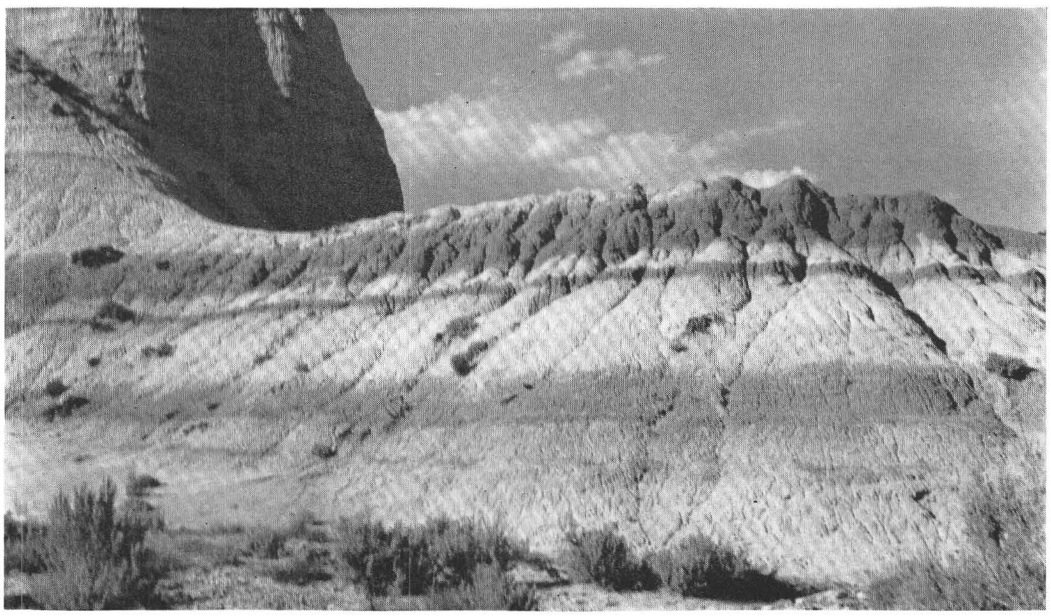


FIGURE 14.—Winsor formation in top of ridge near Cannonville, showing style of erosion and color banding.

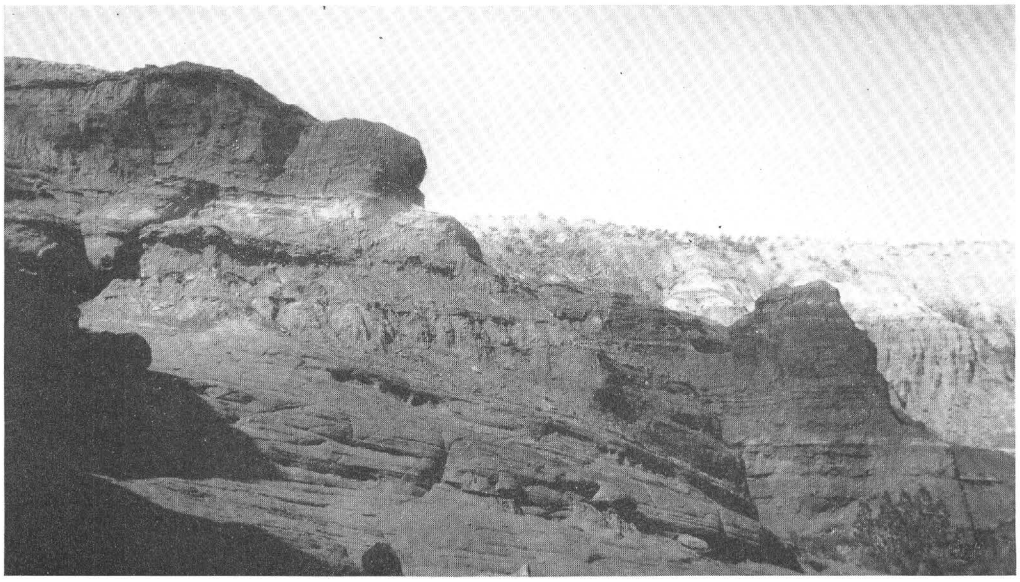


FIGURE 15.—Massive phase of Winsor formation in Paria Valley.

irrigated fields at Cannonville, Henrieville, and the abandoned settlement of Georgetown. Though the rock of the walls is very friable, it is little dissected in places where the protecting cap rock of Cretaceous sandstone is in place, but where fully exposed it is carved by torrential rills into towers, chimneys, buttresses, domes, and statues, picturesque in form and color. Viewed as a whole the Winsor formation in the Paunsaugunt region is a sequence of white sandstones and red sandstones, fine-grained and evenly bedded, and very thinly laminated—measured in inches. Here and there beds a foot or more thick are lenticular, cross-bedded, and so tightly cemented as to project on weathered slopes. The strata are grouped to form color bands, 1 to 8 feet wide, that in areas of considerable size appear to be regularly distributed. In places the rock is prevailing white, but in other places the red bands become broader and more abundant toward the base, until the whole formation appears red except for disconnected streaks and spots of white.

Analyses of specimens from representative parts of the Winsor sandstones show that the red and the white beds are alike in composition except that the cement of the red is chiefly ferric iron and calcite, and of the white, calcite and gypsum. In addition to considerable soluble matter, both types of rock are made up of angular and subangular grains (90 percent) and round grains (9+ percent), of which those more than 0.5 millimeter in diameter constitute 10 to 14 percent, and those 0.2 to 0.3 millimeter in diameter 60 to 80 percent. In one specimen, grains more than 1 millimeter in diameter constitute about 6 percent and in three specimens 10 percent was found to be impalpable dust. More than 90 percent of the grains are quartz, some of them frosted or wind-etched. As determined by Horace Winchell, the heavy mineral constituents rank in order of abundance: magnetite, biotite, zircon, and apatite (?), and the light constituents quartz, calcite, and unclassified clay minerals.

About the mouth of Henrieville Creek the lower part of the Winsor consists chiefly of yellow-red, white spotted, somewhat massive sandstone arranged as lenses 5 to 30 feet thick that on weathering form rounded ledges, domes, and "stone babies," thus simulating thick-bedded Entrada sandstone. Generally these sandstones are separated by thin lenticularly bedded, variegated, calcareous, gypsiferous, rarely argillaceous, shales, and within them are incorporated irregularly shaped bunches of dark red shale, aggregates of chert and chalcedony, quartz-lined geodes, and at one place copper ore associated with petrified wood. This rock mass, seemingly out of place among the Upper Jurassic strata, is thought to represent a local phase of Winsor deposition. From its center outward the thick sandstones decrease in amount and occupy different stratigraphic positions. Laterally in less than two miles the more massive sandstones merge with the normal, regularly bedded, color-banded sandstones, and have essentially the same composition.

The original nature of the sediments that make up the Winsor formation, the position and character of the terrane from which they came, and the mode of transport have not been satisfactorily determined. The mineral content suggests an arkose in which the feldspar has been reduced to clay; the angularity of grains suggests a source not greatly distant; and the regularity of bedding suggests marine deposition. The Winsor formation is the youngest Jurassic known in southern Utah. Seemingly without an intervening time lapse, it rests on fossiliferous beds of the Curtis formation, defined by Baker, Dane, and Reeside (1936, p. 8) "middle upper Jurassic, Divesian, and Argonian."

WINSOR-DAKOTA (?) EROSION INTERVAL

Along the base of the Paunsaugunt Plateau wherever the Cretaceous and Jurassic are exposed the Dakota (?) sandstone rests unconformably on the Winsor formation. (See fig. 16.) The interval is marked by an abrupt change in character of the sediments and by a surface of erosion. In all measured sections white or red- and white-banded fine even-grained sandstone is abruptly succeeded upward by gray lenticular coarse sandstone that includes coal. In some places the top of the Winsor formation is merely worn into broad, shallow depressions and low rounded ridges; in other places it is cut into narrow channels 5 to 10 feet deep, and the depressions thus formed are filled with conglomerate composed of exotic pebbles as much as 1 to 5 inches in diameter. At one place fossil logs and twigs lie at the bottom of a deep pit. The relations duplicate those at the contact of the Moenkopi formation and the Shinarump conglomerate. Even in the absence of diagnostic fossils and persistent physical features, a hiatus between deposition of the Winsor formation and deposition of the Upper Cretaceous Dakota (?) sandstone is readily demonstrated. No lower Cretaceous sediments are recognized in southern Utah. The sources of the material in the Dakota (?) immediately at the Jurassic-Cretaceous contact are unknown. Little if any of it could have come from the Winsor formation. The basal Dakota (?) in the canyons of Yellow Creek, Sheep Creek, and Willis Creek includes worn, hard fragments of green-white sandstone 2 to 9 inches in diameter and bits of green mud shale that in composition and texture are identical with material in the Brushy Basin shale member of the Morrison formation in regions along Glen Canyon which was their possible source.

CRETACEOUS FORMATIONS

DISTRIBUTION AND GENERAL FEATURES

On the geologic map of the plateau country the Cretaceous appears as a belt that begins at the Pine Valley Mountains in southwestern Utah and extends eastward and northward along the Markagunt, Paunsaugunt, Aquarius, Wasatch, and Tavaputs Plateaus, thence southwestward through Colorado into New Mexico and westward into northern Arizona. Generally along this belt the strata are prominently exposed in the topography and little concealed by talus or vegetation, and thus well displayed for study. Under these favorable conditions sections of the entire Cretaceous sequence have been measured at many places in the plateau country and the valuable coal-bearing beds have received particularly close attention. The numerous published papers on these formations make it reasonably certain that no significant stratigraphic feature

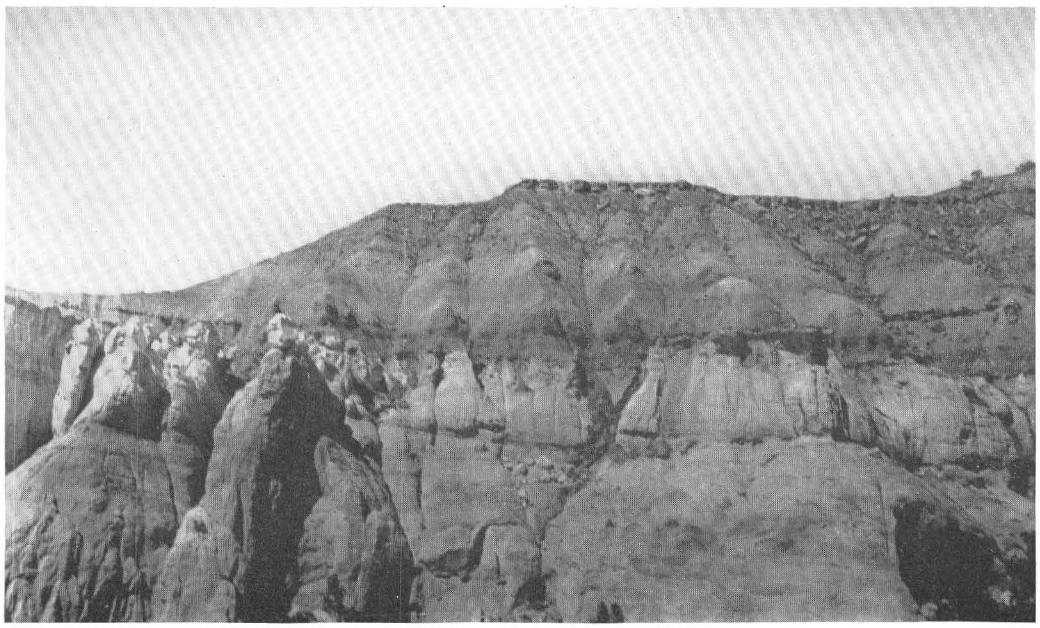


FIGURE 16.—Contact of Jurassic and Cretaceous formations on branch of Henrieville Creek. Winsor formation (base), Dakota (?) sandstone, and Tropic shale.

has escaped observation, but they also show that they record local conditions—that the descriptions of the formations in one area do not apply to adjacent areas. Regional correlation of formations therefore present interesting problems, which have been discussed so fully elsewhere (see Stanton 1893, pp. 34–37; Richardson 1927, pp. 464–475; Spieker and Reeside 1925, pp. 435–454, and 1926, pp. 429–438; Reeside 1924; Gregory and Moore 1931, pp. 111–113; Gregory 1950) as to need no restatement here.

In brief, the chief difficulty encountered in correlating the Cretaceous formations lies in the fact that during the same time interval and within relatively short distances sediments of diverse origin and composition were deposited. Beds several hundred feet thick and essentially alike in lithologic character are of different ages; many beds of the same age bear little resemblances to each other; and the existing knowledge of the fossil fauna is sufficient only for approximate correlation.

From the head of the Paria Valley westward along the slopes of the Paunsaugunt Plateau to the Kanab Valley the Cretaceous extends without interruption and in the numerous deep canyons and knife-edge divides is so fully exposed as to permit almost continuous tracing. Along the west side of the Paunsaugunt the upper part of the Cretaceous, here broken by the Sevier fault, forms the foothills of the Sunset Cliffs south of Hillsdale Canyon. Along the east side of the plateau and at the base of the Table Cliffs (fig. 1) the Cretaceous beds form ridges and the floors of alcoves. On top of the plateau rocks of this system line the valley of the East Fork of the Sevier River for about 15 miles and are exposed in Hillsdale Gap, in Alstrom Hollow, and a few other places. In the regional topography the Cretaceous is easily recognized as a gray-brown band of rock (the Gray Cliffs of Powell and Dutton) between the massive, bright-colored Pink Cliffs (Wasatch formation of Tertiary age) above and the generally white Navajo sandstone (Jurassic) below. In cliffs and slopes the topography expresses also the relative resistance of the various formations and of individual beds within them.

An outstanding feature of the Cretaceous in the Paunsaugunt region is the lack of uniformity in the position, length, and thickness of the beds, also in their texture and composition. This unsystematic arrangement was long ago described by Dutton (1880, p. 154).

SUBDIVISIONS

In conformity with the usage adopted for adjoining areas, five subdivisions of the Cretaceous are recognized in the Paunsaugunt region—the Dakota (?) sandstone, Tropic shale, Straight Cliffs sandstone, Wahweap sandstone, and Kaiparowits formation. As masses of bedded rock these formations possess distinctive features, but their regional and local variation is so great that difficulty is experienced in fixing some of their boundaries. The upper and lower limits of the Cretaceous are well marked by erosional unconformities—with the Wasatch (Tertiary) and the Winsor (Jurassic) formations. Within the Cretaceous well-marked surfaces of erosion strewn with gravel establish the base of the Dakota (?) and of the Kaiparowits, but in the absence of plain horizon markers the base of the Straight Cliffs is somewhat arbitrarily drawn. No persistent features serve to separate the Straight Cliffs and the Wahweap sandstones and these two formations are accordingly mapped as a unit. If the division lines are appropriately placed the thickness of the Dakota (?) in measured sections ranges from 6 to 80 feet; of the Tropic 630 to 1,475 feet; of the Straight Cliffs and Wahweap 535 to 1,620 feet; and of the Kaiparowits 265 to 690 feet.

DAKOTA (?) SANDSTONE

In the Paunsaugunt region the basal Cretaceous formation is a very irregularly bedded sandstone in which are incorporated lenticles of shale, conglomerate, and coal. It is classed as Dakota (?) because of its composition, texture, and its position in the stratigraphic column. Though it may not be the chronologic equivalent of the typical Dakota of Wyoming and eastern Colorado, tracing of its close-spaced outcrops shows clearly its stratigraphic equivalence to the Dakota (?) as mapped elsewhere in southern Utah. However, as features in the topography the Dakota (?) outcrops along the base of the Paunsaugunt Plateau and in the Paria Valley have an unusual expression. Whereas in the San Juan Valley, the formation is the thick cap rock of the extensive Sage Plain and the resistant rim rock of miles of canyons and along the base of the Kaiparowits Plateau forms wide benches, in the Paunsaugunt region it is in general thin and too friable to form prominent cliffs, benches, or even steps on slopes. In places it is lost in the topography; on some canyon walls its position is indicated merely by a black band just above white Jurassic sandstone, and on many slopes by accumulations of pebbles not found in the beds above or below. Here and there the Dakota (?) is resistant enough to remain as the caps of small mesas and narrow spurs and as knoblike masses on eroded surfaces, but in places it is so weakly cemented that no blasting or crushing is required to prepare it for use as road metal.

Everywhere in the Paunsaugunt region the Dakota (?) is a disorderly assemblage of conglomerate, sandstone, shale, and coal; a series of short or long, tapering or stud-ended lenses that seemingly have arrangements peculiar to each outcrop. The conglomerate consists chiefly of pebbles of white and gray quartz, red, gray, and banded quartzite, and chert of various colors, one-eighth to 3 inches in diameter, most of them fairly well rounded. Less common are rounded and subangular fragments of red and gray dense sandstone, hard blue limestone, vein quartz, ironstone, and compact clay. The sandstone in the Dakota (?) is commonly buff gray, coarse-to-medium-grained, and like the conglomerate forms lenticular beds. In a few places it is fine-grained and even-bedded for short distances. In addition to the dominant quartz, microscopic analyses reveal bits of magnetite, garnet, augite (?), and rutile. Most of the subordinate shale is very arenaceous and might as well be classed as thin-bedded, impure sandstone.

All outcrops of the Dakota (?) examined include carbonaceous material—in some places merely disseminated bits resembling charcoal, in other places macerated leaves and twigs, earthy lignite, or bituminous coal. Most of the true coal beds are of small extent and range in thickness from an inch to about a foot. A few short beds are as much as 3 feet thick and have been mined. (See p. 108.) Most of the coal and other carbonaceous matter is near the top of the formation, but some of it is at the bottom, where it is associated with petrified wood. Near Last Chance Creek, east of the Paria Valley, logs 2 to 4 feet in diameter and 10 to 90 feet long are embedded in the basal sandstone.

In thickness the beds here classed as Dakota (?) range from 6 to 80 feet and average about 30 feet. In large part the wide range results from arbitrarily placing the upper limit of the Dakota (?) just below the first fossiliferous bed in the overlying marine Tropic shale, which, however, has no fixed place in the stratigraphic column. In fact, the fresh- and brackish-water conglomerate and associated sandstone and coal of the Dakota (?) grade irregularly upward into beds of similar composition that contain marine fossils, and the Dakota (?) might well be treated as basal Tropic and as marking the beginning of the oscillation of a shore line that permitted the deposition of off-shore, near-shore, and coastal sediments in close proximity.

Except for macerated plants the Dakota (?) sandstone in the Paunsaugunt region is generally unfossiliferous, but in places it includes lenses composed almost entirely of broken shells among which the following brackish-water forms are recognizable:

Anomia sp.
Corbula cf. *C. subtrigonalis* Meek and Hayden.
Corbula cf. *C. perundata* Meek and Hayden.
Ostrea prudentia White.
Turbonilla coalvillensis Meek.
Volsella (*Brachydontes*) *multilinigera* White.

TROPIC SHALE

In the topography the Tropic shale is a broad belt of dark gray or drab rocks that extends from the Paria Valley westward along the foothills of the Paunsaugunt Plateau to the Kanab Valley and onward nearly across Utah. Generally its base is plainly marked by a narrow bench formed by the stripping back of its soft rocks from the surface of the harder Dakota (?) sandstone, and its top by cliffs of buff sandstone. (See fig. 16.) Where the Dakota (?) is thin or friable the Tropic shale appears at a distance to rest on the color-banded sandstone of the Jurassic. Generally it forms gentle slopes and flats broken by irregular benches—surfaces scantily covered with vegetation. In many places it is covered with talus from the cliffs above or coated with a thin porous layer of rock weathered in place. Commonly the lower part of the Tropic consists of soft dark-drab clayey shale and thinly laminated fine-textured sandstone. In the upper part the sandstone beds are thicker, more numerous, and more continuous. All sections measured include three or more coal beds within 200 feet of the base. Thin sheets of gypsum appear here and there, and crystals of selenite are common on weathered slopes. Though the Tropic shale includes hard beds, as a whole it is eroded with relative ease into flat-floored cliff-bounded areas like the Paria and Alton amphitheaters. (See p. 87.)

As shown by tracing about 30 miles of outcrop and the measurement of 18 sections, the Tropic shale in the Paunsaugunt region is an assemblage of shale, sandstone, and coal, remarkable for their variation in bedding and composition. The shale in the Tropic is dominantly the "drab," "blue-gray," or "steel-gray" shale many times described as characteristic of the Cretaceous beds above the Dakota (?) sandstone. Here, as elsewhere in the plateau country, it is regularly bedded, thin-bedded, and consists dominantly of argillaceous material mingled with very fine grains of glistening quartz and subordinate selenite and calcite. Unlike the thicknesses of 800 to 1,600 feet recorded for shale in the corresponding position (lower Mancos) at exposures in eastern Utah and western Colorado, beds of this composition in the Paunsaugunt region attain thicknesses of less than 400 feet, and in most places they are unevenly interstratified with thin layers of calcareous, gypsiferous, carbonaceous, and highly arenaceous shales and include nodules of lime and iron.

In the valley of Thompson Creek, the uppermost 300 feet of the Tropic shale is regularly bedded dark-blue and light-tan gypsiferous shale that breaks into very thin, somewhat overlapping flakes. Within it are a few beds of fine, even-bedded sandstone 2 to 6 inches thick that on weathered slopes project as prominent shelves. Above the shale in seemingly regular sequence lies 85 feet of fine-grained tan sandstone displayed as beds 3 to 10 feet thick and as much thinner beds that include broad, thin lenses of dense, hard, strongly calcareous sandstone which weathers into tubes and columns resembling features in the limestone of the Wasatch. Overlying this sandstone unit is 84 feet of white and dark shale with beds of coal.

Wherever observed the Tropic shale includes several beds of lignite and bituminous coal, generally grouped near its base. As so far revealed by mining, the thickest and commercially the most valuable beds are in the Kanab Valley. (See p. 108.) The relation of the coal beds to the adjoining strata may be illustrated by the following section of an exposure in the Willis Creek Valley, studied by H. B. Wood, field assistant:

Section in Willis Creek Valley

	Feet
9. Sandstone, tan; thin, even beds; fine-grained; calcareous cement; fossiliferous; a hard cap ledge	12
8. Shale, blue gray; argillaceous; fossiliferous	3
7. Coal, massive, good quality	2
6. Sandstone, buff, coarse-grained, in lenticular beds irregularly interbedded with drab calcareous and gypsiferous clay shale; includes lenses of conglomerate, sheets of macerated plants, and calcite nodules	58
5. Coal, lignitic; lenticular beds separated by sheets of hard clay shale	6
4. Sandstone, dark brown, cemented with iron and lime; includes bits of coal and pebbles of quartzite and fossil wood	6
3. Sandstone, gray, and drab shale, somewhat evenly interstratified; richly fossiliferous	22
2. Lignite, brown, earthy; gypsiferous	2
1. Sandstone, dark gray, coarse, in lenticular beds	4
Total thickness	115

Of the sandstones in the Tropic shales, some are regularly stratified, hard, massive, cross-bedded, 2 to 15 feet thick, and so firmly cemented with lime and iron as to form prominent ledges, or so soft as to weather into rounded piles; others are thin-bedded, lenticular, or imbricated. Many of the thick beds split into thin beds and dovetail into clayey shale. Within distances of 100 to 500 feet along the strike and in the same stratigraphic position fine-grained beds grade into coarse-grained beds or change abruptly into conglomerates of quartz, quartzite, chert, and fossil wood. The finer sandstones consist almost wholly of well-sorted spherical grains of quartz; the coarser rock includes many angular grains of quartz, coal, iron oxide, and hard clay. Many beds contain small concretionary masses of limestone, and mudstone.

The fossils in the Tropic shale include both marine and brackish-water species. Commonly those collected from the argillaceous shales are marine; those from the sandy beds both marine and brackish-water forms. Near the base of the formation marine fossils are fairly common in shales, in sandstones, and associated with coal seams. In places oysters and Gryphaeas make up most of calcareous "oyster beds" as much as 3 feet thick. Above the base of the formation the marine forms are much rarer; some collections contain none.

In the following list of fossils obtained during the course of field work those found in the upper part, the middle part, and the lower part of the formation are roughly segregated. These fossils, identified by J. B. Reeside, Jr., fix the age of the Tropic as Late Cretaceous (early Colorado), the equivalent of the lower part of the Mancos shale of Colorado and Utah and of the Hilliard formation of Wyoming. Fossils near the top of the Tropic in Merrill Hollow are classed by Reeside as "about the age of the Greenhorn limestone of the plains region."

Upper part:
- *Anchura* sp.
- *Anomia* sp.
- *Baculites gracilis* Shumard.
- *Barbatia micronema* (Meek).
- *Cardium pauperculum* Meek.
- *Cerithium* n. sp.
- *Corbula?* sp.
- *Corbula nematophora* Meek.
- *Cyrena aequilateralis* Meek.
- *Exiteloceras pariense* (Stanton).
- *Fusus (Neptunea?) venenatus* Stanton.
- *Glauconia coalvillensis* Meek.
- *Inoceramus* sp.
- *Lima utahensis* Stanton.
- *Liopistha (Psilomya) meeki* White.
- *Lunatia* sp.
- *Lunatia* n. sp.
- *Metoicoceras whitei* Hyatt.
- *Ostrea prudentia* (White).
- *Ostrea soleniscus* Meek.
- *Serpula* sp.
- *Sigaretus (Eunaticina?) textilis* Stanton.
- *Turritella whitei* Stanton.

Middle part:
- *Admetopsis subfusiformis* Meek.
- *Cardium pauperculum* Meek.
- *Corbula nematophora* Meek.
- *Cyrena?* sp.
- *Legumen* sp.
- *Lucina?* sp.
- *Mactra* sp.
- *Ostrea* sp.
- *Tellina* sp.
- *Volsella (Brachydontes) multilinigera* Meek.

Lower part:
- *Anatina* n. sp.
- *Anomia propatorius* White.

Baculites gracilis Shumard.
Corbula sp.
Exogyra aff. *E. olisiponensis* Sharpe.
Exogyra columbella Meek.
Gryphaea newberryi Stanton.
Trochocyathus or *Paracyathus* n. sp.
Ostrea prudentia White.
Volsella (*Brachydontes*) *multilinigera* Meek.
Volsella (*Branchydontes*) sp.
Volsella sp.

STRAIGHT CLIFFS SANDSTONE

At its type section (Straight Cliffs, the south wall of the Escalante Valley, Utah) the Straight Cliffs sandstone consists characteristically of hard, very massive fine- to medium-grained tan or buff-brown beds. Most of these resistant beds are 3 to 10 feet thick, but some measure 20 to 50 feet, and a few 60 to 70 feet, and because the interbedded shaly sandstones are thin they combine in forming a vertical unscalable wall as much as 1,000 feet high. Over large areas, its top beds form the surface of the Kaiparowits Plateau, and for about 50 miles west of Glen Canyon the long yellow and tan vertical walls and huge combs of Straight Cliff sandstone are the dominant topographic feature—especially prominent in contrast with the dissected slopes of dark blue shale at their base. As stated elsewhere (Gregory and Moore 1931, p. 101):

> A noteworthy characteristic of the Straight Cliffs sandstone is the presence in several parts of this area of workable beds of coal. In some districts there are thin streaks of carbonaceous shale and poor coal at horizons that range almost from the bottom to the top of the formation, but in others there is no coal at all. The chief coal zone is the middle third of the formation, and this zone contains individual beds 15 to 20 feet thick. Some of the coal beds appear to be persistent over several square miles but pinch out in many places rather abruptly.

Though in mass the Straight Cliffs sandstones that form the surface and the bordering cliffs of the Kaiparowits Plateau appear as a sequence of beds that suggest uniformity of deposition, measured sections show high variability in thickness, composition, texture, structure, and continuity of individual beds, progressively more pronounced as the formation is traced westward. In the Paria Valley thin irregular beds of sandstone are as common as thick regular beds, the shaly and the sandy units are not restricted to definite horizons with equivalent time values, and coal beds are generally absent. Still farther west along the base of the Paunsaugunt Plateau the massive sandstone units thin and thicken unsystematically, intergrade and intertongue with shale beds above or below, or wedge out entirely.

In the topography the Straight Cliffs sandstone of the Paunsaugunt region is the most prominent part of the Cretaceous. It forms steep valley walls, narrow flat-topped ridges, and boxlike heads of canyons. In distant views it appears as continuous vertical cliffs, one above another, each made of a single thick bed of sandstone. Nearer views show that the cliffs are not stratigraphic units and that as topographic units they die out and are replaced by similar cliffs at somewhat higher or lower levels.

Considered as a comprehensive stratigraphic division, the Straight Cliffs sandstone is a sequence of sandstones and shales that varies widely in the position and character of its component parts. Of its constituent strata sandstones more than 10 feet thick make up about 60 percent, thinner sandstones 35 percent, and calcareous, argillaceous, and carbonaceous shale 5 percent. The sandstones range in thickness from a few inches to more than 60 feet; beds 20 to 30 feet thick give character to many canyon walls. Some of the thicker beds are massive and uniform except for small-scale cross-bedding, and some are evenly stratified, but most of them consist essentially of overlapping slabs and wedges of various dimensions, composition, and texture. Some of the thinner sandstones are likewise lenticular, and some are minutely or coarsely imbricated, but many display remarkably even flat or wavy layers of thoroughly sorted grains and on their surface show ripple marks.

The sandstones are made up of clear quartz (95+ percent); feldspar, calcite, selenite, magnetite, and other ferric minerals. In size the rock grains range from microscopic through those the size of grass seed (80+ percent) to those as large as peas and include spherical and angular grains in different or in the same layers. Complete sorting of grains is unusual; in many beds grains within a moderate range of size are intermingled, and in a few beds observed the grains had been accumulated with seeming disregard to their form, size, or specific gravity.

The prevailing cement of the sandstone is lime and iron, separate or mixed in variable proportions. In many beds the iron cement is sufficiently abundant to produce a yellow and tan color and to form resistant cap rocks of cliffs and benches from which softer beds have been stripped. Ironstone concretions are fairly common on weathered slopes. In addition to the dominant medium-grained rock the sandstone includes many lenses of conglomerate, 1 to 6 feet thick and 5 to 50 or more feet long, that consist chiefly of subangular and strongly angular pebbles of quartz, quartzite, and chert one-eighth to 1 inch in diameter, in places mingled with chunks of compact variegated shale, sand balls, and concretionary aggregates of lime and iron. Most of the coarse sandstones are porous and here and there give rise to springs and seeps of palatable water.

The shales in the Straight Cliffs sandstone, as distinguished from the thin-bedded, shaly sandstones, appear as groups of dominantly argillaceous, carbonaceous, or calcareous strata between the sandstones and as lenses of various dimensions within them. Because they are relatively thin and soft they are noticeable in the topography merely as short well-weathered slopes, recessed grooves on steep valley walls, and pockets in otherwise massive sandstone. Most of the argillaceous shale, the most common form, is regularly stratified in units 3 to 20 feet thick and 100 to 1,000 feet long—a few as much as a mile long. Generally its constituent clay is in tiny grains, nicely sorted along bedding planes, but in some places it is a compact amorphous mass and in others an aggregate of balls, ovate pellets, and disks. Physical analyses show that the shale contains fine quartz sand in various amounts, scattered grains of iron oxide and some calcareous matter, and also disseminated gypsum that fills tiny cracks and on weathering spots talus slopes with glistening crystals. The purest shale is blue gray or drab and resembles that in the Tropic shale, but with increasing amounts of silica, lime, and iron oxide the beds display patches of white, yellow, red, and lavender—the "calico rocks" of local parlance. Most of the carbonaceous shale beds occur commonly in very thin units of small extent, are substantially arenaceous shales that contain specks of coal and carbonized wood, lenticular layers of earthy lignite, and in a few places true coal.

The calcareous shales are thinly, irregularly bedded lime silts that contain much very fine quartz sand. They are "hard beds" and though rare and of slight thickness are conspicuous as projecting ledges. Most of them are richly fossiliferous. Within the Straight Cliffs sandstone many contacts between beds of sandstone and between sandstone or conglomerate and shale are surfaces of erosion. So far as noted, such unconformities have moderate relief and no great extent and lack the features indicative of wide areas long exposed to the air. They are thought to mark the position of local channels scoured in sandstones and shales on a coastal lowland and filled with gravel and sand by ocean currents or land streams. As shown by fossils an unconformity in the valley of Willis Creek lies between marine beds, in the valley of Thompson Creek between marine and fresh-water beds, and in Big Hollow between fresh-water beds.

The seemingly heterogeneous composition of the Straight Cliffs sandstone is well shown in the walls of Proctor Canyon. Here the strata that make up the lowermost 40 feet of the formation are thin fine-grained yellow-gray sandstones and dark blue-gray shales mottled with red, and in one place coal. Above this assemblage, represented in the topography by mounds and low ridges, rise cliffs 560 feet high that consist of tan-colored resistant sandstones in beds 2 to 15 feet thick, separated by more friable shalelike sandstones that on weathering form grooves and the tops of benches. One bed for a distance of about a mile averages 30 feet in thickness and another nearly 40 feet. All the dominantly sandy beds are lenticular, and most of them include stringers and angular chunks of lead-colored clay shale, thin sheets of fine conglomerate, and rows of red and black iron concretions that project from the cliff face. Some of the shale stringers disposed in various attitudes consist of 20 to 30 regularly stratified layers as thin as cardboard. The top bed on the cliffs is a dense dark-gray sandstone 2 to 6 feet thick, and about 50 feet below it a sequence of very irregular sandstone beds about 20 feet thick includes overlapping lenses and irregular masses of conglomerate made up of chert, black limestone, quartz, and quartzite pebbles one-eighth to 1 inch in diameter. Distributed in the sandstones without apparent order but more commonly in the lowermost 150 feet are short thin layers of lignite, chips of charcoal, carbonized twigs, leaf impressions and hollow tubes of ironstone that represent branches of trees 1 to 6 inches in diameter. The hand lens shows that the more massive and uniform sandstones consist of medium-sized poorly rounded grains of clear quartz (90± percent), black iron oxide, calcite, and argillaceous material. Some beds are highly porous and in contact with denser beds form zones of seepage. The strata in Proctor Canyon directly underlie the Wasatch formation along a surface of considerable relief from which the Kaiparowits formation has been largely or entirely removed.

In measured sections the sandstone, shale, and conglomerate components of the Straight Cliffs have no systematic relations. In general the lower half of the formation contains more argillaceous shale than the upper half, in places twice as much. But the thickest and most uniform shale may be almost anywhere. In Deer Spring Wash the upper 500 feet of the Straight Cliffs includes very few conspicuous sandstone ledges. In Lick Wash shale beds mark the top. Generally east of upper Meadow Creek (Riggs Canyon) the beds of conglomerate seem capriciously distributed; west of Skutumpah the prominent exposures of sandstone and conglomerate are 160 to 180 feet above the base. On the other hand, the carbonaceous shales and coal appear everywhere at about the same stratigraphic horizon, and few beds of calcareous shale are present in the lower part.

In preliminary field work it was thought possible to use the unconformities, the conglomerates, the massive thick cliff-making sandstone, the "distinctive shale," and the coal as guides in outlining subdivisions in the Straight Cliffs sandstone based on mode of deposition, perhaps also on age. But tracing and retracing of 20 miles of supposed guide beds and measurements of scores of test sections brought the discouraging conclusion that each tentative subdivision included features of all the others: both the marine and the terrestrial sandstones and shales seemed almost unlimited in variety.

WAHWEAP SANDSTONE

In the sequence of Cretaceous rocks the Wahweap sandstone is a series of thin- and thick-bedded sandstones and sandy shales that conformably overlies the Straight Cliffs sandstone and terminates upward at a well-marked plane of erosion above which the rocks are quite different in character. In the topography it is represented in places by a group of steplike cliffs offset some distance from the vertical walls of Straight Cliffs sandstone and in other places combined with the Straight Cliffs to form a regional steep slope crossed by vertical walls at various altitudes. The steepness and regularity of the cliffs are due not so much to thick, persistent beds as to regularly deposited thin beds of uniform composition.

The Wahweap sandstone consists essentially of sandstones and highly arenaceous shales, in places evenly bedded but generally lenticular on a broad scale and in detail very irregular. Among the sandstones the most conspicuous are massive cross-bedded creamy-yellow or brownish-buff beds 10 to 20 feet thick composed of fine and medium, fairly well rounded grains of clear quartz. Such beds, generally restricted to the upper part of the formation and here and there accompanied by sandstones 40 to 60 feet thick, form vertical cliffs that are continuous for several hundred feet—in Sink Valley (pl. 1) and along Sunset Cliffs (fig. 1) for as much as half a mile. Most of them, however, change within short distances along the strike from solid ledges of substantially uniform texture and composition to thin-bedded sandstones and on to sandy shale. The lower part of the formation consists almost entirely of alternating groups of massive sandstone and shaly sandstone arranged as long and short, thick and thin lenses that laterally and vertically meet at gradational contacts or at local unconformities. In addition to the poorly assorted angular and spherical, coarse and fine grains of quartz, iron oxide is a constituent of most sandstone beds and forms a resistant cement of some exceptionally hard layers. In specimens submitted to analysis calcite appears as scattered grains and as the chief cementing material, and feldspar and ferromagnesian minerals are sparsely represented. The rare lenses of conglomeratic material include banded quartzite, black chert, and worn fragments of bones. Most of the beds in the Wahweap recorded in notebooks as "shale" might as well be classed as shaly sandstone or laminated mudstone. At a few outcrops drab clay shales are parts of long, thin lenses of fine-grained sandstone and claylike bands, colored red, pink, yellow, and lavender by iron oxides, which include carbonized wood, gypsum crystals, and aggregates of amorphous calcite, but remarkably few distinctive beds of argillaceous, gypsiferous, and calcareous shale were observed. Fossils found in the middle and upper parts of the Wahweap have been identified as *Neritina* sp., *Physa* sp., *Viviparus* sp., and turtle (?) bones. The well-preserved impressions of leaves await study.

AGE OF THE STRAIGHT CLIFFS AND WAHWEAP SANDSTONES

Fossils fix the age of the Straight Cliffs sandstone in the Paunsaugunt region as that of the upper (Niobrara) part of the Colorado group. They include the species diagnostic of the Straight Cliffs sandstone at its type locality, the Kaiparowits Plateau, and as an assemblage of forms duplicate that in the Straight Cliffs of the Zion Park region. In regional correlation the formation finds its age equivalent in the middle part of the Mancos shale of Colorado and north-central Utah. The few species of fossils collected from the Wahweap sandstone—*Neritina*, *Viviparus*, *Physa*, and *Ostrea*—appear also, though rarely, in the Straight Cliffs sandstone, but the prevalence of fresh-water and brackish-water forms and their likeness to those in the Kaiparowits formation suggest that as a whole the Wahweap is of basal Montana or at least uppermost Colorado age and that a redefinition of the boundary planes of the Straight Cliffs and Wahweap would eliminate the duplication of species. It seems worthy of note that in the score of Straight Cliffs and Wahweap sections measured *Neritina bellatula*—a feature of the topmost Colorado beds at Coalville, Utah—was found in only one place and *Viviparus* sp. and *Physa* sp. at only two places in strata classed in the field as Straight Cliffs, and at these places only in the uppermost beds. The following list of fossils from the Straight Cliffs sandstone, exposed in the Paunsaugunt Plateau and along tributaries to the Paria River, records the identifications made by J. B. Reeside, Jr.:

Admetopsis subfusiformis Meek.
Anomia sp.

Barbatia micronema Meek.
Campeloma? sp.
Cardium curtum Meek and Hayden.
Cardium pauperculum Meek.
Cerithium sp.
Corbula cf. *C. subtrigonalis* Meek and Hayden.
Cyrena securis Meek.
Cyrena sp.
Fusus cf. *F.* (*Neptunea?*) *venenatus* Stanton.
Glauconia coalvillensis Meek.
Gyrodes depressus Meek.
Mactra arenaria Meek.
Neritina (*Velatella*) *bellatula* Meek.
Nucula coloradoensis Stanton.
Ostrea prudentia White.
Ostrea soleniscus Meek.
Ostera sp.
Planorbis? sp.
Plicatula hydrotheca White?
Physa sp., "very large form, probably new."
Turbonilla? coalvillensis Meek.
Turritella whitei Stanton.
Viviparus sp.
Volsella (*Brachydontes*) *multilinigera* Meek.

The frequent overlapping of fine-grained, evenly stratified shalelike beds with beds containing strings, lenses, and irregular masses of conglomerate composed in part of exotic materials, also the numerous local unconformities, indicate deposition in quiet waters and in the channels of streams. In other words, the composition, texture, and sequence of strata in the Straight Cliffs and Wahweap sandstone indicate deposition on a coastal belt of low relief which was covered by sea water and exposed to the air during alternating periods of unequal length and at different times in different places. Consistent with this mode of origin are the many lateral unconformities and surfaces of erosion between beds.

This conclusion finds strong support in the paleontologic evidence. In the Straight Cliffs sandstone marine, brackish-water, and fresh-water fossils were noted in all but two measured sections and in only two at approximately the same stratigraphic position. Between Proctor Canyon and Big Hollow a fossilferous marine bed extends with insignificant change for at least a mile. On the other hand, in Slide Canyon a series of beds 30 feet thick that contain the marine species *Inoceramus cf. labiatus* and *Turritella whitei* is replaced about 700 feet along the strike by strata that contain brackish-water species of *Ostrea*, *Corbula*, and *Glauconia*. In general in the Straight Cliffs sandstone the vertical spacing of the fossil-bearing brackish-water and fresh-water beds is closer toward the top, and in the overlying Wahweap sandstone none of the very few fossils collected are unquestionably marine. It would thus appear that during Straight Cliffs time the sea was intermittently but progressively withdrawing from southern Utah, and during Wahweap time it rarely extended as far west as the Paunsaugunt region.

WAHWEAP-KAIPAROWITS EROSION INTERVAL

All about the base of the Paunsaugunt Plateau the top of the Wahweap sandstone, or in its absence the Straight Cliffs sandstone, is an uneven surface that marks the division between rocks of unlike history and age. In places this surface roughly corresponds in attitude with the underlying beds and appears but slightly worn, but generally it has been eroded into broad valleys, rounded ridges, flat lands, and domes—a surface of postmature erosion buried by the sediments of the Kaiparowits formation. This ancient rough surface is further marked by a conglomerate composed chiefly of materials not found in the beds above or below. In Hillsdale Canyon, where the Kaiparowits unconformably overlies 200 feet of Wahweap sandstone, its base is a series of lenticular conglomerates about 15 feet thick composed chiefly of black chert and quartzite pebbles one-eighth to one-fourth inch thick embedded in calcareous sandstone. As shown by the measured sections (see pp. 62–67), this conglomerate and associated conglomeratic sandstone generally have the form of sheets and lenses of various dimensions and are composed essentially of round, subangular, and angular pebbles of quartz, variegated quartzite, black chert, and compact sandstone one-eighth inch to 2 inches in diameter, but include also sand balls and concretionary aggregates of green-white clay, limestone, and ironstone. The extent and depth of erosion to which this rough gravel-strewn surface has been subjected seem indeterminable. No fossils were found in the beds immediately below it and those just above are but roughly diagnostic. Furthermore in places the sandstone beds above and below the gravel stream surface present the same range of irregularity in bedding and composition, and in the absence of a clearly defined lower limit for the Wahweap the variation in its thickness cannot be ascribed wholly to the removal of its topmost beds. It is believed, however, that the Wahweap was exposed to erosion throughout southern Utah. The unconformity is a feature of all Cretaceous sections measured between the Paria River and the Hurricane Cliffs and though not recorded may have extended east of the Paria and into adjoining regions where both the Wahweap and the Kaiparowits are no longer present. In the time scale the erosion interval may represent not only the youngest Wahweap sediments but also those mapped east of Glen Canyon as post-Mesaverde.

KAIPAROWITS FORMATION

The Kaiparowits formation comprising the youngest Cretaceous sedimentary rock in the Paunsaugunt region, occupies the interval between the Wahweap sandstone (or in its absence the Straight Cliffs sandstone) and the Wasatch formation of Tertiary age. In the landscape it is displayed as a series of dark-gray or green-gray, in some lights almost black belts that except for minor shelflike benches appears as a series of slopes that combine to form a general slope from the top to the bottom of the formation. It thus is strongly contrasted with the buff and tan ledge-making strata below and the pink vertical cliffs above. Also in contrast with the adjoining formations the Kaiparowits is generally friable: in intervalley spaces it weathers into broad, low mounds that are commonly so thickly coated with disintegration products as to prevent the recognition of individual strata, and on freshly eroded canyon walls beds of it are cut by tangled gullies into badlands. In response to heavy showers innumerable rills in tiny runways strip the weathered coating from the gentle slopes, and carry it along into the valleys of ephemeral streams, where it forms greenish sand bars on an otherwise gray valley floor.

Because it lacks the prominent ledge-making units of the other Cretaceous formations, the Kaiparowits appears at a distance as a sequence of shales interrupted at irregular intervals by lenses of sandstone, but closer examination reveals the predominant rock as a weakly cemented sandstone that from place to place displays a wide range of bedding, texture, and composition. (See fig. 17) Few of the beds are more than 5 feet thick—many are measured in inches—and few of them retain their individuality for as much as 1,000 feet. Some of them consist of thin regular layers of round, fine, thoroughly sorted grains; others of alternating sheets of fine and coarse grains; and still others of short overlapping cross-bedded lenses in which coarse and fine grains, round and angular grains, are intermingled like those in storm-made cones and sandbars. In places several beds of uniform bedding and composition lie one above another, but generally vertical sections 20 to 50 feet thick show regular beds and lenticular beds of quartzose, feldspathic, calcareous, and argillaceous sandstone. A composite analysis of eight samples thought to be characteristic of the sandstone shows roughly 75 percent of round quartz grains, 0.40 millimeter in diameter, and 15 percent of larger size; orthoclase, albite, biotite, and muscovite, 4 percent; calcite, gypsum, clay, iron, coal, and miscellaneous minerals, 6 percent. Many of the feldspar fragments are kaolinized and where associated with biotite and other dark minerals appear as white grains in a mixture of salt and pepper color. As cementing materials the abundant lime and the rare gypsum are inconspicuous on exposed rock surfaces, but iron oxide is prominent in the hard beds and has blotches of red, yellow, and green on weathered surfaces.

In addition to the sandstone the Kaiparowits formation includes short irregular beds of brown, white, and greenish limestone, some of it sandy and some of it pure lime silt in layers as thin as cardboard. At many outcrops the arkosic beds include lenses of impure limestone conglomerate and concretions, lying alone or closely

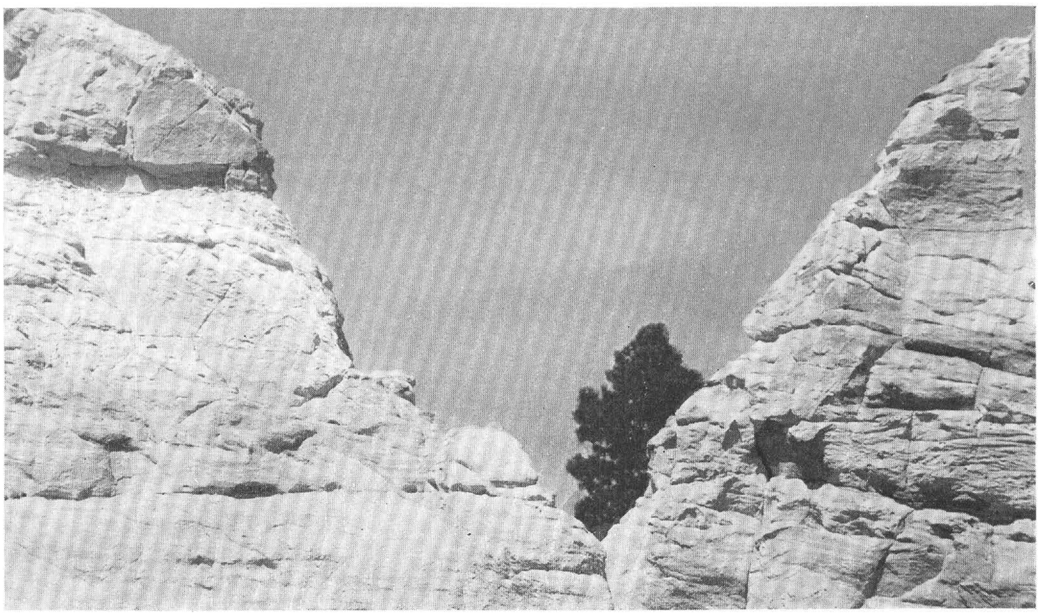


FIGURE 17.—Fossiliferous white sandstone of the Kaiparowits formation in Tenney Canyon.

packed like oolite. In most measured sections the top of the Kaiparowits in contact with the Wasatch is a sandy calcareous blue and purple shale, irregularly interleaved with sandstone and underlain by broad lenses of yellow and tan sandstone that weather in knobs and pinnacles and contain fossilbones and petrified wood. Distributed seemingly without order are ironstone masses, some as much as 30 feet long, in the form of disks, balls, and tubes; concretions of limestone, chert, barite, and gypsiferous mudstone; and angular fragments of chert, hard black limestone, metamorphic rock, igneous rock, sandstone, and hard clay. At the head of Hillsdale Canyon, where the Kaiparowits formation is 660 feet thick, conglomeratic masses of subangular quartzite pebbles 1 to 4 inches in diameter intermingled with iron concretions and slabs of sandstone as large as 4 by 4 by 6 feet, are features of strata 23 and 55 feet above the base, and 140 feet above the base flat clay pellets make up a large part of a thick bed of yellow-gray sandstone that is otherwise evenly stratified. Other unusual features of the formation at this locality, also near Tenney ranch, are almost pure white, friable, strongly cross-bedded sandstones, bearing iron-coated fossil wood and bones, a thin layer of concretionary limestone, 12 feet of purple-red banded, thinly laminated clay shale, and pockets and broad grooves in the topmost beds filled with pebbles as much as 8 inches in diameter. Here and there the argillaceous and gypsiferous shales include considerable carbonaceous material; specks like charcoal, aggregates of leaves and twigs; and logs of partly carbonized wood.

As shown by the following lists of fossils collected during the course of field work in the Paria Valley and westward along the rim of the Paunsaugunt Plateau, the age of the Kaiparowits formation is upper Montana. The lists include the fragmentary vertebrates examined by C. W. Gilmore and the invertebrates identified by J. B. Reeside, Jr. The fossil plants, so far incompletely studied, include species of *Dammarites*, *Podozamites*, *Platanus*, *Betula*, *Menispermites*, *Cinnamomum*, and *Viburnum*.

Vertebrates:

- *Adocus* sp.
- *Baena* cf. *B. nodosa* Gilmore.
- *Basilemys* sp.
- Hadrosauridae (duck-bill dinosaurs).
- Nodosauridae (armored dinosaurs).
- Theropoda (carnivorous dinosaurs).
- Trionychid turtle.

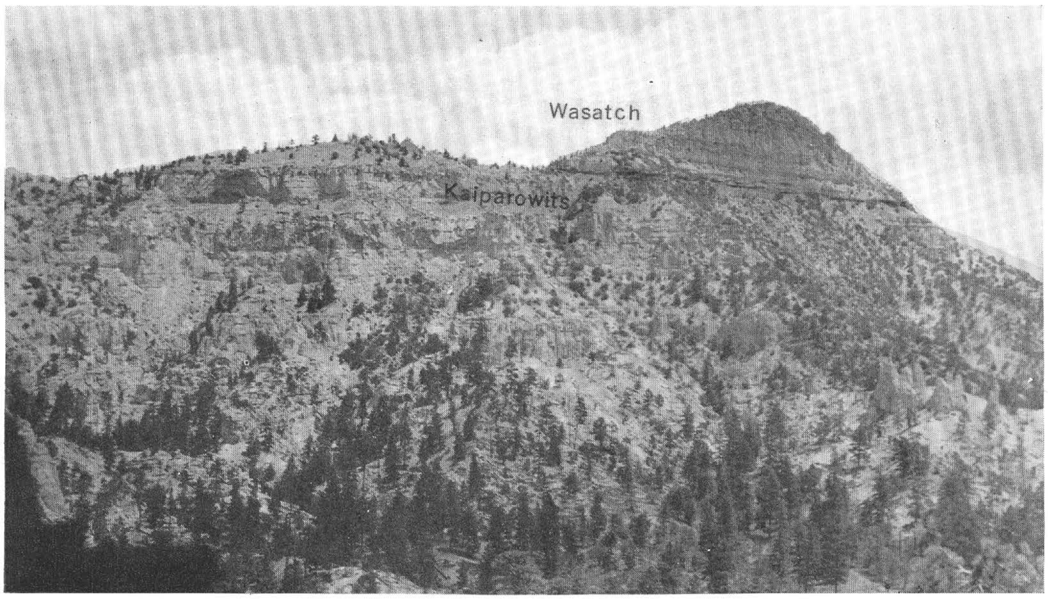


FIGURE 18.—Kaiparowits formation in Hillsdale Canyon in contact with Wasatch formation in Wilson Peak (upper right).

Invertebrates:

- *Bulinus subelongatus* Meek and Hayden.
- *Campeloma?* sp.
- *Goniobasis subtortuosa* Meek and Hayden.
- *Helix* sp.
- *Physa* cf. *P. pleromatis* White.
- *Physa* cf. *P. reesidei* Stanton.
- *Planorbis?* n. sp.
- *Unio* aff. *U. amarillensis* Stanton.
- *Unio* cf. *U. danae* Meek and Hayden.
- *Unio* cf. *U. neomexicanus* Stanton.
- *Unio* sp. "suggesting *U. brachyopisthus* White."
- *Unio* cf. *U. haydeni* Meek.
- *Viviparus panguitchensis* White.
- *Viviparus* cf. *V. leai* (Meek and Hayden).
- *Viviparus* cf. *V. leidyi* Meek and Hayden.

In general aspect the Kaiparowits invertebrate fauna resembles that in the Tertiary Wasatch formation. In several collections from strata less than 100 feet below limestone unmistakably assigned to the Wasatch formation the only fossil definitely indicative of Cretaceous age is *Viviparus panguitchensis*. Other collections contain also "Unio aff. U. *amarillensis*, Stanton, late Cretaceous." But most of the abundant *Physa*, *Planorbis*, and Unios found in this position have Tertiary as well as Cretaceous relations. Regarding a large collection from a bed in the Kaiparowits 90 feet below the Wasatch, Reeside remarks, "This fauna would fit a late [Cretaceous] horizon, though until the fresh-water faunas of late Mesozoic and early Tertiary age have been restudied I hesitate to make a very definite assignment."

On faunal evidence it seems reasonable to correlate the Kaiparowits with the Fruitland formation and overlying Cretaceous formations of Colorado and New Mexico (Reeside, 1924, p. 24) and with the lower part of the North Horn formation of the Wasatch Plateau, Utah. (Spieker, 1931, pp. 42–43.) However, in physical features these three formations are markedly dissimilar. In contrast with the Kaiparowits, which consists almost entirely of sandstone underlain by other sandstones and in direct contact with Eocene beds, the Fruitland and overlying formations include much shale and some coal and are overlain by a considerable thickness of Paleocene strata. Similarly measured sections of the Kaiparowits and North Horn formations show considerable differences in arrangement and composition of beds and in the relation to the overlying Tertiary strata. (See pp. 61–68 and pl. 2.)

CRETACEOUS-ECONE EROSION INTERVAL

The relation of the Tertiary to the Cretaceous sedimentary beds in the intermountain region presents problems that have so far not been satisfactorily solved; attempts to answer the questions raised by the pioneer geologists of the Wheeler, Powell, King, and Hayden Surveys 70 years ago have resulted in no generally accepted conclusion. The difficulty lies in the facts that in many places no physical break separates the two systems, and the rocks near the boundary are unfossiliferous or contain faunas that are not specifically diagnostic.

In publications dealing with the plateau province the oldest Tertiary rocks have been assigned to the Wasatch formation, of Eocene age; and the youngest Cretaceous to variously named formations of Montana age. However, it has long been recognized that in different areas the strata classified as the "Wasatch formation" occupy different positions within the Tertiary time scale, and likewise that in some areas the underlying beds have not received a definite age assignment within the Cretaceous. Consequently in areas where prominent Cretaceous beds pass upward in unbroken sequence into beds known to be Tertiary their contact has been more or less arbitrarily placed, and where a hiatus in deposition is obvious its significance has been variously interpreted.

In the Wasatch Plateau the North Horn formation rests conformably upon the Price River formation and bears in its lower third a reptilian fauna like that of the Fruitland and Kaiparowits formations. In the upper third of the North Horn a mammalian fauna of lower Paleocene age is present. No satisfactory plane of division between the two portions has been recognized.[5]

South of the Wasatch Plateau a hiatus represented by an unconformity at the base of the Wasatch formation is measured in large terms. In the Tushar Plateau Cretaceous beds, if ever deposted, were eroded away before Tertiary sediments were laid down, and in the Markagunt and Paunsaugunt Plateaus and parts of the Kaiparowits Plateau large parts of the Cretaceous known in surrounding regions are lacking.

Callaghan (1938, p. 103) points out that in the Marysville region "the Wasatch (?) formation was probably distributed over an irregular surface of older beds that included Permian, Triassic, and Jurassic sedimentary rocks." Likewise at the east edge of the Aquarius Plateau the Wasatch rests on the Jurassic Navajo sandstone.

In the Paunsaugunt region the massive pink limestones of the Wasatch formation rest on gray sandstones, and the two groups of rocks are radically different in composition and mode of origin. (See figs. 19, 24.) The division between them is a surface of erosion that is everywhere marked by topographic irregularities and in places by discordance in attitude of the beds. Just east of the Paria River the Wasatch lies flat on the eroded edges of the steeply upturned Cretaceous beds in the East Kaibab monocline. In many places the Cretacous-Tertiary unconformity is further marked by beds of conglomerate derived from various sources. The pebbles in the conglomerate are composed chiefly of quartzite, quartz, chert, and siliceous igneous rocks obviously not derived from the Tertiary beds above or the Cretaceous beds below. Some of them are incorporated in the basal Wasatch, but most of them occupy depressions worn into the surface of the Kaiparowits formation.

The information so far available indicates that in north-central Utah at the beginning of Tertiary de-

[5] Spieker, E. M., unpublished data.

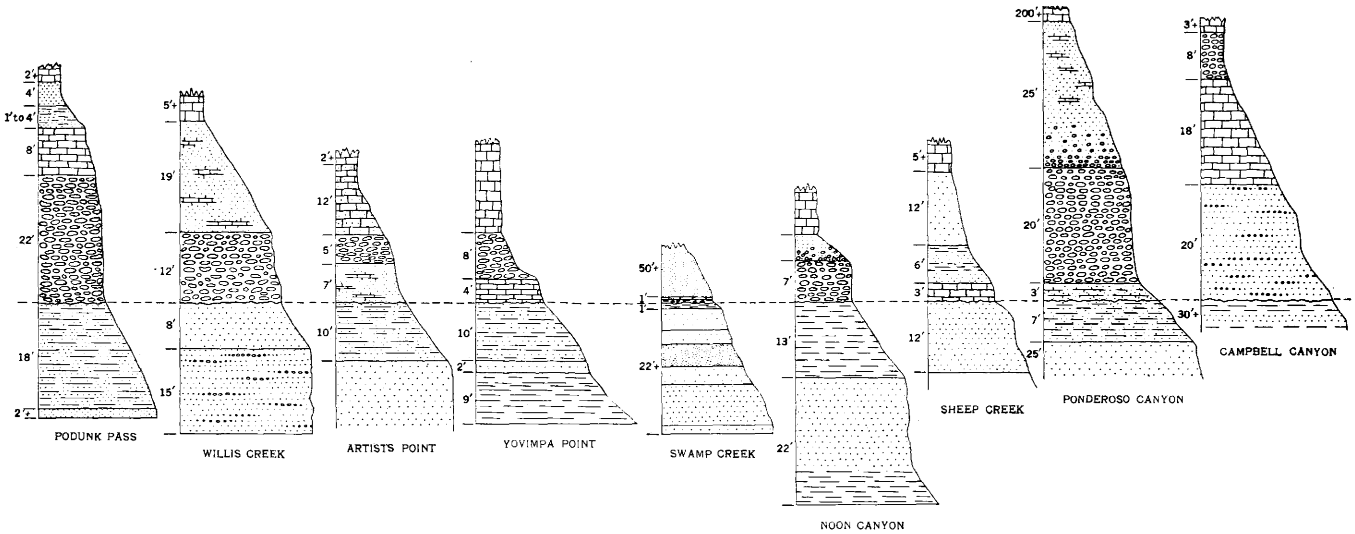


FIGURE 19.—Diagrams showing features of the Cretaceous and Tertiary formations at their contact.

position the Cretaceous rocks presented a surface of low relief, in contrast to the relative ruggedness of the landscape in the Paunsaugunt-Kaiparowits region, where streams were powerful enough to line their channels with tons of cobbles brought from distant unknown sources.

TERTIARY FORMATIONS

DISTRIBUTION AND REGIONAL FEATURES

Thick calcareous sediments of Tertiary age form the surface of Table Cliffs and the Paunsaugunt and Markagunt Plateaus, lie beneath the volcanic sheets of the Aquarius, Sevier, and Apawa Plateaus, constitute the bulk of the Wasatch Plateau, and are widely exposed in the Uinta Mountains. As shown on geologic maps their expanse in Utah exceeds 1,500 square miles. In contrast with such thicknesses as 1,500 feet in the Aquarius Plateau and 5,000 feet in the Wasatch Plateau, the maximum measured thickness of the Tertiary in the Paunsaugunt Plateau is 1,180 feet, but measurements of 400 to 800 feet are more characteristic, and in places on top of the plateau the once thick Tertiary sediments have been entirely worn away, exposing the Cretaceous sandstones.

Where they appear in the Pink Cliffs of south-central Utah Howell divided the "Tertiary formations" into four series, including, however, beds now assigned to the Cretaceous. Dutton (1880, pp. 158–169) classed as "Tertiary lacustrine formations (1) upper white limestone and calcareous marls, 300 feet; (2) pink calcareous sandstone, 800 feet; (3) pink conglomerate, base of the series, 550 feet." By later writers the rocks in this stratigraphic position have generally been described as constituting the Wasatch formation and treated as a unit or variously grouped, with the recognition, however, that the formation has many aspects and that correlations of widely separated exposures are speculative.

As mapped in the present report, the Wasatch formation (Eocene) covers most of the plateau top and forms the Pink Cliffs; the Sevier River (?) formation (Pliocene or Pleistocene) appears in a few places as the local representative of post-Wasatch rocks that are well exposed in regions farther north and west.

WASATCH FORMATION

GENERAL FEATURES

Though the Wasatch formation consists dominantly of thick-bedded limestone, it varies widely in color, composition, texture, arrangement of beds, and manner of erosion. In places where the entire formation is exposed, red or pink dense limestone in poorly defined beds 5 to 40 feet thick makes up solid vertical walls 100 to 400 feet high, which include wedge-shaped beds of light-gray limestone, conspicuous because of the contrasting colors. In addition to the limestone, complete exposures include cliffs of white calcareous conglomeratic sandstone and series of evenly bedded shale-like siltstone mottled with red and white, usually circular blotches. Common to all exposures are narrowly spaced vertical joints, brecciated masses, strings and bunches of conglomerate, and lenses of relatively resistant material that in the fresh rock on cliff faces suggest large-scale cross-bedding and on weathered surfaces stand as benches and knobs.

In a broad sense, the Wasatch of the Paunsaugunt Plateau consists of three parts: (1) a basal, generally red massive limestone with sparingly distributed exotic pebbles, or a conglomerate with calcareous cement, 20 to 100 feet thick; (2) a pink and red, irregularly bedded limestone with subordinate calcareous shales, limestone, conglomerates, and breccias, 0 to 800 feet; (3) white limestones and sandstones with much gray conglomerate and some pyroclastic sediments 0 to 300 feet.

Though regionally and in the mass conspicuous, these major subdivisions based on color and gross composition have no clearly definable stratigraphic boundaries. In much modified forms they are recognizable in the neighboring southern parts of the Aquarius and Sevier Plateaus and the eastern part of the Markagunt Plateau, but no corresponding units have been recognized farther north in the Awapa and Wasatch Plateaus. Howell (1875, p. 266) long ago noted that "to the north these [Tertiary] beds are mostly soft calcareous shales and marls, with only a few sandstones and hard limestones. Southward there is an increase in limestone, and at the most southeastern exposure, the Last Bluff, there are over 1,200 feet of more or less compact limestone."

Within the subdivisions themselves the variation in composition, texture, thickness, and extent of individual beds is extreme. Traced along the strike, thick beds of nearly pure limestone may grade into sandstone or abruptly terminate in masses of conglomerate, and the sandstone in turn may change to compact limestone or laminated calcareous shale. Furthermore, the rare fossil shells and the rarer leaf prints are not restricted to specific layers. Correlation of sections measured in the Sunset Cliffs and in the cliffs of Bryce Canyon National Park reveals as much divergence as similarity, and sections a mile apart contain unlike units. It is interesting to note that though no two exposures are alike in detail, the range in difference is about the same in the Markagunt and Aquarius Plateaus as in the Paunsaugunt Plateau, thus indicating similar conditions of deposition throughout southern Utah. It seems also noteworthy that along miles of bare cliff face the thinly laminated, regular, even-grained, fine-grained calcareous beds characteristic of lacustrine deposits are sparsely represented.

The interbedding of massive limestones, sandstones, and conglomerates is well shown in Red Canyon. Here the canyon wall of pink limestone is capped by stratified calcareous sandstone. In the sandstone and locally replacing it are lenses of conglomerate 1 to 5 feet thick and 10 to 50 feet long, also strings of individual pebbles. Most of this material is coarse, and parts of it include pebbles of quartzite, limestone, and hardened clay as much as 2 inches in diameter. The relatively soft bedded sandstone weathers into narrow platforms, and the harder conglomerates are worn into shelves, little mesas, and towers—picturesque carvings in gray on a surface of pink. The lower cliff slopes are thickly strewn with colored pebbles. Some of the masses of conglomerate measure the width and depth of ancient stream channels, and in general they resemble bars in streams and on fans. Some, however, coincide in bedding with the sandstone and limestone above and below as if they had been suddenly piled on top of beds that had not been eroded.

BASAL BEDS OF THE WASATCH FORMATION

The basal bed of the Wasatch formation is generally a conglomerate of exotic materials in a calcareous matrix (figs. 19, 20). It rests unconformably on the Cre-

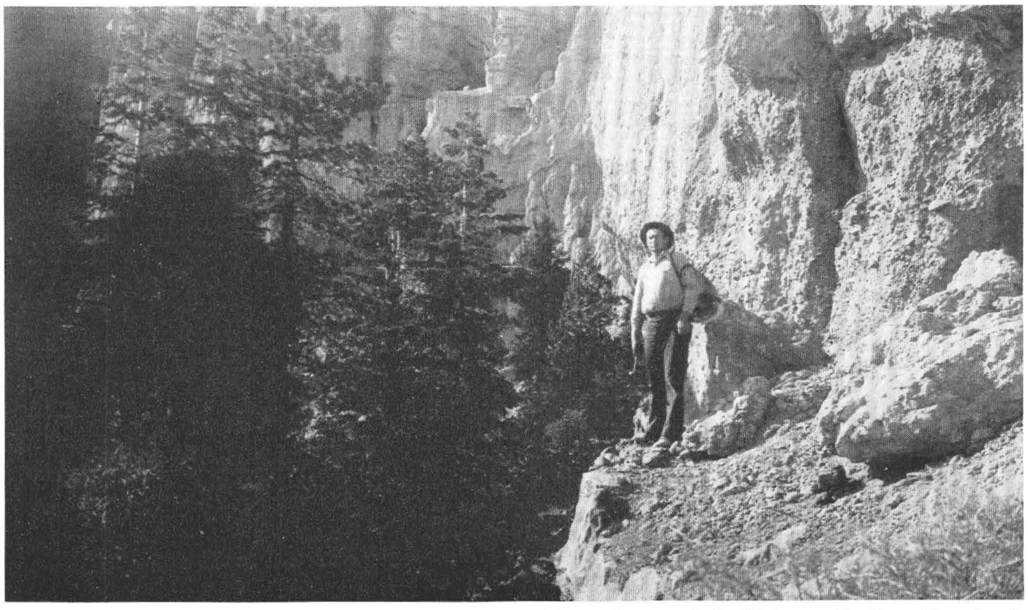


FIGURE 20.—Basal conglomerate of the Wasatch formation in contact with sandstone of the Kaiparowits formation, head of Mill Canyon.

taceous below but is not clearly separated from the limestone above. Observations at many exposures show wide variation in thickness, in the size and relative amounts of the component materials, and in the purity of the matrix. At Yovimpa Point rounded pebbles of white quartz, banded and massive quartzite, black and gray chert, and red limestone 1 to 10 inches in diameter are embedded in coarse sandstone which includes also lenses of shale. Near the head of Black Birch Canyon red, pink, purple, and black well-worn banded quartzites, dense igneous rocks, and fragments of quartzitic sandstone a quarter of an inch to 3 feet in diameter are cemented with a mixture of calcium carbonate mingled with very fine sand. Immediately overlying this material is 4 feet of dense, brittle, finely laminated limestone and a conglomerate composed chiefly of small chert pebbles. At the head of Bull Valley the basal Tertiary bed is coarse calcareous sandstone that contains small pebbles of quartz, quartzite, and chert, sand aggregates, and angular chips of shale and limestone. At Iron Springs rounded and angular masses of varicolored quartzite, gray limestone, and flint, the largest 2 feet in diameter, make up a bed 22 feet thick. Some of the cement is lime, but more of it is iron oxide, and iron oxide is a conspicuous part of the excessively fine-grained quartz sand in which the rock fragments are packed. Above the conglomerate at this place lie in turn 8 feet of resistant bedded limestone, 1 to 4 feet of purple argillaceous shale, 4 feet of brown hard sandstone, and 34 feet of dense gray limestone that includes sporadic quartzite boulders, 3 to 6 feet in diameter, and slabs of sandstone, limestone, and shales that seem to have been parts of the beds beneath. In a western branch of Willis Creek the basal bed is a fine-grained calcareous sandstone that grades upward into conglomerate 20 feet thick made of pebbles less than 2 inches in diameter. At the head of Willis Creek the usual basal conglomerate is replaced by coarse sandstone arranged in cross-bedded lenses, and in Noon Canyon, Swamp Canyon, and Yellow Canyon both the conglomerate and the sandstone are absent at this horizon. In Campbell Canyon the basal bed is a thick coarse conglomerate displayed as inclined lenses 1 to 3 feet thick, and 18 feet above it a second conglomerate is arranged as a series of lenses 200 feet long and 8 feet thick embedded in massive red limestone. In Big Hollow, on the west wall of the Paunsaugunt Plateau, the basal Tertiary bed is evenly stratified arenaceous limestone 36 feet thick, which with gradual change in color and increase in amount of sand continues upward for 72 feet to a bed of conglomerate 15 to 25 feet thick composed of well-rounded pebbles and cobbles (85 percent quartzite) a quarter of an inch to 6 inches in diameter. At the head of Slide Canyon the conglomerate is represented by pebbles sparingly distributed in the lowermost 10 feet of a high cliff of massive red limestone. On top of the plateau at Tropic Reservoir a thick conglomerate of subangular pebbles half an inch to 1½ inches in diameter, chiefly black, red, and gray quartzite and black limestone, lies directly on the Cretaceous sandstone and terminates abruptly upward at a limestone bed.

Along the fire trail below Bryce Point the basal part of the Wasatch, 10 to 30 feet thick, is a series of coarse and fine sandstones interbedded with conglomerates composed of rounded pebbles of tan and pink limestone, chert, quartz, and quartzite 1 to 3 inches in diameter. Generally the conglomerate grades laterally into coarse then fine sandstone, but at one place a bed of coarse conglomerate 8 feet thick ends abruptly.

Considered as a stratigraphic unit, the coarse conglomerate is not continuous. Within distances of 1,000 to 2,000 feet masses as much as 20 feet thick taper out into sandstone of like thickness or are represented by scattered pebbles. For nearly 2 miles west of Yellow Creek the conglomerate is missing; the basal Wasatch is a hard, strongly colored, evenly stratified calcareous mudstone. In general aspect the conglomerate resembles the coarser parts of sandbars in shallow, moderately broad channels that on the divides between the ancient streams are replaced by finer sediments sorted and graded in response to the behavior of tributary runways. Because of its predominant calcareous cement the basal Tertiary conglomerate is a relatively friable bed; on weathering it forms slopes at the base of the massive limestone, and its pebbles are strewn thickly over the talus. Also because of its weak cement it is in places porous and affords a passage for ground water. It is the site of many springs. (See p. 112.)

PINK BEDS

In the Paunsaugunt and adjoining plateaus the most prominent parts of the Wasatch formation are the massive, thick-bedded limestones that give character to the Pink Cliffs. (See figs. 21, 24, 60.) Generally in the cliffs beds of this character occupy a position between the red and gray basal conglomerate and the capping white arenaceous beds. However, the massive limestone is not everywhere bounded by the same kind of strata, and the rock itself is widely variant in texture and composition.

In places the dominant thick pink beds overlie and underlie thin layers of hard limestones indifferently red, white, and mottled, or sheets and lenses of gray

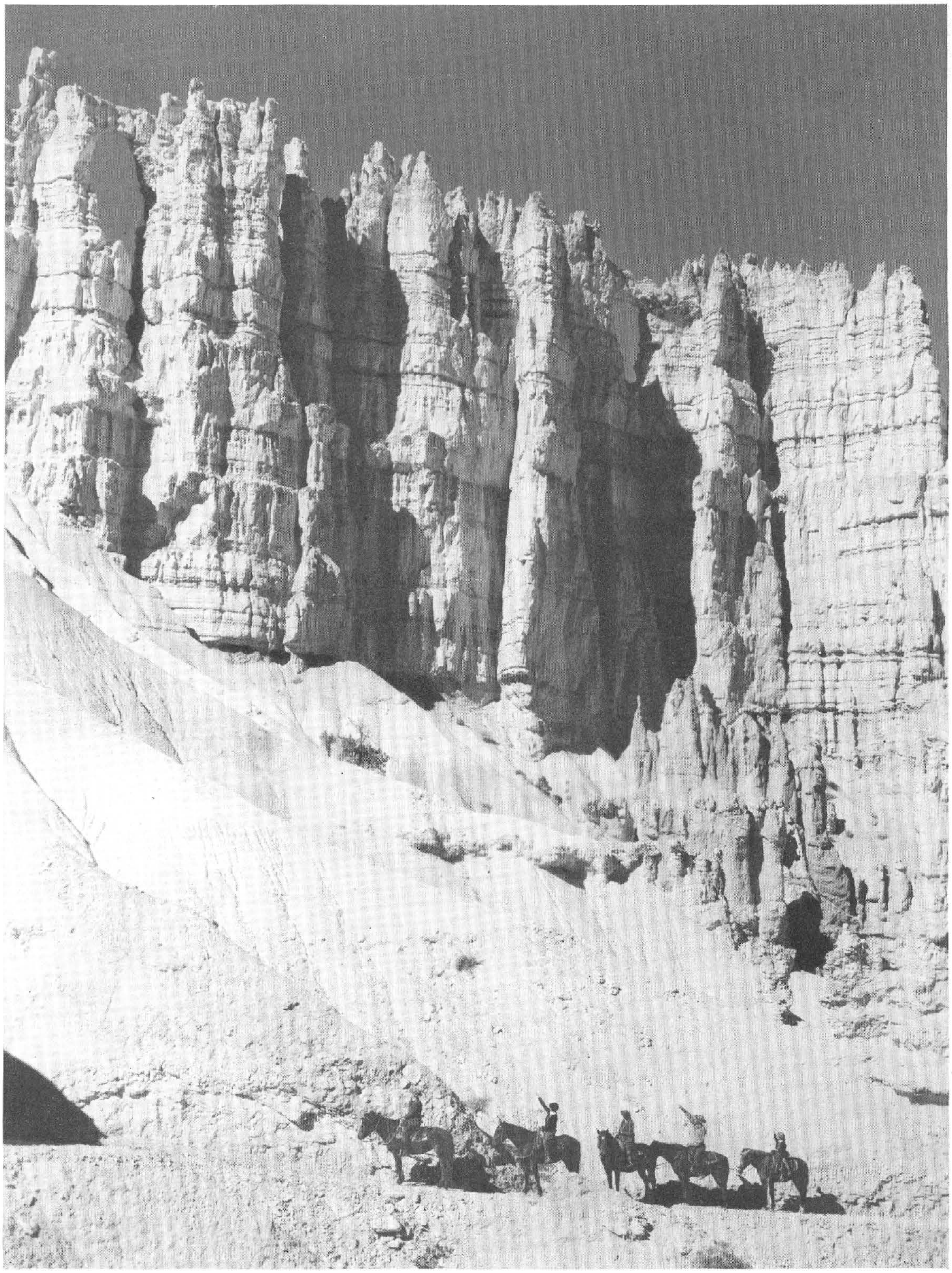


FIGURE 21.—Characteristic erosion features in the massive limestone of the Pink Cliffs along the Tropic trail.

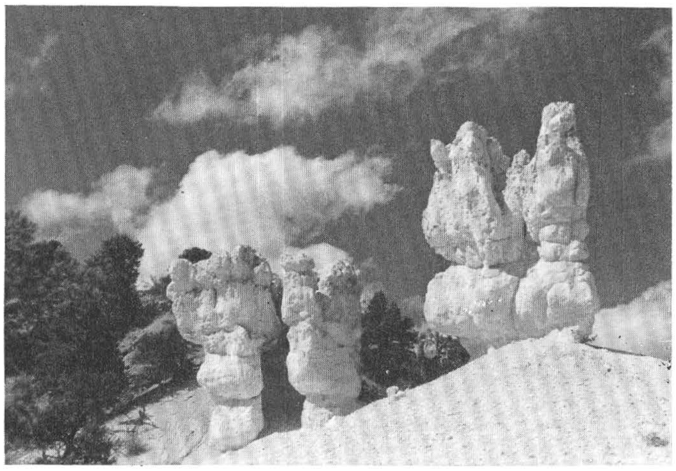


FIGURE 22.—White upper conglomeratic part of the Wasatch formation in Castle Wash, branch of Sevier River.

sandstone loosely or tightly cemented with lime. In some places thick beds appropriately classed as limestone are absent; in their place are sandstones irregularly bedded with thin limestones and containing lenticular conglomerates, the whole making up sections 200 to 500 feet thick. (See figs. 23, 24.)

Partly embedded in the limestone are concretionary nodules and large exotic (?) pebbles of exceptionally resistant limestone that on weathering project and give footholds for climbing vertical cliffs. In places the limestone consists entirely of hard angular dense fragments tightly cemented by coarsely crystalline calcite. These chunky brecciated masses, some as much as 20 feet in diameter and distributed without order, are integral parts of the beds that are otherwise undisturbed, and so far as could be ascertained they are unrelated to sources of pressure; they seem to represent the local adjustment of sediments before consolidation. Some of the limestone is cellular; it includes numerous cavities a few inches in diameter, bare or lined with calcite crystals, and some larger cavities from which stalactites have been collected. Irregularly interbedded with the massive limestone are sheets of porous rock that resemble travertine and contain fossil shells; some thin slabs have the form of coquina. Where purest, the main mass of limestone—parts of it dolomitic—is compact, homogeneous, and so fine-textured that a hand lens reveals no grains. As viewed under the high-power microscope some specimens have the consistency of chalk that includes tiny fragments of quartz.

The general color of the unweathered limestone of the Wasatch formation is pale pink, red, or gray, in places nearly white, but weathering produces a strong pink tone, giving in distant views the remarkable appearance that has made these exposures famous; in southern Utah "Wasatch" and "Pink Cliffs" are nearly synonymous terms. The coloring matter is chiefly iron and, in small amounts, manganese, and the gradation from light pink to red represents the state of oxidation of these metals. The rock thus records the amount of iron—the chief coloring matter—in the sands and silts from which the beds were formed and the chemical changes induced by weathering. The densest, reddest rocks contain the most iron; the more porous, sandy, whiter rocks probably originaly contained little, and much of that has been removed by seepage. Laboratory examination showed red ferric hydroxide as the most

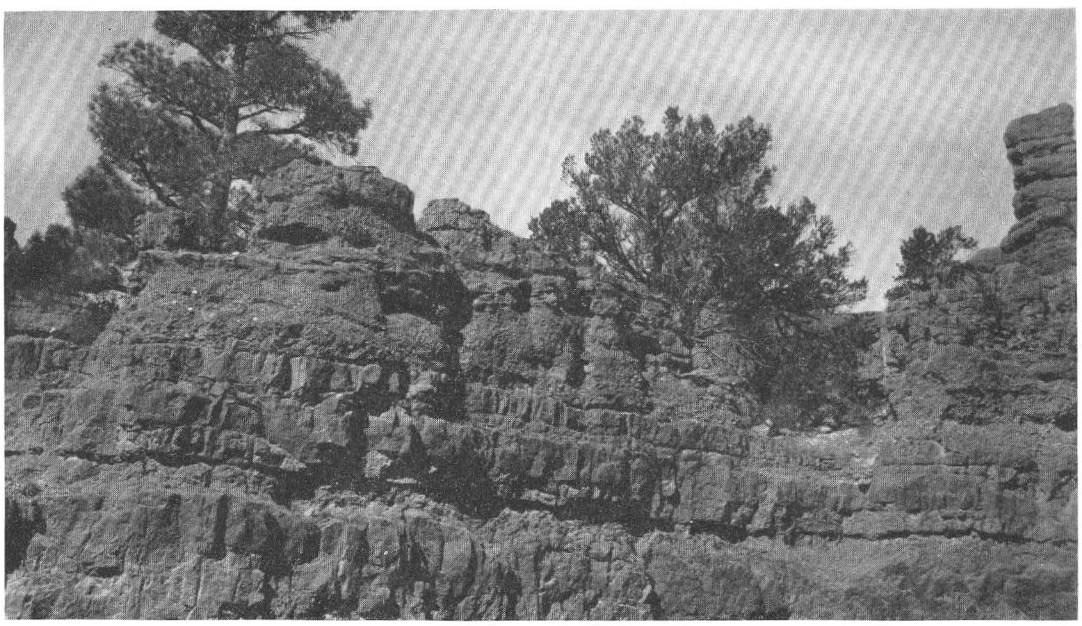


FIGURE 23.—Conglomerate of the Wasatch formation interbedded with pink limestone. Red Canyon.

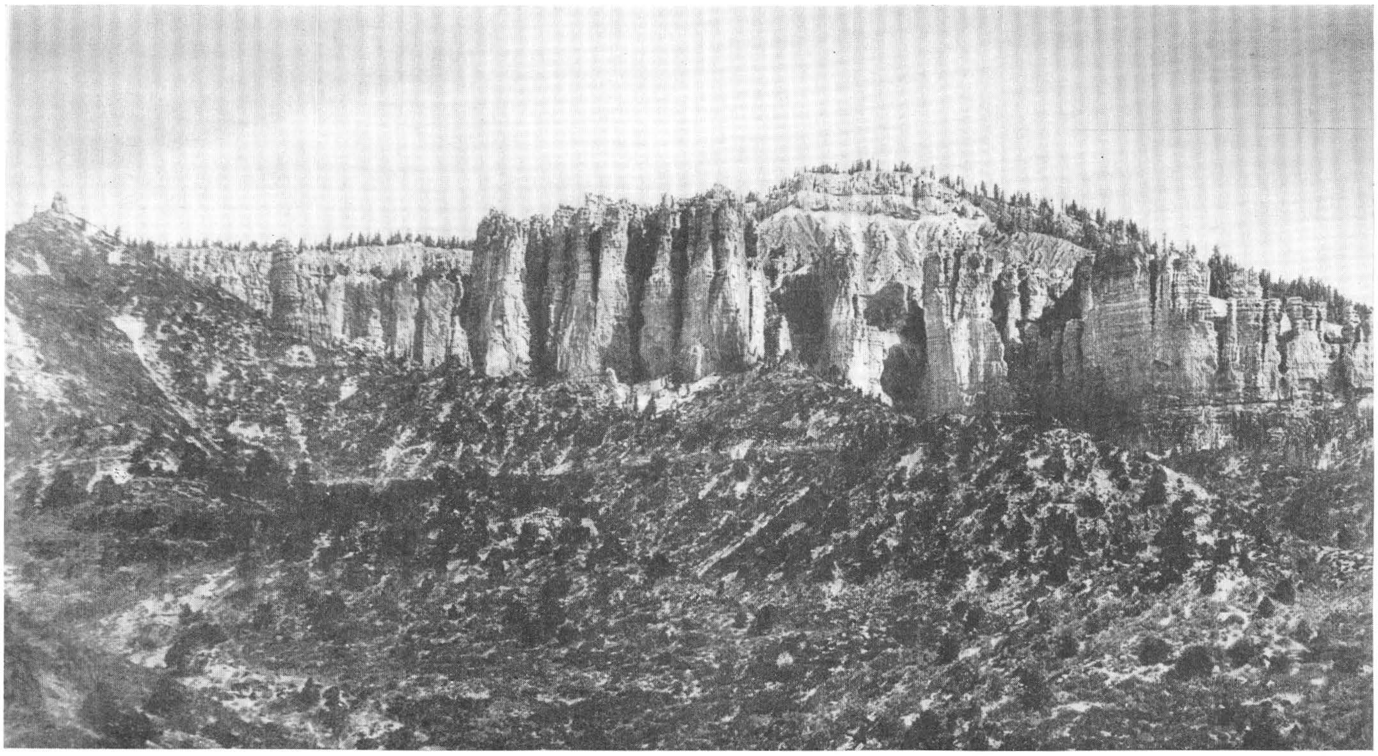


FIGURE 24.—Wasatch formation (cliffs) unconformably overlying the Kaiparowits formation (slope). First known view of the bordering wall of the Paunsaugunt Plateau. Considered by C. E. Dutton as typical of the Eocene and Upper Cretaceous sediments. (From Dutton, 1880.)

common coating of sand grains, particularly in the coarser rocks. Some thin lenses, a source of red paint for the Piutes, are nearly pure hematite and may be chemical precipitates. In the siltstones also ferric oxide is abundant and mingled with clay and calcite gives rise to yellow and buff tones and various shades of pink, purple, and lavender. The manganese dioxide is commonly in aggregates 1 to 3 millimeters in diameter, sporadically distributed in beds of all classes. On weathering it combines with lime carbonates to produce a blue-gray paintlike material.

To determine the nature of the coloring matter as bearing on the conditions of sedimentation optical and chemical studies of 21 specimens from the Pink Cliffs near Rainbow Point were made by H. B. Wood under the direction of Prof. W. A. Tarr at the University of Missouri. As hand specimens these samples included red, tan, and white limestones; pink, lavender, and yellow calcareous siltstones; red and brown sandstones; red, buff, and bluish-gray shales; and red marls. The tests included spots and bands. In substance Mr. Wood reports:

Only two metallic elements were definitely proved to be present—namely, manganese and iron. In a bed of bluish-gray calcareous shale approximately 15 feet thick manganese occurs as small black grains of manganese dioxide, embedded in a bluish-gray aggregate of carbonates and clastics, heterogeneously distributed. The aggregates vary from 1 to 5 millimeters in diameter and have a sharp contact with the surrounding shale. When the fresh rock is weathered the manganese spreads over the adjacent surface, coloring it a bluish gray. The black grains of manganese dioxide are easily disintegrated in water, and wherever there is a large concentration of these black grains the weathered rock is colored black. It is possible that the manganese dioxide was originally deposited with the sediments as small clastic grains, thus being primary in origin, or it might have been deposited as manganese carbonate and subsequently oxidized to the manganese dioxide. Where a little iron oxide accompanies the dominant manganese dioxide the resulting color is lavender. Where a greater quantity of the iron oxides is mixed with manganese dioxide, the basal blue gray assumes a slight tint of red. The iron is present as ferric hydroxide ($Fe_2O_3 \cdot nH_2O$) with smaller amounts of ferrous oxide (FeO).

In a measured section of interbedded red sandstones and shale 200 feet thick the iron oxide is present as a clastic constituent of the sediments and also serves as the chief cementing material between the sand grains. A 2-foot layer of red shale, the "paint rock" in Wall Street Canyon, contains an abundance of hematite, some clay minerals, and a little calcium carbonate, strongly suggesting a chemical precipitate.

The stages of oxidation of iron are well shown in a fine-textured, slightly calcareous siltstone exposed on Peekaboo trail in Bryce Canyon. In accord with the degree of weathering the color of the rock changes from dull yellow, buff, and pink to pink lavender and purple, and the spots on its surface range in color from white through secondary colors to red. Tests show that these various colors are due to the mingling of the ferric and ferrous oxides in different quantities in various degrees of hydration. The iron oxides are very finely disseminated through the rock, and here and there they replace calcium carbonate as the cementing material.

WHITE BEDS

The "white beds" that in southern Utah lie at the top of the Wasatch formation are displayed at Boat Mountain, at Whiteman Bench, along the crest of the Sunset Cliffs (fig. 1), and in a few other places but have been generally stripped from the surface of the Paunsaugunt Plateau. Along the west base of the plateau, where they lie on the downthrown block of the Sevier fault, they are preserved, and on the divide between the northward-flowing Sevier River and the southward-flowing Parunuweap River and Kanab Creek they cover large areas and are conspicuously exposed in ravines. (See fig. 22.) They are prominent also in the Table Cliffs. Wherever examined these white beds—in places gray or light brown—include sandstone, conglomerate, and limestone that is more siliceous than the pink beds below and contain all the volcanic ash and tuff so far found in the Wasatch formation. Sections measured record impure limestone in even beds and in irregular beds without noticeable stratification, none of them continuous for more than a few hundred feet. Associated with the limestones and in places more abundant are beds of sandstone 2 to 10 feet thick, in part cross-bedded, that also appear and disappear within short distances along the strike. Most of the sandstone is coarse-grained and contains individuals, stringers, and wedges of medium-grained conglomerate in various positions and attitudes. Broken bits of quartz sandstone and calcareous shale are mingled with the predominant quartzite, chert, black limestone, and fragmentary lava, and are held together by lime cement. At some exposures the conglomerate is largely an aggregate of smooth egg-shaped pebbles of black, white, and gray limestone suggestive of oolite. Some of it resembles the coarse concrete used in building operations.

Generally in tributaries to the South Fork of the Sevier River the topmost white sandstone of the Wasatch maintains a fairly constant relation to the prevalent limestone. A typical section shows the following beds:

	Feet
1. (top). Sandstone, white to gray, very calcareous, generally fine-grained; includes subangular pebbles, 90 percent of them less than ¼ inch in diameter; chiefly quartz, black flintlike chert, chalcedony, and decomposed lavas; gravel used for roads	30
2. Limestone, white, roughly bedded; weathers to hard, smooth surface; includes stringers of black chert (?)	100
3. Limestone, pink or red, generally massive; decomposed readily; includes lenses of dense resistant calcareous sandstone that project like benches on the high cliffs	400±

Reporting the result of a microscopic analysis of No. 1, Clarence S. Ross writes:

> All the pebbles observed except one were quartz of some kind. The coarser-grained ones are quartzite, and the finer ones chertlike. One coarse-grained pebble is granite. The conglomeratic specimens are composed of pebbles and sand grains that are largely chertlike, in a matrix of calcium carbonate.

Among the constituents of the white beds and of the rare bluish-green beds is decomposed volcanic material in positions higher than any known Tertiary lava beds from which they might have been derived. The few small exposures found after rather extensive search lie at or very near the top of the pink limestones characteristic of the Wasatch formation and immediately below the Recent basalt flows. Petrographic analysis of a sample of bluish-gray shale revealed sharply angular, glassy fragments of quartz; fairly fresh grains of igneous rock; tiny feldspars that show good cleavage; and milky grains that have indices characteristic of zeolites. Among the slides made of adjacent rocks none show these features, but some show grains of angular glassy quartz mingled with spherical grains. The deposits classed as pyroclastics—thin sheets and lenses of small area—are stratified and present other features of water-laid sediments. They grade horizontally into siliceous limestone, calcareous sandstone, and siltstones. From the places where they were originally accumulated they seem to have been distributed along stream channels or carried into local water-filled depressions. The source of the volcanic material is unknown.

In field studies these white beds were given special attention in view of the possibility that they represented a formation that in origin and history differed from the prevailing pink beds below. However, no consistent plane of separation from other parts of the Wasatch was established, and the rare fossils are generally like those found in the underlying pink limestone.

ORIGIN AND AGE

Except for Howell's observations and measurements (p. 6) the members of the Wheeler and Powell Surveys gave little attention to the Tertiary rocks of the Paunsaugunt region. Dutton (1880, p. 255) remarks, "The Paunsaugunt itself is a simple tabular block of lower Eocene beds. * * * It is exceedingly simple in its structure and * * * presents little matter for special comment."

In Dutton's (1882, pp. 214–219) view all the Tertiary sediments in Utah were deposited in a fresh-water lake.

It is apparent in any event that the plateau country formed one continuous lake south of the Uinta Mountains. The vertical movement which followed the close of the Cretaceous shut it off from access to the sea. * * * Soon after the advent of the Eocene the waters became fresh and remained so until they entirely disappeared. * * * In the southern portion of the lake basin only the lower Eocene was deposited, while in the northern portion around the Uintas the whole Eocene formation is present. Whence we infer that the final desiccation of the lake began in the southern and southwestern portions and that the lake shrank away very slowly toward the north, finally disappearing at the base of the Uintas at the close of Eocene time.

Recent studies of the distribution and physical features of the Tertiary strata of the plateau country give no support to Dutton's assumption that the interbedded and lateral intergraded limestone, shale, and sandstone which make up the Wasatch formation were contemporaneously deposited in a "continuous lake." Doubt of the validity of the lake hypothesis seems first to have been expressed in print by Davis, (1903, pp. 44–45) who recognized as lacustrine the thick limestones in the Pink Cliffs about Alton but for the Wasatch formation as a whole reached the conclusion that

Whatever share may have been taken by lakes in providing a site for these various deposits, it seems evident that the persistent existence of a single large, continuous water body does not supply the conditions necessary for the accumulation of strata in which variations of composition, texture, and structure are so common.

Generally in a long-lived lake of considerable extent and depth the central bottom is covered by very fine-grained, thinly and evenly stratified sediments and the near-shore areas by deposits of various sorts. In the Wasatch of the Paunsaugunt region the compact, thinly laminated, fine-grained, nearly pure limestones indicate deposition in quiet water, but the dominantly massive, roughly bedded arenaceous limestones, the lenticular sandstones, and the conglomerates obviously are not lacustrine sediments, and deep-lake sediments seem to be absent. The physical make-up and the lateral and vertical distribution of the various kinds of sediments suggest separate basins of deposition, of different sizes and depths, some of them overlapping, others widely separated; some fairly permanent and others filled and dried up in response to seasonal rainfall. In shallow lakes fluctuating in volume and in shape of shore line the entire bottom might be covered with sand, gravel, and silt contributed by feeding streams. The probable conditions that controlled sedimentation seem to be reproduced on a small scale by little streams that now carry the weathered debris from outcrops of Wasatch, Carmel, and other calcareous formations and leave it along their channels or in ephemeral pools. Small patches of stratified and unstratified lime silt of various color and composition and thin beds of arenaceous limestone and pebble conglomerate are formed in depressions after each torrential rainstorm and the travertine about present springs is closely similar to that embedded in the limestones of the Wasatch.

That the Wasatch formation is of terrestrial origin is shown by fresh-water fossils, by its style of bedding, and by the distribution, kind, and regionally disproportional amounts of limestone, sandstone, conglomerate, shale, and carbonaceous material. But the source of the huge mass of material that constitutes the Wasatch formation of Utah can at present only be conjectured.

Howell (1875, p. 266) found that the difficulty of correlating sections of the Tertiary—

even when taken only a few miles apart, * * * is especially noticeable in comparing sections near the western boundary of the system with each other, or with sections to the east, while the eastern sections show more uniformity in character. These facts are consistent with what might be expected when we consider that the Basin Range system was the ancient continent, which furnishes the sediments for these beds, and we find their variability such as is usually noted in off-shore deposits.

Dutton (1882, p. 217) thought that in central Colorado post-Cretaceous deformation left highlands from which streams carried the products of erosion westward across Utah, and that some of the Wasatch sediments came from the Uinta Mountains, the Wasatch Mountains, and the Tushar Plateau. He surmised (1880, pp. 184–185) that in early Eocene time "the Park Ranges of Colorado were standing, * * * the Uinta chain then existed, * * * In some form or other the Wasatch was then in existence," and the Tushar "stood upon the course of the western shore line of the great Eocene lake."

Spieker and Reeside (1925, p. 452) expressed the belief that—

during the period of major mountain making, post-Price River [Cretaceous] and pre-Wasatch, ranges of Mesozoic and earlier rocks were thrown up on the west, vigorously eroded, and the products of erosion were carried widespread over the region to form the present Wasatch formation.

Studies in the Paunsaugunt region throw no new light on the source of the Wasatch sediments. Some of the tightly cemented sandstone in the basal conglomerates may have come from the relatively nearby Tushar Plateau, which, as shown by Callaghan (1938, p. 103) possibly was a highland area subject to erosion in Eocene time—in Dutton's phrasing "a peninsula or an island in the lake." However, no recognized or suspected source seems adequate to supply material for the masses of quartzitic conglomerate, volcanic ash, and igneous breccias, or for the hundreds of square miles of thick calcareous sediments represented in the Pink Cliffs of the Paunsaugunt and adjoining plateaus.

The age of the Wasatch in the Paunsaugunt region has not been satisfactorily determined. The invertebrate fossils sporadically distributed in the dense limestones, rarely in the sandstones, are not clearly diagnostic, and the leaf impressions in the shales have given no specific information. However, the fauna as so far studied serves to fix the age of the formation as Eocene. In the collections of fragmentary fossils from the Natural Bridge and Bryce Point, Reeside identified *Physa pleromatis* White and *Physa* cf. *P. bridgerensis* White and remarked, "Eocene, according to records of the species." In equivalent strata on the Markagunt Plateau Reeside recognized *Physa* sp., *Bulinus* sp., "age undetermined by the fossils"; also *Planorbis utahensis* Meek, "not reported below the Wasatch."

The correlation of the strata classed as Wasatch in Utah, Wyoming, Colorado, and Arizona is necessarily tentative. The great range in thickness and in character of the deposits, the paucity of diagnostic fossils, and the widely unlike relations to the Cretaceous beds below and the younger Tertiary beds above present problems so far unsolved. (See Spieker, 1925, p. 452; 1936, pp. 62–63; 1946, pp. 117–161; Gazin, 1938, pp. 271–277; Matthews, 1937, pp. 346–349.)

Spieker [6] calls attention to the essential continuity of the Wasatch formation from its type locality, Wasatch Station, Utah, southward through the Uinta Basin and the Book Cliffs into the Wasatch Plateau and points out that—

> the upper strata of the High Plateau cannot be traced continuously southward. At best there is an unrecoverable gap of about 25 miles, and considering what we see of the lateral relation where the [Wasatch] section is exposed, comparisons across such a gap must be taken with strong reservations.

Aside from the fact that they include equivalent faunas and somewhat similar beds of limestone the outcrops of the Wasatch formation as recognized in the Wasatch Plateau and in the Paunsaugunt Plateau bear little mass resemblance. As exposed in the Wasatch Plateau, a generalized section of the formation (Spieker 1931, pp. 11, 16, 46) shows a basal member comprising variegated shale, sandstone, limestone, and conglomerate 1,000 to 2,000 feet thick; the cliff making Flagstaff limestone 800 to 1,000 feet thick, and, at the top, variegated shale similar to the lower member, 1,000 to 1,200 feet, total thickness, 2,800 to 4,000 feet. In the Paunsaugunt Plateau, where in few places it is as much as 1,000 feet thick, the Wasatch lacks strata in any way comparable to the lower and upper members that make up about three-fourths of the formation in the Wasatch Plateau. Furthermore, in the Wasatch Plateau the sequence of Cretaceous and Tertiary sediments appears to be unbroken; the division plane between these systems is difficult to define. Whereas in the Aquarius, Paunsaugunt, Sevier, and Markagunt Plateaus the Cretaceous and Tertiary strata are separated by a large scale erosional and structural unconformity. It thus appears that during early Tertiary time deposition was in progress in north central Utah while the rocks in the southern High Plateaus were being destroyed, and that the Wasatch in the Pink Cliffs and the lower part of that formation in the Wasatch Plateau are of different age. The existing evidence suggests radically unlike contemporaneous conditions of sedimentary orogeny, and erosion in two large areas less than 50 miles apart.

[6] Spieker, E. M., personal communications, March 25 and May 25, 1940.

TERTIARY OR QUATERNARY FORMATION

SEVIER RIVER (?) FORMATION

In the Paunsaugunt region volcanic conglomerates, clays, and calcareous silts clearly younger than the Wasatch formation are exposed along the South Fork of the Sevier River, between Hatch and Panguitch and in tributary valleys that head in the Sunset Cliffs. (See fig. 25.)

On the south side of Red Canyon near its mouth these sedimentary beds constitute part of a cuestalike outcrop 10 to 30 feet high and about 400 feet long that has been warped and broken by local faults. The material that makes up the outcrop is plainly stratified in slightly curved beds, 3 inches to 2 feet thick, and sufficiently consolidated to form a low cliff. The thicker beds consist chiefly of rounded and subangular cobbles 3 to 10 inches in diameter of andesite (?) quartz-diorite, basalt, quartz, and quartzite embedded in a matrix of smaller pebbles of like composition, in quartzose sand, or in volcanic ash. In texture and composition most of the thinner beds resemble the thicker ones, but some of them consist essentially of intermingled pyroclastics and impure clay. In places the talus slopes are coated with white or greenish debris in which fragments of hornblende, magnetite, mica, olivine, and epidote (?) are detectable. The western edge of the conglomeratic mass is overlapped by recent alluvium, and its eastern edge is deeply buried under talus. However, its relation to the basalt flows and to the Sunset Cliffs suggests that it is part of deposits that once had considerable extent and that it owes its preservation to its position on the downthrown side of the Sevier fault. (See p. 75.)

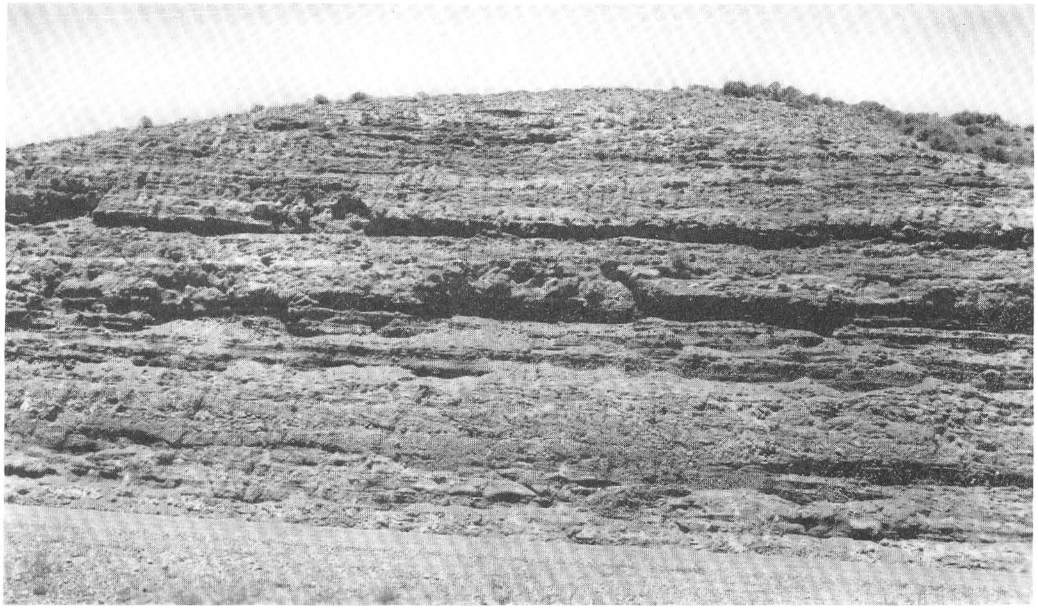


FIGURE 25.—Sevier River (?) formation along Highway 89 between Panguitch and Hatch showing style of bedding typical of these outcrops.

In road cuts near Hillsdale strata tentatively correlated with those along Red Canyon consist of basaltic conglomerate containing boulders as much as 2 feet in diameter, dark-brown, fine-grained volcanic debris, clay, calcareous silt, and chert. (See fig. 26.) The deposits at Red Canyon and Hillsdale and similar ones north of Red Creek were obviously water-lain, and the texture, the style of bedding, and the numerous lateral unconformities indicate streams of fluctuating volume flowing in poorly defined channels. In general the texture and distribution of the formation suggest fanglomerate of local origin deposited in local basins, most of them shallow and separated by indefinite divides.

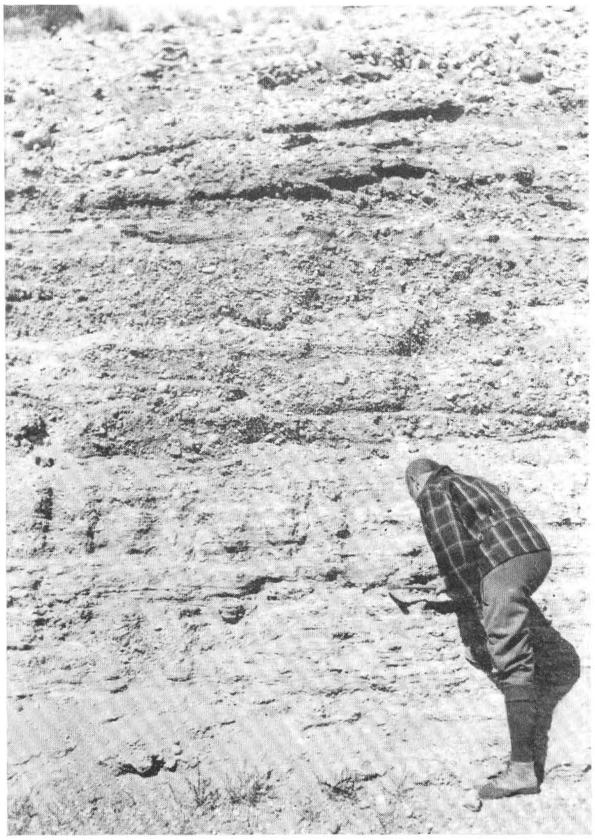


FIGURE 26.—Volcanic conglomerate, standstone, and sandy clays in Sevier River (?) formation in road cut 2+ miles south of Hillsdale.

The age and stratigraphic position of these post-Wasatch sediments have so far not been satisfactorily established. Along the South Fork of the Sevier River they underlie the latest basalt flows and the alluvial valley fill and probably the nearby fossiliferous Pleistocene deposits. At Red Canyon they overlie the white highly siliceous limestone of the Wasatch formation that northward grades into pyroclastics. The source of the material is conjectural. Little of the sandy silt, clay, and ash could have come from the dominantly calcareous Wasatch formation, and the gravel as a whole differs in composition and texture from the material in Sanford Canyon northeast of Panguitch which Dutton (1880, pp. 237–238) describes as volcanic conglomerate, marls, and sandstones presumably derived from the disintegration products of "propylites and hornblendic andesites" that once covered the Tertiary limestone. On the other hand, they resemble the beds of "fanglomerate, conglomerate, sand, and silt" that north of Sevier, Utah, constitute the Pliocene or Pleistocene Sevier River formation as defined by Callaghan (1938, p. 101).

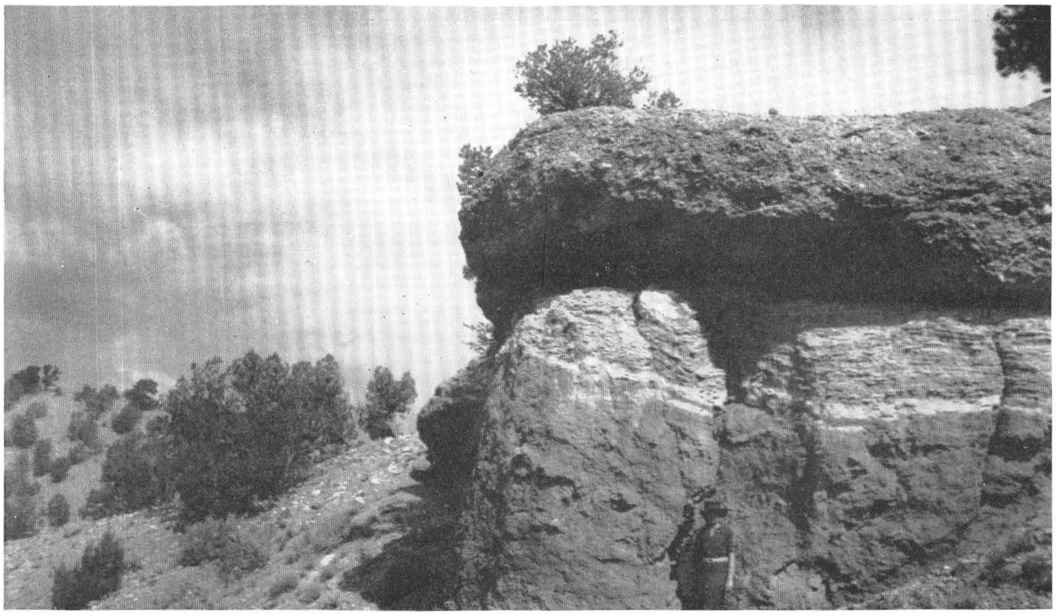


FIGURE 27.—Pleistocene or Pliocene (?) conglomerate overlying Winsor formation, Paria Valley.

The post-Wasatch volcanic gravels in the Paunsaugunt region are tentatively correlated with the Sevier River formation, chiefly because of their distinctive physical features. The correlation is strengthened by Callaghan's belief,[7] after visiting outcrops in the Red Creek Valley and along the Panguitch-Hillsdale highway, that "the folded and faulted material in the Panguitch Basin, composed as it is largely of basaltic debris, belongs to the Sevier River formation."

QUATERNARY FORMATIONS

PLEISTOCENE DEPOSITS

As pointed out by members of the Wheeler Survey (1875, pp. 88, 112, 300), the distinctive topography resulting from glaciation is well expressed on the Fish Lake, Aquarius, and Tushar Plateaus and the Table Cliffs, and the presence of Pleistocene ice masses on other high lands in Utah has been fully demonstrated by later studies (Dutton 1880, pp. 262–265, 285–286; Gregory and Moore 1931, p. 116; Gould 1939, pp. 1370–1380; Spieker and Billings 1940, pp. 1173–1189).

On the Paunsaugunt Plateau incipient glaciation and strong nivation is recorded on detached ridges at altitudes of about 8,500 feet, and around the base of the plateau sediments that contain Pleistocene fossils and others that may be Pleistocene are parts of the valley fill. These sediments are of various kinds and appear in various positions, but typically they are either coarse fluvial gravels that lie near the tops of canyon walls or lacustrine deposits in the bottoms of valleys where the most recent stream cutting has brought them to light. (See figs. 27, 28.) The high-lying gravel is exposed as terracelike patches, 5 to 30 feet thick, plastered against the valley walls and as dissected sheets on interstream spaces. Its chief components are con-

FIGURE 28.—Detail of Pleistocene or Pliocene (?) conglomerate, Sink Valley.

[7] Callaghan, Eugene, Personal communication, May 10, 1940.

glomerates and roughly bedded, tapering sheets of coarse and fine sandstone that lie in disorderly fashion between overlapping sheets of cobbles. In Sink Valley and other tributaries to Kanab Canyon the coarsest rock consists of angular slabs of Cretaceous sandstone, 1 to 3 feet in length, partly rounded pebbles of Tertiary limestone, iron concretions, and compact mud balls. Of the pebbles less than 3 inches in diameter the commonest are gray-brown banded quartzite, black and white chert, and sparingly distributed angular fragments of black limestone, shale, and basalt. The fine- and medium-grained sandstone is displayed as lenticular beds, and the coating of the larger pebbles is dominantly quartz but includes enough calcite and iron oxides to cement the whole gravel mass into resistant rock. In the Paria Valley near the mouth of Yellow Creek masses of elongate pebbles, chiefly varicolored quartzite and pink limestone, 1 to 3 inches in diameter, have been consolidated into calichelike beds that cap mesas and cliff projections 60 to 70 feet above the present stream. On divides between branches of Willis Creek gravel of this character is 15 to 25 feet thick, and here and there along other streams tributary to the Paria and the Kanab patches of coarse, generally consolidated gravel stand as terraces on the valley walls. Wherever exposed this high-level gravel rests indifferently on the eroded surfaces of Jurassic, Cretaceous, and Tertiary formations, across which streams of fluctuating capacity carried material available for transport. As pointed out elsewhere, (Gregory 1950) the distribution of these deposits of consolidated gravel on the walls of canyons and on low divides suggests that they once wholly or partly filled many stream channels in southern Utah. It also suggests that when the gravel was laid down the canyons were substantially as deep and wide as today. As here interpreted the gravel records a period of vigorous aggradation and a period of extensive erosion, in early Pleistocene or perhaps Pliocene time, antedating the formation of the sand and gravel terraces that line the present streams. (See pp. 84, 103.)

The lacustrine type of Pleistocene deposits is represented by outcrops near the mouths of Red Creek and nearby Casto Creek and probably underlies the alluvial fans along the South Fork of the Sevier River. (See fig. 29.) The material is chiefly stratified buff lime silt and white marl that the microscope shows to be impure calcite mingled with varying amounts of fine spherical quartz grains and some clay. In places tongues of volcanic conglomerate and gray clay are included. The base of the deposit is not exposed; its top unconformably underlies the alluvial valley fill. Regarding fossils in beds in the Red Creek Valley Josiah Bridge,[8] of the United States Geological Survey, writes:

FIGURE 29.—Fossiliferous Pleistocene marls, clays, and limestone in Red Creek Valley.

> Your collection has been examined by paleontologists of the Survey and biologists of the National Museum. It contains species referred to the following genera: *Stagnicola*, *Physa*, *Gyraulus*, *Ferrissia*, *Valbata*, *Pisidium*, and *Musculium*. These are all fresh-water forms, and the general opinion is that the formation is probably of Pleistocene age.

RECENT DEPOSITS

In the Paunsaugunt region sediments that postdate any known Pleistocene deposits include local accumulations of talus, wind-blown sand, travertine, marl, peat, and piedmont gravel; considerable gravel and sand on hard-rock benches and on old erosion surfaces; and large amounts of stratified alluvium displayed as fans and valley fill. Particularly prominent is the composite fan, which between the South Fork of the Sevier River and the Sunset Cliffs covers an area of about 50 square miles, and the terraces that border most streams. The age of the fan with reference to other alluvial masses is not readily determined: no complete section was seen

[8] Personal communication, August 14, 1940.

along the ephemeral streams that cross it, and the river at its edge flows on alluvium. As it incompletely covers the Wasatch strata and contains materials like those characteristic of the Pliocene or Pleistocene Sevier River (?) formation and also of the fossiliferous Pleistocene deposits, it has possibly been in process of building ever since late Tertiary time, when in consequence of movements along the Sevier fault a broad lowland area was brought into abrupt contact with a cliff-walled highland. (See fig. 49.)

The age of the deep valley fill now being cut into terraces is also uncertain. Much of it is obviously Recent; it contains human artifacts and traces of ancient agricultural fields, but some of it is doubtless older than human occupancy. (See figs. 30, 31.) The valley fill is marked by unconformities that indicate

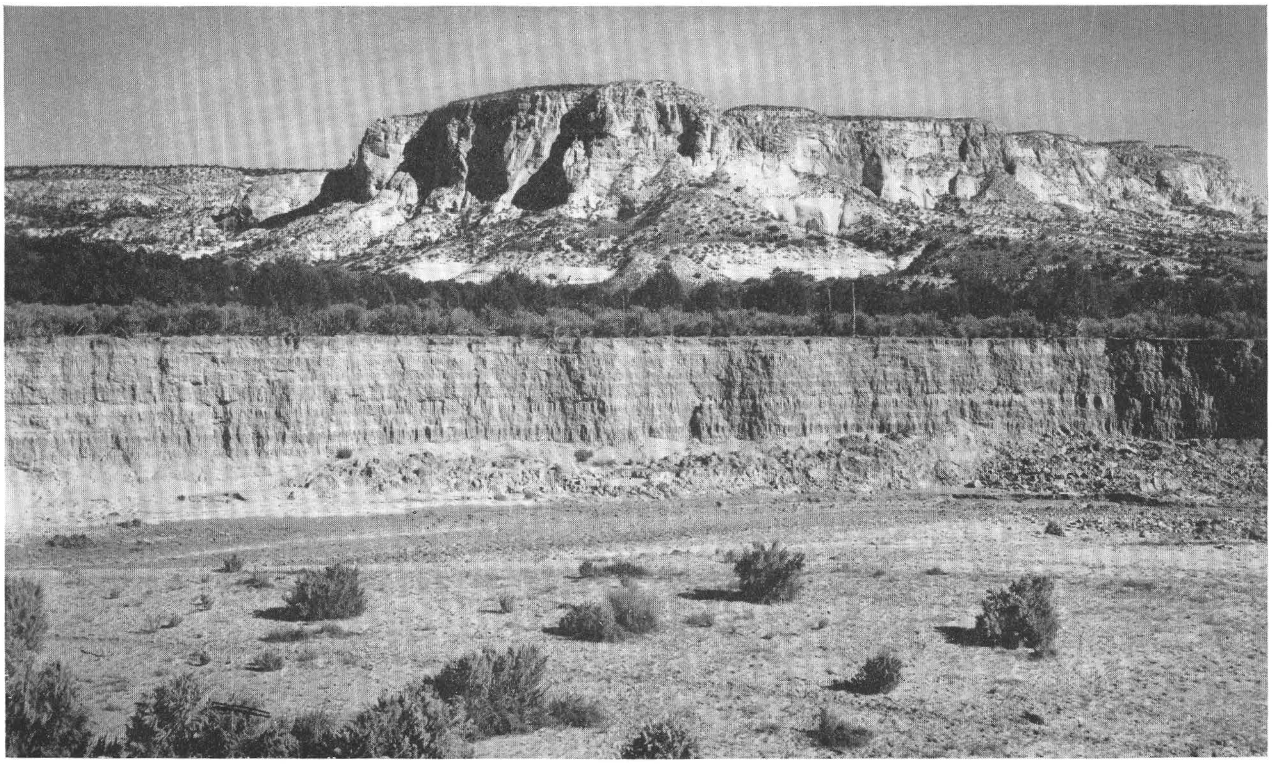


FIGURE 30.—Alluvial terraces in Johnson Canyon, formed since 1900 (?). Navajo sandstone in White Cliffs (background).

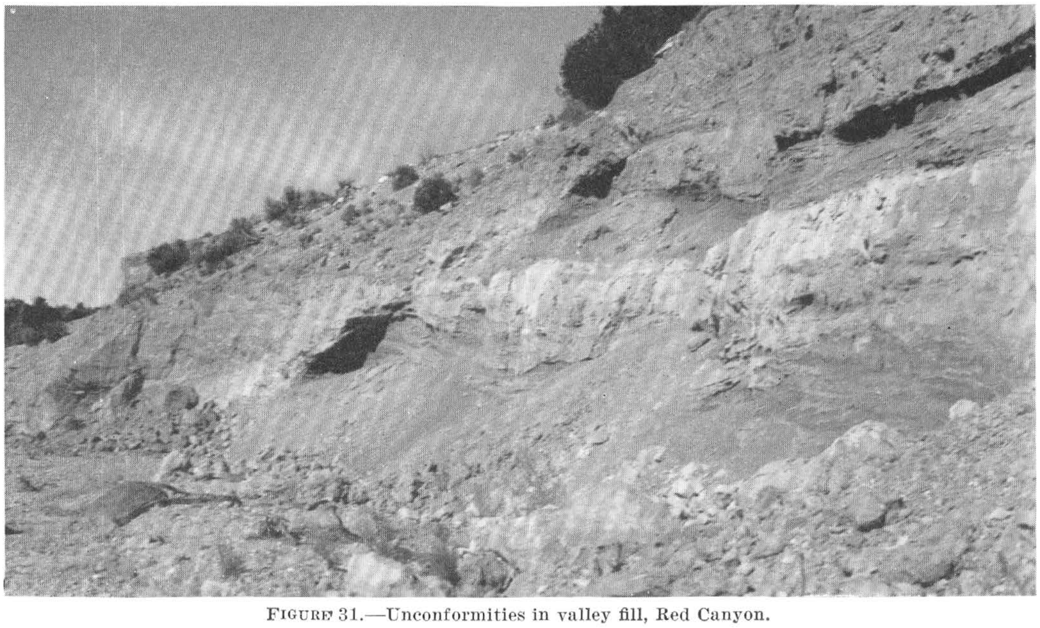


FIGURE 31.—Unconformities in valley fill, Red Canyon.

alternate erosion and sedimentation, and it may be that at intervals during both Pleistocene and Recent time the valleys were choked with alluvium and then partly or wholly worn down to the original rock floor. In this connection it is interesting to note that the basin of Lake Sevier, the final resting place of the erosional debris carried by the Sevier River from the Paunsaugunt region, includes both Iowan and Wisconsin sediments. (See Callaghan, in Woolley 1947, p. 32, pl. 5a.)

STRATIGRAPHIC SECTIONS

1. *Section in Paria Valley extending from Cannonville about 5 miles south to the "box"*

	Feet
Dakota (?) sandstone:	
23. Sandstone, coarse grit with thin lenses of conglomerate; gray quartzite and white chert as much as 1 inch in diameter, also fragments of clay shale, mud balls, and bits of carbonized wood; coal beds 20±feet from base; in part gypsiferous	36
Unconformity: surface of erosion.	
Winsor formation:	
22. Shale, sandy, or thin sandstone, banded white and red; red strata thinner and fewer toward the top; top 20 to 40 feet white and less regularly bedded; most beds gypsiferous and very friable; thin beds of relatively resistant white calcareous sandstone form benches on cliff face; includes lenses of green-white clay, mud balls, and concretionary lime conglomerate; weathers as sand without talus; average thickness of section measured	332
21. Sandstone, yellow-red, streaked diagonally and horizontally with white or green-white and dark-red sandy shales in lenses and thin beds; remarkably irregular in texture, structure, and arrangement of beds. Some beds, commonly at the base, are massive and cross-bedded and extend as much as 1,000 feet with thicknesses of 6 to 15 feet; most of them are thin and short and overlap other beds in a seemingly haphazard fashion; the rock is fine-grained and coarse-grained and includes individuals, aggregates, and lenses of green-white shale, sand balls cemented with iron, and individuals and strings of quartz-lined geodes. Most of the shale lenses are lumpy and include concretionary limestone; the red sandstone is weakly cemented with lime, iron, and gypsum, and is guided by lenticular bedding; weathers as tilted steps and grooves and detached mounds and low towers; the more massive beds show blind arches, caves, and "toe holes"; grades laterally and vertically into No. 22; thickness for 3 miles along the strike ranges from 70 to 215 feet; estimated average	100

	Feet
Unconformity (?): Abrupt change in color and lithology; wavy contact sandstone seems to be squeezed into shale; patches of pebbles of blue-gray shale; no clear evidence of erosion.	
20. Shale, sandy, or thin sandstone; regularly banded red, pink, and white; gypsiferous; crumbles readily	46
19. Gypsum, gray, lumpy, somewhat sandy; 6 to 14 inches thick; in places two to four thin lenticular beds separated by shale	1
18. Sandstone, light red, pink, and brown; and shale, light red, dark red, and white striped; make attractive banded cliff with general purplish tone. Sandstone 6 inches to 6 feet thick; fine-grained quartz with tiny iron grains; weakly cemented; appears massive but has obscure bedding, thickest and most massive beds at base; shale 3 inches to 2 feet thick, made up of paper-thin regular layers. Beds much faulted on small scale; locally folded; joint cracks filled with white calcareous sandstone; thickness estimated	110
17. Sandstone, light red; in some places a single massive, strongly cross-bedded stratum, in other places a massive bed overlain by one or more beds of sandstone 3 to 10 feet thick and intervening beds of irregular red shale; consists of fine grains of clear quartz cemented chiefly by lime; scattered through it are angular bits of dark-red shale; the top 3 to 5 feet of the massive bed is conglomeratic, with angular pebbles of gray, red, and black quartz and chunks and twig-like forms of petrified wood, in places impregnated with copper; conglomerate terminates upward as a brown bed 2 feet in greatest thickness sufficiently firm to form a projecting ledge; generally friable; weathers as rounded masses; in few places a strong cliff; contact with No. 18 in places seems to be gradational but in other places wavy, and overlying banded sandstone fits into depressions; thickness 2 miles along the strike 60 to 90 feet	70
16. Sandstone, light red to pink, fine-grained; appears massive but has inconspicuous bedding planes and in places includes thin white beds; at the top a 6-inch bed of dark red finely flaked shale and a thin bed of sandstone are irregularly in contact with No. 17; cement chiefly gypsum; very friable; steep slope largely covered	85
Total Winsor formation	780
Curtis formation:	
15. Limestone or calcareous mud shale, gray blue; very even-bedded; breaks into porcelainlike sheets one-sixteenth to 1 inch thick; conspicuous band of cliffs; average thickness in three measured sections	32
14. Sandstone, white, massive, gypsiferous, friable; includes bands of red shale; at the top lenses of gypsum	5

Curtis formation—Continued	Feet
13. Sandstone, light red, some thin white bands; very thin-bedded; fine quartz grains; lime and gypsum cement; crumbles easily; forms a slope, largely concealed	70
12a. Gypsum, impure, plastered tightly on No. 12	4
12. Limestone, gray blue, fissile, firm, in even beds as thin as cardboard; a cliff	3
11. Gypsum, gray and red, massive, earthy; irregularly interbedded with calcareous shale; weathers in nodular masses and pits; with No. 10 forms cliff	6
Total Curtis formation	120

Entrada sandstone:	
10. Sandstone, white, massive, fine-grained; clear quartz; weak cement	6
9a. Sandstone, calcareous; thin lenses of gypsum at the top	3
9. Standstone, banded dark and light red; beds 1 inch to 1 foot thick; fine quartz grains cemented by lime and gypsum; friable; forms slope; thickness in various places 42 to 90 feet; average about	60
8. Sandstone, buff at bottom, red at top; massively bedded; consists essentially of gray and blue clay fragments embedded in a groundmass of loosely cemented quartz grains	8
7. Limestone or calcareous shale, gray and buff; in layers about one-sixteenth inch thick; foliation surfaces; lumpy with flakes of hardened lime silt and gypsum; deposited on uneven surface of No. 6; average thickness	3
Unconformity (?).	
6. Sandstone, gray; weathers ocher yellow; separated by obscure foliation into beds that average about 5 feet in thickness; many cross-bedded, some contorted and kneaded; composed of medium-sized uniformly round, clear quartz grains and bits of black (iron ?) weakly cemented by lime and iron; at the top is an uneven layer of hard brown coarse sandstone; crumbles to yellow sand rather than talus blocks; forms prominent cliff in which weathering has produced caves and pits; thickness estimated	70
Total Entrada sandstone	150

Carmel formation:	
5. Shale, red, sandy, unevenly bedded, with green bands and spots	2
4. Shale, calcareous, or limestone, gray, in thin beds with somewhat uneven surfaces; includes some beds of red medium-grained irregular sandstone and of buff limestone with obscure fossils	40
3. Sandstone, gray brown, calcareous, in beds 3 to 8 inches thick separated by thin layers of gray-green shale; some beds essentially thinly foliated limestone; some lenticular beds include strings of gray and green mud lumps; many beds ripple-marked; worm trails common	7
2. Shale, calcareous, or limestone, blue-gray; weathers cream-colored; includes a few beds of finely crystalline limestone; in places appears as single massive bed but splits readily into even sheets as thin as cardboard that form a talus of resistant angular slabs as large as 2 by 3 feet; a few beds ripple-marked	29
1. Sandstone, gray, calcareous, and limestone, gray and brown, ferruginous; in thin beds irregularly alternating; foliation surface uneven and sprinkled with tiny quartz grains; lime concretions and bits of chalcedony; some fragmentary shells; increasingly calcareous and regularly bedded upward	15
Total Carmel formation	93

Unconformity: Channeled surface; patches of limestone and conglomerate.

Navajo sandstone.

As the Upper Jurassic strata in the Paria Valley are incompletely exposed, section 1 has been compiled from partial sections thought to be representative. In the whole sequence between the Carmel formation and the upper half of the Winsor formation (units 20–6) the subdivisions here defined grade vertically and laterally into others of unlike physical character, and so irregularly that measured sections only a few hundred feet apart are not directly comparable. In the stratigraphic section units 22–19 are substantially the equivalents of units 42–19 classed as "Morrison (?) and upper part of San Rafael group" by Gregory and Moore (1931, pp. 84, 85.) Unit 16 has previously been assigned to the Summerville (?) and also to the Curtis formation.

2. *Section in Sheep Creek above the boxhead of its canyon*

[Measured with the assistance of Norman Williams]

Winsor formation:	Feet
11. Sandstones, inconspicuously banded red and white, friable; weathered into flat surfaces and low mounds; thickness estimated	500

Curtis formation:	
10. Limestone, gray blue, weathers white; thin-bedded, forming ledges	21
9. Shale and sandstone, red and yellow, in thin wavy and irregular beds, calcareous; form a gentle slope	53
8. Limestone, thin-bedded, sandy	11
7. Sandstone, brown, massive, loosely cemented, slightly gypsiferous	15
6. Shale red, gypsiferous, irregularly bedded	16
5. Gypsum lumpy, massive; in places sandy; thickness along strike 5 to 9 feet	3
Total Curtis formation	119

Unconformity.

	Feet
Entrada sandstone:	
4. Brown sandstone and interbedded dark-brown shale	10
3. Shale and silt, predominantly red, but containing some brown, light buff, and yellow shades	36
2. Sandstone, yellow ocher and tan gray; fine to medium, translucent quartz grains; cement lime and iron; beds 2 to 4 feet thick, in part crossbedded; forms a sheer cliff	65
Total Entrada sandstone	111
Carmel formation:	
1. Limestone, gray, thin-bedded, highly cleavable, brittle, ripple-marked. Some thicker beds project as ledges on otherwise uniform steep slope. Includes layers of brown, red-purple, and white sandy shale	84
Unconformity.	
Navajo sandstone.	

3. *Section along Willis Creek*

[Measured by Norman Williams]

Dakota (?) sandstone: Coal	
Winsor formation:	
11. Light-yellow sands and shales; Marked absence of red strata	207
10. Banded red and yellow sands and shales. The reds become more abundant toward the base	163
9. Massive sandstone in long, oblique lenses; little stratification; predominantly red	220
Total Winsor formation	590

Nos. 9 and 10 grade vertically into each other, and along the strike the zone of gradation lies at various horizons.

Curtis formation:	
8. Thin-bedded white limestone	27
7. Red shales and siltstones	50
6. Thin-bedded limestone	20
5. Red shales and siltstones	68
4. Gypsum	9
Total Curtis formation	174
Entrada sandstone:	
3. Red shales; some yellow discolorations	29
2. Yellow sandstone in alternating massive resistant beds and friable stratumlike beds	73
Total Entrada sandstone	102
Carmel formation:	
1. Thin-bedded, shinglelike limestone: no particular lithologic differences throughout section. Some harder lenses make small ledges	96
Unconformity.	
Navajo sandstone.	

4. *Section in Everett Hollow*

	Feet
Curtis formation:	
17. Limestone, drab and blue gray; thin-bedded; in part argillaceous; at one place includes a knob of gypsum 2 by 9 feet; forms surface of a wide bench. Beds 200+ feet above are fossiliferous	4
16. Shale, brown; calcareous, gypsiferous; forms covered slope	8
15. Limestone, thin, brittle, like Nos. 1 and 5	2
14. Shale, reddish, sandy, calcareous and gypsiferous; even-bedded; small sheets and crystals of gypsum on weathered slope; friable; largely covered	83
13. Gypsum, massive, white, greenish, and reddish; in short distances along strike measures 2 to 24 feet	16
Total Curtis formation	113
Entrada sandstone:	
12. Sandstone, yellow tan; lower part somewhat regularly bedded; composed of poorly rounded, poorly sorted grains of two sizes, many of them coated yellow with limonite, and on weathering produces yellow sand; upper part massive or roughly bedded and composed chiefly of round glistening quartz grains. On cliff faces contact of red, bedded No. 11 and massive yellow No. 12 is sharp	28
11. Sandstone, reddish gray; fine-grained, in part cross-bedded; exposed as two beds about 18 feet thick and one bed 5 feet thick, separated by thin-bedded red shale. With No. 12 forms a prominent cliff continuous for miles	82
10. Sandstone, maroon; in shalelike calcareous beds; friable; forms a groove between Nos. 9 and 11	3
9. Sandstone, gray; fine-grained; massive; a persistent hard bed	5
Total Entrada sandstone	118
Carmel formation:	
8. Limestone, reddish, sandy, nodular; irregularly interbedded with porous sandstone and streaks of hard yellowish shale; cement chiefly lime and iron; includes aggregates of iron sand and lenses of limestone breccia; forms a prominent ledge	9
7. Limestone, blue gray on fresh surface; like Nos. 1 and 5 but thicker and less regularly bedded; includes a few thin beds of greenish shale; forms a steep slope with rounded contours	22
6. Shale, drab; calcareous and arenaceous; very thin, even beds; breaks into cubical fragments; forms a flat slope	14
5. Limestone, thin-bedded; brittle, like No. 1	5

Carmel formation—Continued	Feet
4. Shale, buff; evenly thin-bedded; very soft; forms a slope, largely covered	6
3. Gypsum, greenish white and reddish; extremely irregular lumpy beds; in some places nearly pure, in others about half quartz sand, aggregates of clay and calcite; within 1,000 feet the thickness ranges from 6 inches to 12 feet, average about	4
2. Shale, drab; very thin layers; calcareous and argillaceous; red sandy layers at the top. Forms a covered slope	10
1. Limestone and subordinate shale. Limestone buff and blue gray; lower part sandy, unevenly bedded; upper part very thin, dense, brittle, regularly bedded, many beds beautifully ripple-marked. Shale drab and yellowish, calcareous; at the base irregular masses of imbricated and lumpy mud flakes; elsewhere even-bedded and marked by ripples and "tadpole holes"; includes lenses of fine limestone conglomerate. Forms a benched steep slope	23
Total Carmel formation	84

Unconformity; eroded surface.
Navajo sandstone; white, strongly cross-bedded.

5. *Section in Bull Valley*

Curtis formation:	
6. Gypsum, the caps of low mounds in undetermined contact with the Entrada; above it in places gypsiferous shale and thin-bedded limestone; outcrops form broad undulating surfaces unfavorable for stratigraphic measurements. Thickness estimated	120
Entrada sandstone:	
5. Sandstone, red gray, weathering yellow, roughly bedded; predominantly composed of coarse well-rounded quartz grains cemented by lime and iron. Half a mile distant along the strike the corresponding unit is 8 to 18 feet thick, in part cross-bedded, and contains many iron grains and abundant calcareous cement which on weathering leaves a porous rock	32
4. Sandstone, light red, fine-grained, generally thinly, evenly bedded, slightly gypsiferous; crossed by white bands; includes a few thin short lenses of earthy limestone, very friable; broad surface of low mounds largely covered. Thickness estimated	80
Total Entrada sandstone	112

Carmel formation:	Feet
3. Limestone, blue gray; thin, evenly stratified, entirely calcareous beds, with some thicker sandy beds; many ripple marks; breaks into hard clumps and cubical blocks that stream over steep slopes	96
2. Shale, green, red, and purple, imbricated, ripple-marked; includes at the base individual grains and aggregates of glistening white quartz; rests in depressions worn in No. 1	0–4
Total Carmel formation	100

Unconformity.
Navajo sandstone:
1. Sandstone, white, much fractured.

6. *Section at head of Lick Wash*

Entrada sandstone:	
5. Sandstone, red, thin-bedded, very friable, surface covered; in distance seen to underlie ledges of gypsum (Curtis formation). Thickness estimated	200
4. Sandstone, gray white, roughly bedded, slabby, coarse-grained; thins and thickens along strike from about 10 to 35 feet	22
3. Sandstone, thin-bedded, gypsiferous, very friable, slope largely covered	30
Total Entrada sandstone	252
Carmel formation:	
2. Limestone, gray blue; weathers white; very thin bedded, dense, ripple-marked; includes units of calcareous shale as much as 10 feet thick, and thin layers of fine sandstone; basal sandy beds overlie truncated laminae of No. 1	110

Unconformity.
Navajo sandstone:
1. Sandstone, white, crumbly at the top.

7. *Section at the mouth of Mill Creek west of Skutumpah*

Carmel formation:	
7. Limestone, sandy, dense, resistant, in three beds	5
6. Limestone, gray, tan, thin-bedded, sandy, rippled	25
5. Sandstone, dense, calcareous, very uneven, lenticular	1
4. Limestone, gray, shaly, some red shales	33
3. Sandstone, yellow, imbricated, much rippled	1/6
2. Limestone, arenaceous, light tan; some beds thin as paper, some 4 to 8 inches thick, break into hard chips; surface looks like stubble field	44
	108 1/6

Unconformity.

	Feet
Navajo sandstone:	
1. Sandstone: strongly cross-bedded (to southwest), evenly planed off at top; forms canyon walls leading to Johnson Creek.	

8. *Section on Willis Creek above the mouth of Sheep Creek*

[From Gregory and Moore, 1931, p. 99]

	Ft.	in.
Cretaceous:		
Tropic shale:		
14. Sandstone, fine- to medium-grained, massive and thin-bedded; contains several lenses of shale; yellowish but weathers brilliant red in places; a middle bed about 2½ feet thick contains abundant fossil fragments chiefly *Ostrea prudentia* and a few other pelecypods	75	
13. Coal; appears locally; poor grade and contains shale and sandy material	2	
12. Shale, gray; weathers soft; many fragments of *Ostrea*	20	
11. Sandstone, yellow brown, middle part dark brown, cross-bedded; contains some fine conglomerate with here and there pieces of charcoal and bands of carbonaceous material one-sixteenth to one-eighth inch in thickness	20	
10. Shale, carbonaceous, upper 6 inches fissile; carries some sulfur	2	6
9. Coal, impure but black and glistening; contains much sulfur		2
8. Shale, gray; weathers soft; many fragments of *Ostrea*	3	
7. Coal, very impure and contains much sulfur; mostly a hard very carbonaceous shale		4½
6. Shale, like No. 14	8	
5. Sandstone, yellow gray, hard, a single massive bed	1	6
4. Shale, like No. 14	33	
3. Coal:		

	Ft.	in.
Coal, fair quality	2	4
Bone		4
Coal, good quality	1	10
Sandstone, gray		⅝
Coal, fair quality, contains sulfur and gypsum	1	2½
Sandstone, gray		½
Coal, fair quality; contains sulfur and gypsum	10	
Sandstone, hard, clayey, fine-grained, lenticular	2	
Coal, poor quality	4	
Clay	5	
Coal, fissile	3	
Coal, brown, impure, poor quality	1	1
Shale, bluish, carbonaceous	2	6
(Total of No. 3)	33	4⅝

	Ft.	in.
Cretaceous—Continued		
Tropic shale—Continued		
2. Shale, gray; weathers soft; many fragments of *Ostrea*	75	
Total Tropic shale	273+	
Dakota (?) sandstone:		
1. Sandstone conglomerate, yellow and white, hard, massive	6	
Unconformity.		
Jurassic: San Rafael group.		

9. *Section near head of Slide Canyon*

	Feet
Tertiary:	
Wasatch formation:	
Pink generally massive limestone; forms a vertical cliff about 400 feet high; basal beds a conglomerate of quartzite cobbles.	
Unconformity: eroded surface and angular contact.	
Cretaceous:	
Kaiparowits formation:	
21. Sandstone, brown and gray, in beds 2 to 4 feet thick; grains of quartz (95 percent), iron, and feldspar generally fine and poorly assorted; many of the thinner beds arranged as sheets overlapping like shingles, especially noticeable on weathered surfaces; includes irregular lenses of clay fragments, a few iron concretions, and rare fossil bones and leaf prints; forms a terraced slope partly covered	110
20. Sandstone, light gray, inconspicuously bedded, friable; very fine quartz and iron grains cemented with calcite; includes numerous angular clay fragments and "mud lumps"; weathers to a fairly smooth steep slope	30
19. Shale and thin friable sandstone; probably much like No. 20; slope covered	26
18. Sandstone, tan, in dense beds 6 inches to 4 feet thick, some cross-bedded; sequence interrupted by numerous lenses of clay sheeted or in lumps; weathered surface marked by grooves, pits, and spherical knobs	32
17. Shale and thin sandstone; variegated in places, nearly white; like Nos. 14 and 15; rough slope largely covered	43
16. Sandstone, dark gray, unevenly bedded; fine-grained stratified beds separated by patches and sheets of tightly cemented sand balls; forms a cliff	26
15–14. Shales and very thin friable sandstones separated by a bed of hard tan sandstone 5 feet thick; upper beds brown and purple, rich in iron; lower beds gray, highly calcareous, include lenses of clay and concretions of sand; forms a broken slope	35
13. Sandstone, gray brown; dense; tightly cemented with lime; fine spherical quartz grains (about 90 percent) mingled with iron and other dark minerals and white decomposed feldspar and calcite produce a "pepper and salt rock"; forms a cliff	22

Cretaceous—Continued	
Kaiparowits formation—Continued	Feet
12. Sandstone, dark gray, thin-bedded, fine-grained, generally even-bedded; includes lenses of coarse sandstone and of lumpy gray clay; fossiliferous; weathers like shale; slope largely covered	32
11. Sandstone, tan, compact bed of fine quartz sand cemented chiefly by iron; dense, brittle, resistant to erosion	3
10. Sandstone, tan, fine-grained; thin, fairly even beds weakly cemented by lime	10
9. Sandstone, gray tan, irregularly bedded on large and small scale; the predominantly thin, fine-grained, fairly even friable beds are interstratified with lenses of coarse, massive, cross-bedded, resistant rock 100 to 500 feet long and 6 to 20 feet thick; at the top a thin bed of iron-cemented sandstone forms a hard surface from which No. 10 has been stripped; particularly in the coarser beds lime and iron concretions, clay balls, and sand pellets are common; contains fossil wood and bones; in the topography appears as a rough-faced cliff	90
8. Shale, banded white and purple, essentially a clay silt, lacustrine (?), friable, protected from erosion by No. 9	6
7. Sandstone, drab, thin-, irregular-bedded, fine-grained; includes lenticular aggregates and scattered individuals of clay lumps and balls; forms a steep slope	18
6. Shale, banded red and purple; beds thin and regular; resembles lacustrine clay silt; some beds imbricated; forms a steep slope	26
5. Sandstone, gray, weathered brown and yellow; very uneven coarse-grained beds; many lenses and strings of pebbles as in No. 4	21
4. Conglomerate, gray, roughly bedded, chiefly quartz and quartzite pebbles, gray, white, brown, and black, mostly ¼ to 1 inch in diameter, the largest 2½ inches; include rare clay fragments and sand balls	1–4
Total Kaiparowits formation	534
Unconformity: conglomerate rests on eroded surface of No. 3.	
Wahweap and Straight Cliffs sandstones:	
3. Sandstone, tan, streaked with yellow, coarse-grained, cross-bedded, indefinitely bounded strata 2 to 4 feet thick; round and subangular grains of quartz (about 98%), feldspar, iron, calcite, and clay; generally resistant to weathering; forms a prominent cliff	47

Cretaceous—Continued	
Wahweap and Straight Cliffs sandstones—Con.	Feet
2. Sandstone, tan, thin-bedded, fine-grained; includes many imbricated shalelike beds; forms a steep slope broken by shelves	44
1. Sandstone, gray (white in distant views), a series of cross-bedded lenticular strata; coarse grains of white quartz, iron-stained quartz, and rare feldspar, magnetite, and garnet (?); includes many rounded and oblong concretions of ironstone; weathers as a cliff modified by hoodoos and other fantastic forms	14
Wahweap and Straight Cliffs sandstones measured	105
Total Cretaceous measured	639

10. *Section near Tenney Ranch, in Tenney Canyon*

Tertiary:	
Wasatch formation:	
52. Conglomerate, in part rough breccia, chiefly gray masses and strings of well-worn quartz, quartzite, and black limestone pebbles, one-eighth to three-fourth inch in diameter, included in the basal 20 feet of otherwise uniformily massive pinkish limestone; isolated cobbles of banded quartzite measure 6 to 8 inches in diameter and slabs of sandstone and laminated limestone more than 1 foot; the sharply defined base of a vertical cliff about 300 feet high.	
Unconformity; eroded surface; change in composition and age of sediments.	
Cretaceous:	
Kaiparowits formation:	
51. Sandstone, dark gray, mostly thin-bedded, probably similar to No. 46; steep slope, covered	66
50. Sandstone, dark gray, chiefly fine, subangular grains of clear and clouded quartz (85 per cent), black iron, calcite, and mud pellets; includes patches of hard yellow clay, calcite aggregates, and ironstone in thin sheets and concretionary lozenges; top bed hard, fine-grained, iron-cemented sandstone; a prominent ledge continuous along the strike for at least 1,000 feet	22
49. Sandstone, much like No. 46; forms steep slope, largely covered	50
48. Sandstone, uneven-bedded, fairly coarse, poorly rounded grains of white quartz (95 percent), feldspar, iron, and calcite; "pepper and salt" rock, very friable	8

Cretaceous—Continued

Kaiparowits formation—Continued

	Feet
47. Sandstone; weathers greenish gray, very friable, no unweathered outcrops; disintegration products on steep slope include round and angular coarse and fine quartz grains, kaolinized feldspar, tiny lime and iron concretions, chunks and balls of clay, fragmentary shells and bones, very rare selenite; probably much like No. 43	103
46. Sandstone, dark gray, roughly bedded; overlapping lenses of coarse and fine texture; dark (iron) and white quartz and feldspar grains give "pepper and salt" appearance; includes clay balls and sand balls; forms a rough-faced cliff	44
45. Sandstone, dark gray, coarse-grained, thin, irregular-bedded, and some reddish mud shale, very friable; only about 6 feet of rock exposed on flat slope	71
44. Sandstone, tan and dark gray in irregular lenticular beds, 5 to 20 feet thick, alternating with tan, red, and greenish shale, 6 inches to 3 feet thick. Sandstone coarse and fine, locally conglomeratic; subangular and rounded quartz (95 percent), feldspar, magnetite, calcite, and bits of clay, weakly cemented with lime; friable. Shale sandy, argillaceous, some of it strongly calcareous. Weathers as a steep slope of unevenly placed steps and risers	142
43. Sandstone, greenish gray, very roughly bedded; fine, poorly rounded quartz pebbles (95 percent) iron grains, and decomposed feldspar; includes sheets of coarse sandstone, flat lozenges of yellow shale, lenticular limestone conglomerate, wrinkled beds of red calcareous shale, and argillaceous and greenish clay aggregates marked by plant remains; forms irregular steep slope	47
42. Shale, dark gray; slope covered	13
41. Sandstone, tan gray, generally coarse, subangular grains, roughly bedded; includes lenses of conglomerate, made up chiefly of yellow mud balls; plant impressions on finer-grained beds	11
40. Shale, dark gray, sandy, and fine, even-grained sandstone in overlapping beds; at the top a strongly calcareous bed forms a hard uneven surface; a steep stairlike slope	42
39. Sandstone, gray tan, thin-bedded, and shale, green gray, in lenticular beds; upper half fine-grained arkosic sandstone, marked by fossil leaves; forms a cliff	13
38. Sandstone and conglomerate, light greenish gray, in places white; main mass is sandstone, conspicuously bedded, angularly cross-bedded, composed chiefly of coarse subangular grains of quartz weakly cemented with lime; regionally includes lenses composed almost wholly of quartz and feldspar; at the top lenses 2 to 4 feet thick of fine-grained hard sandstone; conglomerate at the base and irregularly above forms beds 2 to 5 inches thick, 20 to 100 feet long, and stubby lenses 1 to 4 feet thick of conspicuously angular, cleanly washed pebbles one-eighth to one-half inch in diameter; black pebbles included and gray limestone (30 percent); white, gray, banded, some brecciated quartzite (20 percent), white quartz (40 percent), feldspar, and chert; weathers into mosques, hoodoos, and towers; forms a prominent, generally white ledge of wide extent	90
Total Kaiparowits formation	722

Unconformity; No. 38 rests on the maturely eroded surface of Nos. 37 and 36; dip of the beds slightly different.

Wahweap and Straight Cliffs sandstone:

	Feet
37–36. Shale, greenish gray, especially argillaceous, sandy in upper part; includes thin short layers and stub-ended lenses of fine-grained, nearly pure quartz sandstone and calcareous sandstone; generally friable; capped with bed of tightly cemented calcareous sandstone that includes dark-brown nodules and pancakes of ironstone and gray chert; forms a cliff with overhanging top, continuous for long distances	30
35. Sandstone, tan; a fine-grained hard ledge	4
34. Sandstone, dark gray; mostly in shalelike beds; includes a lens of massive coarse sandstone about 10 inches thick and thin sheets of red shale; forms a cliff	36
33. Sandstone, fine-grained, hard; forms a persistent ledge	2
32. Shale or thin sandstone, greenish brown, roughly bedded; includes thin lenses and irregular patches of hard dark-brown ironstone; forms a steep slope	40
31. Sandstone, tan, irregular-bedded; hard, massive ledge making beds interstratified with layers that weather like honeycombs; includes irregularly distributed clay pellets disks of limonite, and calcareous sand balls	8

Cretaceous—Continued

Wahweap and Straight Cliffs sandstones—Con.	*Feet*
30. Shale, gray mottled with red and purple; a covered slope	36
29. Sandstone, drab, coarse-grained, porous	4
28. Shale and thin-bedded fine-grained sandstone, drab; a few thin short lenses of fairly coarse calcareous sandstone; top 2 feet drab, sticky calcareous clay that contains fragmentary plants and specks of charcoal; alternating steep slopes and cliffs that weather into square blocks [Nos. 28 to 34 measured about half a mile northeast of the other units.]	35
Local (?) unconformity; abrupt changes in the type of sediments.	
27. Sandstone, dark gray, very irregular beds, some cross-bedded, cement chiefly lime, porous; includes small geodes lined with calcite, concretionary balls of lime and iron, and lenses composed of small quartz pebbles, worn fragments of vertebrate bones, shells, chunks of chert and hard limestone; forms a cliff decorated with resistant knobs and with pits and slots from which water seeps	60
26. Shale, drab and gray, red at top, highly calcareous, in places substantially a flaky limestone; includes tiny lenses and grains of decomposed iron minerals; forms a slope largely covered	16
25. Sandstone, tan, in thin, hard, fairly regular lime-cemented beds that include aggregates of calcite	3
24. Shale and thin sandstone, drab, red, and purple, unevenly bedded; forms a steep slope, largely covered	30
23. Sandstone, mottled gray, white, and black in fairly regular hard beds; fine quartz grains mingled with a little iron and decomposed feldspar; forms a cliff marked by irregularly placed pits and grooves	41
22. Shale and thin-bedded fine-grained quartz sandstone, drab; includes lenses of arenaceous limestone and of decomposed "pepper and salt" sandstone in which feldspar, calcite, and iron grains are conspicuous; forms a slope, largely covered	63
21. Sandstone, tan, generally a massive cross-bedded hard ledge, roughly bedded in places, fairly fine quartz and iron grains	27
20. Sandstone, tan gray, generally coarse-grained, cross-bedded; arranged as lenses 6 to 20 feet thick and 40 to 500 feet long separated by irregular thin beds of fine-grained gray sandstone and evenly stratified purple and drab sandy shale; forms a steplike steep slope; in places along the strike forms one or more prominent cliffs	138

Cretaceous—Continued

Wahweap and Straight Cliffs sandstones—Con.	*Feet*
19. Sandstone, yellow and tan, fine spherical grains of quartz and black iron; a firm ledge stained with limonite	4
18. Shale, drab, and thin brown sandstone; slope covered	38
17. Sandstone, tan, hard beds 2 to 3 feet thick, separated by dark-gray sandy shale; includes flat concretions of sand and a few leaf casts; forms steps on a steep slope	17
16. Sandstone, tan, irregular beds 2 to 16 feet thick, generally massive and coarse-grained; includes beds and long, thin lenses of thin, fine-grained tan sandstone and drab shale; very friable; forms a steep slope, largely covered	79
15. Sandstone, yellow tan, coarse-grained, in irregular beds 4 to 10 feet thick; generally soft and porous, weakly cemented with calcite and limonite; includes rare feldspar, many iron grains, and hard brown patches of ironstone that weathers as caps of little mesas; forms a vertical cliff marked by borings of "rock bees"	27
14. Sandstone, gray and tan, in massive beds 2 to 10 feet thick, in places separated by lenses of sandy shale; generally coarse-grained and friable; forms with No. 15 a prominent cliff, continuous for as much as a mile	12
13. Shale, brown, in places yellow, resistant, very thinly laminated beds; ocherous iron coats many grains and appears as yellow powder on the sloping surface	12
12. Sandstone, tan, in thick, massive uneven beds, coarse-grained; in part cross-bedded and lenticular; weakly cemented with lime; forms benches on a steep cliff	50
11. Sandstone, tan, coarse and fine-grained, even-grained, in irregular massive beds about 2 feet thick; includes thin lenses of conglomerate like No. 9; some fossil leaves; forms a cliff	14
10. Sandstone, tan, in irregular shaly beds; forms a slope deeply covered with debris	8
9a. Conglomerate composed of angular fragments of red, white, and gray quartz, hematite (?), and limonite one-eighth to one-fourth inch in diameter; weathered surface strewn with reddish iron chips, iron balls, and casts of *Ostrea* and *Cyrena* (?); lime and iron cement; rare gypsum	1
Total Wahweap and Straight Cliffs sandstone	835

Local (?) unconformity.

Cretaceous—Continued	
Tropic shale:	Feet
9. Shale, blue gray, argillaceous and arenaceous, oily; includes seams of gypsum, impure coal, fragments of leaves, broken marine shells; forms a slope, unevenly weathered	28
8. Sandstone, yellow drab, thin-bedded, soft, roughly interstratified with argillaceous, calcareous, slightly gypsiferous soft shale; forms a slope, largely covered	18
7. Sandstone, gray tan, thin-bedded, coarse-grained, many black grains; top beds firmly cemented with lime; forms a bench	3
6. Shale, drab, in places dark blue, evenly bedded	16
5. Sandstone, drab, thin-bedded, in places cross-bedded, coarse-grained; includes layers of impure coal and considerable iron	4
4. Shale, purple and gray; includes specks of charcoal, sheets of impure coal, macerated leaves and stems; a lens about 12 feet long	3
3. Sandstone, buff, thin-bedded; composition like No. 2	28
2. Sandstone, dark yellow gray, fine, even-grained, fairly regular shalelike beds; a few argillaceous and gypsiferous beds, very friable; chiefly subangular glistening pure quartz grains; some angular black iron and calcite grains; weakly cemented with lime and iron; top beds harder, lenticular, and weather as little towers; forms a steep slope	78
1. Shale, drab, locally covered with talus; in distance appears as yellowish-gray even-bedded shale with layers of sandstone near top; gypsum crystals on the surface; thickness estimated	300
Total Tropic shale exposed	478
Total Cretaceous measured	2,035

11. *Section in Sink Valley*

[Measured by G. B. Richardson, 1927, pp. 474–475]

Wasatch formation:	Feet
Conglomerate, rounded pebbles of limestone and quartzite, 1 to 6 inches in diameter.	
Unconformity.	
Montana group [Kaiparowits formation]:	
Sandstone, massive, buff	55
Shale, drab	27
Sandstone, massive, buff	30
Shale, light	6
Sandstone, massive, buff, containing the following fossils: *Unio* (casts of two or more species), *Physa* sp., *Planorbis kanabensis* White, *Campeloma?* sp., *Viviparus panguitchensis* White	60
Concealed (probably shale)	27
Montana group [Kaiparowits formation]—Continued	Feet
Sandstone, massive, buff	33
Conglomerate, rounded pebbles of limestone and quartzite, 1 to 2 inches in diameter	27
Total Kaiparowits formation	265
Unconformity.	
Colorado group [Wahweap and Straight Cliffs sandstones]:	
Sandstone, grayish white	150
Shale, purplish drab	20
Sandstone, massive, buff	65
Concealed (probably shale)	60
Sandstone, massive, buff	16
Concealed (probably shale)	50
Sandstone, massive, buff, fine-grained	65
Sandstone, yellowish, coarse-grained	25
Sandstone, conglomeratic; pebbles small and scattered	5
Sandstone, massive, buff	50
Concealed (probably shale)	10
Sandstone, massive, buff	11
Shale, carbonaceous	7
Sandstone, buff	11
Shale, light	8
Sandstone, containing oysters	11
Sandstone, massive, buff	100
[Total Wahweap and Straight Cliffs sandstones]	664
[Tropic Shale]	
Shale, drab, clayey and sandy, and local thin beds of sandstone, containing the following fossils in the lower part: *Inoceramus* sp., *Lucina* sp., *Liopistha* (*Psilomya*) *meeki* White, *Turritella whitei* Stanton, *Aporrhais prolabiata* (White), *Sigaretus textilis* Stanton?, *Baculites gracilis* Shumard?, *Helicoceras pariense*, White, *Metoicoceras whitei* Hyatt	1,200
Sandstone, massive, buff	60
Shale, carbonaceous	25
Sandstone, buff	6
Shale, light	11
Shale, carbonaceous	20
Sandstone, massive, buff	25
Shale, drab	80
Coal and shale	8
Concealed (probably shale)	40
[Total Tropic shale]	1475
Dakota (?) sandstone:	
Sandstone, gray	7
Conglomerate, rounded pebbles of limestone and quartzite	15
Total Dakota (?) sandstone	22
Total	2,426

12. *Section in Big Hollow, Sunset Cliffs*

[Measured by F. W. Christiansen; description revised by Herbert E. Gregory]

	Feet
Tertiary:	
Wasatch formation:	
37. Limestone, banded gray, pink, yellow, and red; poorly stratified; near base dense, crystalline, crossed by veinlets of calcite; forms ledges and slopes leading to the top of the Sunset Cliffs.	
36. Conglomerate and sandstone, light grey, in lenticular beds. Sandstone, coarse grains, well rounded and sorted; conglomerate, well-rounded pebbles 1 to 6 inches in diameter, compacted quartzite (85 percent), chert (5 percent), sandstone (5 percent), limestone (5 percent); conglomerate lenses near the base 12 feet thick; rests on uneven surface of No. 35; forms a cliff	25
35. Limestone, variegated hard, crystalline, in poorly defined beds; many open joints and cavities filled with calcite crystals; forms a ledge	18
34. Limestone, red, yellow, and gray, arenaceous; includes locally lenses of coarse, poorly sorted conglomeratic sandstone in which some rounded grains are half an inch in diameter; forms a bare steep slope	42
33. Sandstone, gray, calcareous, and pinkish limestone, irregularly interbedded; includes a few lenses of sandstone and scattered small pebbles; forms a cliff	12
32. Limestone, pink, dense, massive, sandy, and thin reddish sandstones in fairly regular beds composed of spherical, well-sorted quartz grains; some layers of soft claylike material; forms steep slope	36
Total Wasatch formation measured	133
Unconformity; eroded surface and abrupt change in type of sediments.	
Cretaceous:	
Kaiparowits formation:	
31. Sandstone, dark gray, arkosic, and sandy clay shale; beds generally thin, evenly stratified, and friable; grades laterally into ledges of irregularly bedded resistant sandstone and mudstone; forms a steep slope	39
30. Sandstone, brownish red, thinly laminated, wavy beds; grains chiefly quartz, somewhat angular, poorly sorted; includes grains of iron, weathered feldspar, and augite (?); forms a slope, largely covered	79
29. Sandstone, buff and tan, irregularly bedded, cross-bedded, composed of medium-sized subangular grains of pure quartz (70 percent), iron and other dark minerals (20 percent), and white material, some of it kaolin (10 percent); forms a steep slope	46

	Feet
Cretaceous—Continued	
Kaiparowits formation—Continued	
28. Shale, blue to gray, in regular and wavy beds; interstratified with buff sandstone in beds 6 inches to 2 feet thick, composed of fine, round, well-sorted grains tightly cemented with lime and iron; on a slope largely covered with fine talus the sandstone beds project as ledges	75
27. Sandstone, dark greenish gray, in interbedded soft and hard layers; forms a slope, largely covered	19
26. Sandstone, yellow gray, a series of irregular beds and lenses, generally cross-bedded; beds of white coarse-grained weakly cemented sandstone that include angular fragments of hard fine-grained sandstone; lenses of conglomerate; thin dark bands and chunky masses of iron-cemented sandstone; circular masses of dark-gray sandstone; ironstone in the form of pancakes, lozenges, and cylindrical tubes; impressions of leaves; forms a conspicuous ledge marked by pits and projections	45
25. Sandstone, dark gray, irregularly bedded, in part cross-bedded; includes many angular fragments of white clay; forms a slope	29
24. Conglomerate; angular fragments of brown, white, and greenish clay and gray sandstone; includes a few broken shells	3
23. Sandstone, tan, indefinitely bedded; grains well rounded and sorted; very friable; weathers as a smooth slope	33
22. Sandstone, dark gray spotted white, irregularly bedded, coarse- and fine-grained, arkosic; parts of it made up of fragmentary shells	3
21. Shale, greenish gray, argillaceous and arenaceous, resistant to weathering; retains its individuality for at least 600 feet	2
20. Sandstone, buff; forms a slope, covered with weathered debris	23
19. Sandstone, yellow, fine-grained, firmly cemented with iron; includes many ironstone concretions; conspicuous as a projecting ledge	2
18. Sandstone, dark gray, irregularly bedded, inconspicuously cross-bedded; lower layers composed of moderately fine, well-rounded grains; upper layers of coarse subangular clear quartz grains (85 percent), iron, iron-stained minerals, and clay fragments; includes many ironstone concretions and impressions of plant leaves and stems; forms a cliff marked by irregular grooves and shelves	96
17. Shale, greenish white and dark blue, argillaceous and calcareous, and sandstone, generally buff; forms a slope, largely covered	18

Cretaceous—Continued

Kaiparowits formation—Continued *Feet*

16. Conglomerate, buff to dark gray, in lenses 3 to 8 feet thick, separated by layers of coarse-grained cross-bedded sandstone 1 to 3 feet thick; pebbles that make up the conglomerate and the few in the sandstone are dominantly rounded fragments of chert, quartsite, and quartz, 1 to 3 inches in diameter, but include rhyolite (?), hard clay, and broken shells; a resistant ledge maker that forms the top of spurs on the slopes below Sunset Cliffs; rests in depressions eroded in the surface of No. 15; average thickness ---------- 25

Total Kaiparowits formation ---------- 537

Unconformity.

Wahweap and Straight Cliffs sandstones:

15. Sandstone, gray, buff, locally stained deep red, hard, slightly cross-bedded, fairly even basal beds of irregular shaped coarse and fine grains grade upward to friable, strongly cross-bedded lenticular layers of fine sandstone, coarse sandstone, and conglomerate; fully 95 percent of the grains are pure quartz; forms a prominent cliff ---------- 62
14. Sandstone, light gray and broad irregular bands of yellow; thick long lenses of massive cross-bedded medium- and coarse-grained sandstone separated by short beds of thinly stratified fine-grained sandstone; composed chiefly of clean spherical well-sorted quartz grains (90 percent) and iron or iron-stained minerals; the upper part includes lenses of concretionary iron, aggregates of sandstone pellets, and angular chunks of hard gray clay; at the top a hard layer of brown iron-cemented sandstone; forms cliffs one above another that in the distance appear as a single escarpment ---------- 92
13. Shale and thin sandstone, blue, white, and buff; forms a slope, largely covered ---------- 28
12. Sandstone, light buff, massive, irregularly bedded, cross-bedded, friable; coarse grains of pure quartz (85 percent), iron-stained quartz (10 percent), magnetite and other black minerals, cemented by calcite and iron; includes aggregates and strings of angular clay fragments, sandstone pellets, and iron concretions; topmost 8-foot bed very resistant, mostly ironstone; forms a cliff with uneven face ---------- 45

Cretaceous—Continued

Wahweap and Straight Cliffs sandstones—Con. *Feet*

11. Sandstone, buff, medium-grained, cross-bedded, unevenly stratified with blue to gray arenaceous shale; forms a steep slope ---------- 39
10. Shale and sandstone, yellow and tan; sandstone in beds 1 to 3 feet thick, cross-bedded, friable, very porous, composed of medium-sized grains of clean white quartz (90 percent), well rounded but poorly sorted; includes lenses and concretions of ironstone; forms an uneven slope, largely covered ---------- 45
9. Sandstone and arenaceous shale, generally yellow; topmost bed, 1½ feet thick, is dense, hard, and iron-cemented; otherwise friable and on disintegrating covers bedrock on a slope ---------- 34
8. Sandstone, yellow tan; quartz grains tightly cemented with calcite and iron oxides; forms a sharply defined cliff ---------- 12
7. Shale and sandstone; covered except for protruding knobs of cross-bedded coarse and fine tan sandstone ---------- 57
6. Sandstone, light buff; medium and fine grains of pure quartz (90 percent), iron-stained quartz (10 percent), magnetite and auite (?) (3 percent), and kaolinized feldspar (2 percent); arrangement of grains of various colors produces the "salt and pepper" type; forms ledge that 500 feet along the strike breaks into three ledges separated by arenaceous shale; forms a steep slope ---------- 56
5. Shale, blue to buff, arenaceous and argillaceous, resistant to weathering ---------- 5
4. Sandstone, light cream-colored, beds 1 to 3 feet thick, cross-bedded, firmly cemented with lime and iron; magnetite and other black grains constitute about 10 percent of the rock; forms steep slope ---------- 28
3. Sandstone, buff, irregularly bedded, cross-bedded on large scale, soft, poorly compacted, generally fine-grained; includes lenses of coarse sandstone, sheets of earthy lignite, scattered grains of kaolin, and considerable powdery yellow ocher; forms a ledge with recessed grooves and pits ---------- 58
2. Sandstone, cream-colored to buff, cross-bedded, friable; poorly rounded and sorted grains; cement of lime and iron, largely decomposed, represented by a yellow pasty mass between grains and ocherous stain on the rock face; forms a stairlike slope ---------- 51

879992—51——6

Cretaceous—Continued

Wahweap and Straight Cliffs sandstones—Con.

	Feet
1. Sandstone, light cream-colored, interbedded with dark-gray arenaceous shale; most of medium-sized and coarse grains that compose the sandstone are coated with white and yellow powdery substances that represent original cement; friable; weathers into knobs and low cliffs on a steep irregular slope; much of it covered; a few hundred feet along strike the basal sandstone enlarges into a prominent cliff	74
Total Wahweap and Straight Cliffs sandstones measured	686

At the place where this section was measured the Cretaceous beds below No. 1 have been cut off by the Sevier fault.

13. *Section of the third ridge northwest of Rainbow Point, Pink Cliffs*

[Measured by H. B. Wood]

	Feet
Wasatch formation:	
8. Limestone, gray; grades upward into pink; contains shale layers and many geodes	51
7. Sandstone, banded yellow and purple, thinly laminated, calcareous	3
6. Limestone, brown gray, dense, resistant; contains pockets as much as 4 feet in diameter filled with limonite sand and gravel; includes also quartzite pebbles 3 to 6 inches in diameter and angular fragments of calcareous sandstone	34
5. Sandstone, brown, quartzitic, slightly cemented with calcite; lenticular beds	2
4. Shale, purple, blue and yellow, slightly sandy and calcareous; disappears along strike	1
3. Limestone, pink, hard, resistant, inconspicuously bedded; contains scattered angular fragments of buff limestone and grains of quartz; forms vertical cliff; thickness estimated	700
2. Conglomerate, pink gray, pebbles of quartzite embedded in limestone: cement calcite, silica, and ferrous iron	22
Total Wasatch formation	813
Unconformity.	
Kaiparowits formation:	
1. Shale, gray and purple, sandy, interbedded with dark-green arkosic sandstone; contains fossil wood and bones	14

DISTRIBUTION AND PREVIOUS RECORDS

In contrast with their thickness and wide expanse in the neighboring Aquarius, Sevier, and Markagunt Plateaus, the igneous rocks in the Paunsaugunt region cover small areas and take little part in determining the topography.

As shown on the geologic map (pl. 2), there are no igneous rocks on the Paunsaugunt Plateau, and about its base they are exposed in but five places—along the Sevier River between Hatch and Hillsdale, in the Sunset Cliffs, in upper Kanab Valley, in upper Johnson Valley, and in Tenney Canyon. Naturally in the regional studies of the pioneer geologists these scattered outcrops of igneous rock were given little attention. On the geologic atlas of the Wheeler Survey (1874, sheets 56, 67) the prominent basalt flows at the mouth of Red Canyon and in upper Johnson Valley are roughly outlined, and by error large areas of "basalt" and of "trachyte and rhyolite" are mapped along the East fork of the Sevier. On the maps of the Powell Survey only the lavas in Johnson Valley are shown. In the reports of these surveys the character and relations of the volcanic rocks in the Paunsaugunt region are not discussed by Howell or Gilbert and are but incidentally mentioned by Dutton (1880).

VOLCANIC AREAS

SEVIER VALLEY

In the Paunsaugunt region as here outlined, the westernmost exposures of igneous rocks are thin sheets of lava that cap two knolls on the east side of the Sevier River 3 miles south of Hillsdale. The sheets, which cover about 2 acres, consist of amygdaloidal lava, in part scoriaceous, about 27 feet thick, are outliers of the masses that cover large parts of the Markagunt Plateau and that along the west side of the Sevier River between Hillsdale and Hatch terminate in rugged cliffs. South of Hatch lava exposed in the highway extends westward from the mouth of Mammoth Creek to its source in a crater about 8 miles distant.

SUNSET CLIFFS

Along the crest of the Sunset Cliffs sheets of olivine basalt overlie the Wasatch formation (Dutton 1879, atlas sheet 2). North of Red Canyon they cover about 150 acres; south of the canyon only three small outcrops were found. Below the cliffs and on the north side of Red Creek lava extends westward nearly to the Sevier River, and south of the creek its forms a ridge that terminates nearly a mile north of Hillsdale Canyon. These detached outcrops are doubtless parts of a once continuous expanse of basalt; the northern outcrops have been separated from the southern by the erosion that produced Red Canyon, and the high eastern parts from the low-lying western parts by the vertical movement along the Sevier fault. (See page 75 and figs. 32, 37.) In consequence of irregularities in its original deposition and of subsequent erosion the lava ranges in thickness from 10 feet to more than 300 feet. The thicker sheets are generally dense, regularly bedded, and but slightly scoriaceous at the top; some of the

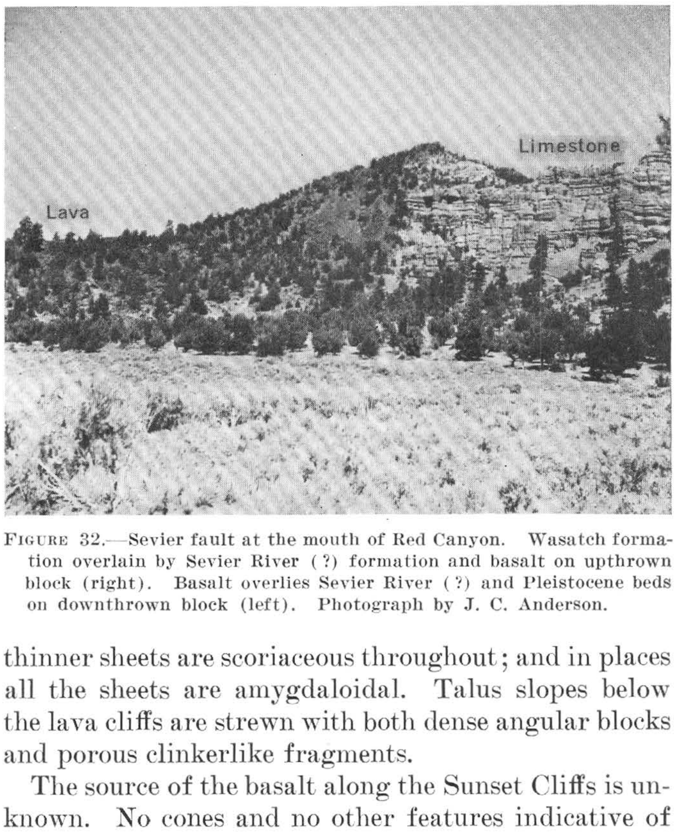


FIGURE 32.—Sevier fault at the mouth of Red Canyon. Wasatch formation overlain by Sevier River (?) formation and basalt on upthrown block (right). Basalt overlies Sevier River (?) and Pleistocene beds on downthrown block (left). Photograph by J. C. Anderson.

thinner sheets are scoriaceous throughout; and in places all the sheets are amygdaloidal. Talus slopes below the lava cliffs are strewn with both dense angular blocks and porous clinkerlike fragments.

The source of the basalt along the Sunset Cliffs is unknown. No cones and no other features indicative of centers of extrusion were found on the plateau above the cliffs or on the flat lands at their base. Doubtless, like the much more extensive flows that cover the nearby Sevier Plateau, the lavas originated in dikes now concealed from view.

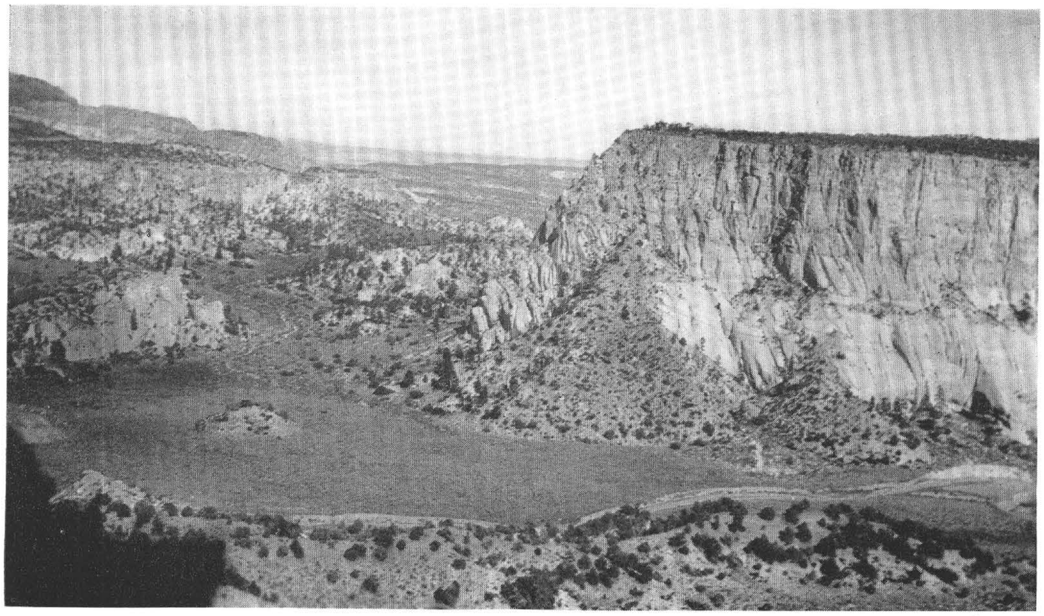


FIGURE 33.—Swallow Park fault. Navajo sandstone capped by limestone of Carmel formation in No Mans Mesa (right) stands about 400 feet above corresponding beds (left). See also map, pl. 4.

KANAB VALLEY

In Kanab Valley, south of Alton and near the mouth of Sink Creek, masses of igneous rocks are displayed as craters and lava flows (Gregory 1950).

North of Alton at the mouth of Roundy Canyon they are represented by a dike; the core of a narrow ridge about half a mile long and 20 to 90 feet high, trending N 35° E. For about 1,000 feet the dike is exposed as a crumbling wall 25 feet wide. Its contact with the country rock is sharp, and hexagonal jointing at right angles to the cooling walls is conspicuous. Though its intrusive origin is obvious, the dike is a curious assemblage of material—in general view a breccia or conglomerate rather than a mass of igneous rock. The parts identified as olivine basalt include wholly crystalline, vesicular, amygdaloidal, and brecciated masses of various sizes, without definite boundaries, placed indifferently within and at the edges of the dike. As viewed under the microscope, typical fragments of the igneous rock have phenocrysts of both olivine and augite in a fine-granular or vesicular groundmass of plagioclase, augite, and magnetite. Fully one-third of the dike, in places one-half, consists of included slabs of sandstone, limestone, and shale, a few inches to 6 feet long, arranged with little reference to size or position. Many of the shale fragments have been hardened by the heat, and some of the slabs, particularly those of limestone, have been partly absorbed. A resistant knob on the crest of the ridge consists almost wholly of basalt. From its center close-spaced joints extend radially outward, and at a distance of about 6 feet these are gradually replaced by other joints, likewise radial in position, which outline hexagonal columns. These structures suggest a vent that may have given rise to flows now entirely removed by erosion. The dike is on the floor of a valley bordered by cliffs 800 to 1,500 feet high. The nearest volcanic rock is about 7 miles distant.

JOHNSON VALLEY

Bald Knoll, at the head of Johnson Creek, is a symmetrical cone that rises 450 feet above a flat surface developed in Tropic shale. It retains much of its original form (fig. 34). At its top a crater about 600 feet long and 400 feet wide and nearly 200 feet deep is surrounded by a continuous narrow rim. The walls of the crater and the outer slopes of the cone are but slightly scoured by rills and are thickly strewn with bombs, masses of spongy lava, clinkers, and lapilli, and among them a few chunks of dense olivine basalt and aggregates of volcanic ash. From Bald Knoll came the lavas that cover the floor of upper Johnson Valley, and except where trenched by tiny canyons conceal from view the underlying Jurassic and Cretaceous rocks. North of Bald Knoll, up the regional dip slope, the lava spread over a few acres; southward down the valley in broad sheets or in roughly parallel bands that curve around rugged mesas of sandstone, it extends 5 miles to the box head of Johnson Canyon. Within the canyon a flow from the main mass, now represented by disconnected patches, continues between walls of Navajo sandstone and can be traced for another 2 miles to its termination in a low, black cliff (fig. 35). Traverse of the rough

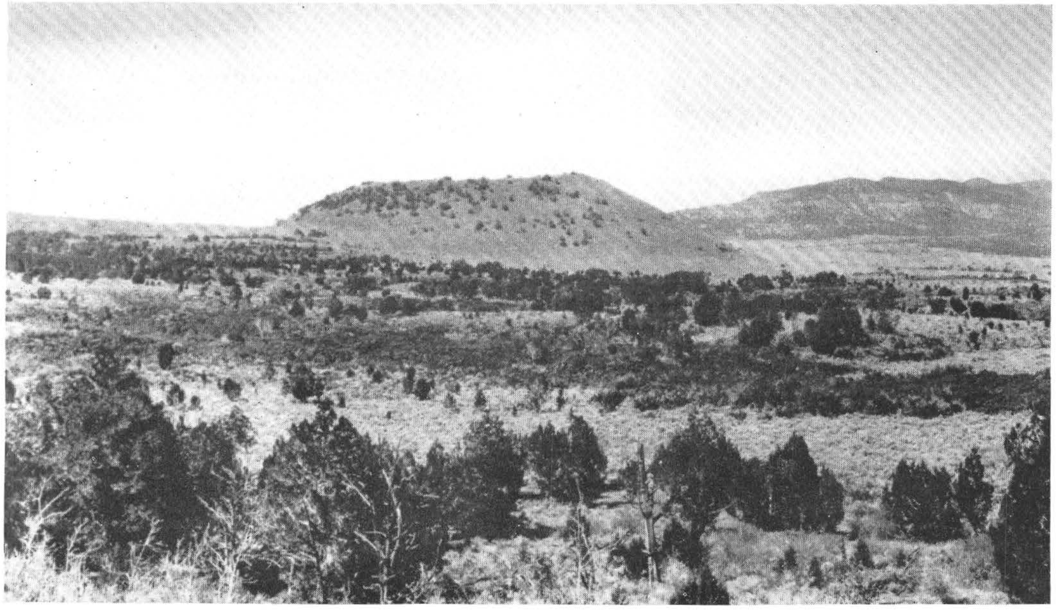


FIGURE 34.—Bald Knoll, source of the lava flow in Johnson Valley. Photograph by G. B. Richardson.

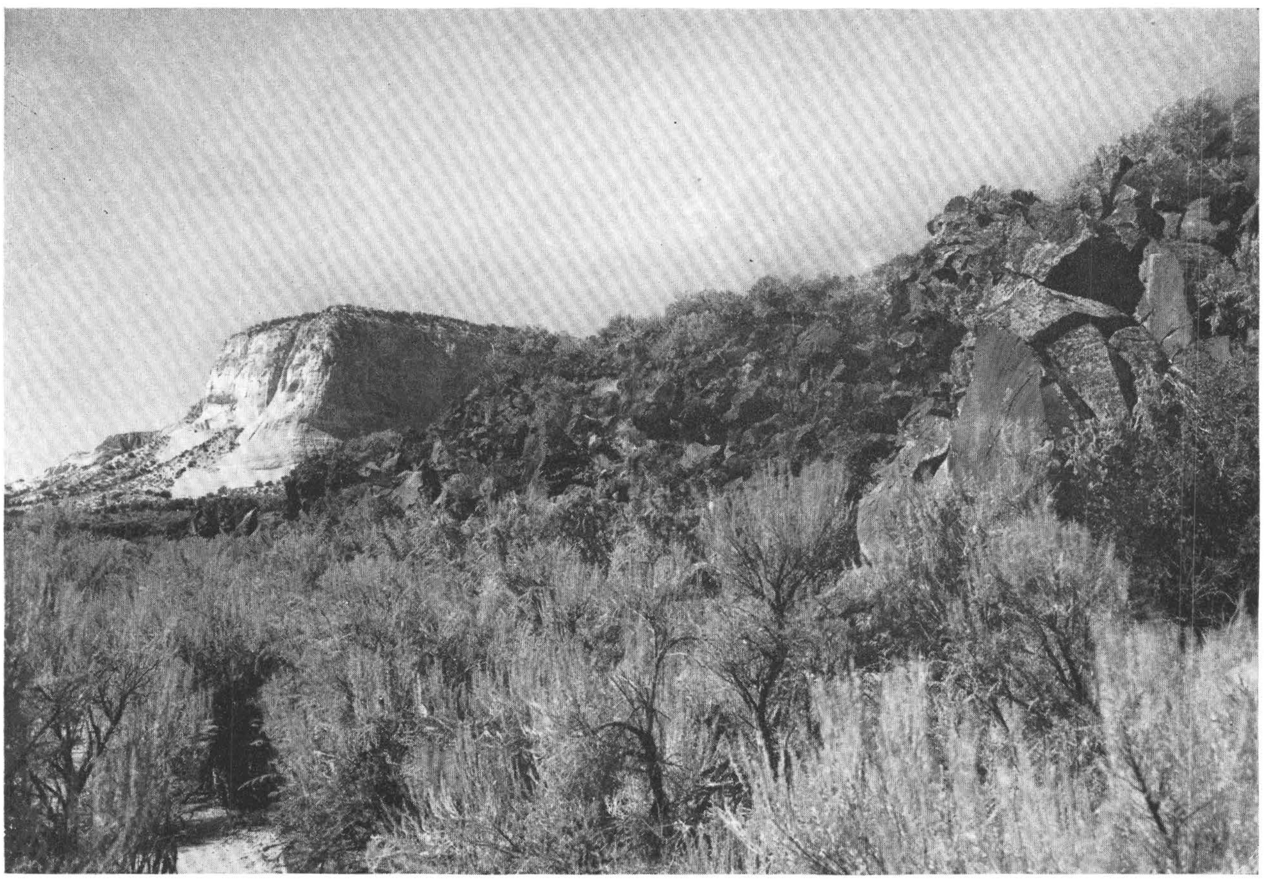


FIGURE 35.—End of the lava flow in Johnson Canyon. Abuts against projection of the White Cliffs.

surface reveals a series of successive intermittent flows of different outline, thickness, and texture, which unite in coalescing streams. Many of the individual flows are 10 to 15 feet thick, some no more than 5 feet thick, but commonly overlapping flows form masses as much as 30 feet thick. Along their courses the sheets show ropelike twisted strands, broken gas chambers, a structure, and other features characteristic of highly fluid extrusions. In the thicker sheets much of the rock is dense or slightly amygdaloidal; in the thinner sheets commonly amygdaloidal or scoriaceous. The lavas are olivine basalt, generally fine-grained.

The lava streams in the Johnson Valley seem to be older than the volcanic clastic rocks that form the cone at Bald Knoll. Where they abut against the base of the cone they are hidden beneath bombs and clinkers, and no breaches in the cone mark possible exits. These relations suggest two stages of volcanic activity—the outpouring of lavas from feeding dikes, followed by explosive eruptions of fragmental material suitable in amount and character to build a steep-sided cone.

TENNEY CANYON

An unusually interesting mass of igneous rock is exposed in the east wall of Tenney Canyon about 9 miles north of Skutumpah ranch—a conspicuous outcrop locally known as Black Knoll. Viewed from the west the exposure is a vertical wall 50 to 60 feet high that rises above a steep slope and terminates in low mounds thickly strewn with volcanic debris. Examination reveals the wall as the face of a dike characterized by features common to intrusives (fig. 36). The bulk of the dike rock is porphyritic olivine basalt—crystals of bright olivine as much as one-eighth of an inch in diameter in a dark-gray aphanitic groundmass. Parts of it are dense in texture and at the contact with the bordering Cretaceous sandstone are exceedingly fine-grained, in places glassy. In it are included grains of quartz, slabs of sandstone, and fragments of hardened shale from the bordering Cretaceous rocks, and on its surface are outlined the ends of 5-sided and 6-sided columns. Traced upward from its base the dike becomes increasingly amygdaloidal and includes masses of twisted spongy rock mingled with denser fragments giving the appearance of volcanic agglomerate. A branch dike that extends eastward for about 500 feet shows a similar arrangement of materials. At its north end the rock in the dike is increasingly vesicular upward and becomes agglomeratic and finally scoriaceous. Immediately beyond the point to which the dike can be definitely traced the predominant rock is a friable black cinderlike mass that includes fragments of scoria, some xenolites and xenocrysts, and a few bombs. The lava poured from the dike is now represented by four patches on top of the knoll, 30 to 50 feet thick, remnant masses of larger flows that doubtless

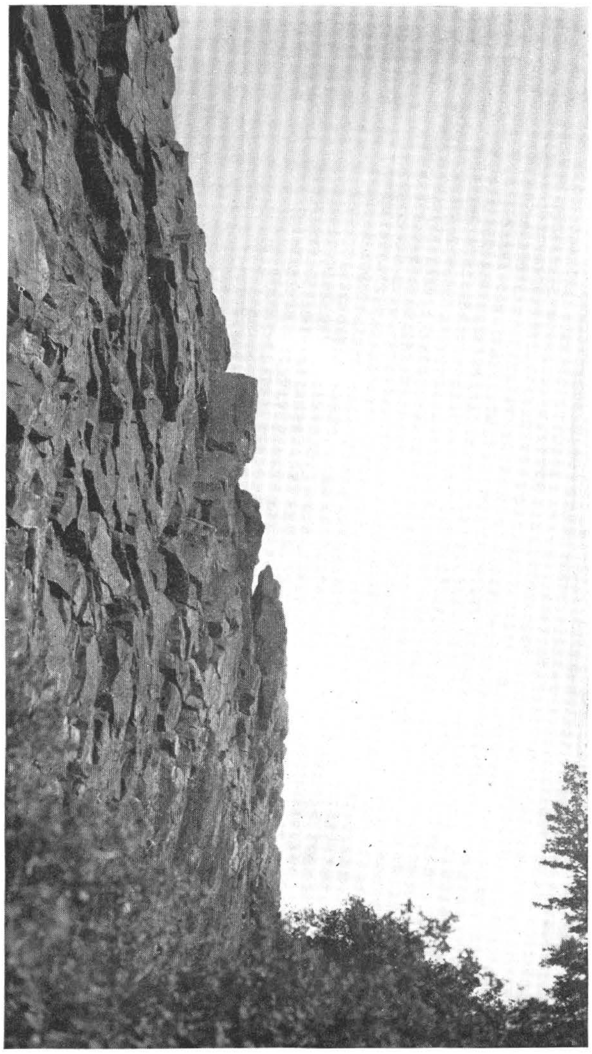


FIGURE 36.—Dike of compact basalt in wall of Tenney Canyon, the source of the breccias and lavas.

once covered the sloping wall of Tenney Canyon. Some of the lava is dense like the dike rock, but much of it is ropy and vesicular, and in places only red scoria appears. All the specimens studied are made up of plagioclase feldspar (chiefly labradorite), pyroxene (augite?), olivine, iron, and a little biotite. The character and relations of the various types of igneous rock in Black Knoll indicate a center of eruption in which the change from intrusive to extrusive material can be traced. Apparently as the feeding dike approached the surface it lost its compact texture and became a mass of spongy material in which dense and vesicular fragments, huge balls, slabs, and pellets assumed various shapes and sizes. When this heterogeneous mass reached the surface part of it was shattered by explosions, but most of it remained as liquid rock that for a time flowed southward and westward down slopes. If the face of the feeding dike had not been exposed by erosion, Black Knoll would probably appear in the topography as rough-topped overlapping sheets of lava not connected with a cone or with other obvious source. It seems probable that this process of eruption was common in southern Utah and that the great sheets of acidic and basaltic lavas that cover the Sevier, Aquarius, and Markagunt Plateaus are the outpourings from dikes concealed below them.

AGE

The age of the igenous rocks in the Paunsaugunt region is known only with reference to the sedimentary formations on which they lie and the amount of erosion they have undergone. Along the Sevier River and in the Sunset Cliffs the lavas overlie in some places the limestone of the Wasatch formation and in other places post-Wasatch conglomerates, sandstones of Pliocene or Pleistocene age, or lacustrine sediments that contain plants and shells characteristic of Pleistocene time. Since their extrusion the basalts of the Sunset Cliffs have been trenched by Red Canyon and broken by the great Sevier fault. On the upthrown side of the fault the sheets remain in position north of the canyon but have been largely removed from the higher lands to the south. Near their source in Bald Knoll the lavas in the Johnson Valley overlie Cretaceous sandstone and shale; toward their end they lie directly on stream gravel. Where the flows are confined to an ancient streamway, recent erosion has resulted mainly in cutting shallow gulches along their edges and here and there removing parts of the thinner sheets. Some of the boulders and big cinders at Bald Knoll retain much of their original form, little of the finer clastic material has been reduced to sand and clay by weathering, and the lava streams retain so many features characteristic of Recent flows that in spite of considerable trenching by high-powered ephemeral streams it is difficult to think of them as more than a few hundred years old. All the basalt flows about the Paunsaugunt Plateau are obviously much younger than the latites, andesites, trachytes, and agglomerates that cover the adjoining Sevier Plateau to depths exceeding 500 feet.

STRUCTURE

GENERAL FEATURES

In the Paunsaugunt region the strata have been disturbed by great faults, minor faults, and local folds, but as compared with the adjoining Kaiparowits region and with the Colorado Plateau province as a whole the tectonics are simple. Outstanding structural features are the prevailing northeasterly dip of both surface and deep-seated strata and the Sevier and Paunsaugunt faults, which break the continuity of all rocks exposed.

The general inclination of the strata that constitute the Paunsaugunt Plateau and its bordering lands is remarkably persistent. The tabulation of measurements made in many places show regional dips of 0.5° to 3° north, northeast, and east. Of scores of recorded dips on widely exposed rock surfaces only three are in the southeast quadrant, and none trend south, west, or northwest. Dips exceeding the regional average seem to be restricted to fault contacts, to small-scale upwarps, and to wrinkles in the otherwise nearly flat rocks.

Both the northerly component of the regional northeast dip and the generally somewhat smaller easterly component are reflected in the present areal distribution of the sedimentary rocks and especially in the topography. Thus the sedimentary formations that crop out in the Sevier and upper Kanab Valleys are about 2,000 feet higher than in the Paria Valley, and along the north-south lines of major faulting the formations are offset for long distances. The streams that follow the dip of the strata northeastward flow in broad, shallow valleys; those that trend opposite to the dip develop cliffs trenched by canyons. Southward from the rim of the Paunsaugunt Plateau, as the edges of one formation after another are exposed, the topographic profile rises gently to the crest of a cliff and then drops abruptly to a lower level. Because the cliffs are the truncated edges of tilted strata their height does not measure the thickness of the strata that compose them. The stratigraphic thickness of the Jurassic, Cretaceous, the Tertiary averages about 5,000 feet; the vertical distance between their lowest and highest beds about 3,500 feet.

Like the prevailing dips, the great faults have exercised a major control in the physiographic development of the Paunsaugunt region. They have broken the original extensive surface into plateau blocks at various altitudes and thus to a large degree determined the position of the sedimentary strata and the lava flows. Gilbert (1875, p. 44) remarks, "In the Sevier country the faults and the volcanic outflows have created all the geographical features." In the topography of southern Utah the linear arrangement of highlands and lowlands reflects the position of faults, and the height and inclination of the most prominent escarpments are roughly the measure of the amount and the character of the displacement. Thus in accord with the lines of cliffs, the sinuous master faults have a north-northeasterly trend, and along them the short parallel faults that outline slivers have a like direction. All the small faults observed and for long stretches the great Sevier and Paunsaugunt faults are vertical or steeply inclined. Most of them are clean-cut fractures accompanied by little breccia and very few striae. Many other faults independent of the great fractures also have trends within the northeast quadrant, though some of small dimensions are variously oriented. The faults in Swallow Park and near Skutumpah trend northwest, and the fault that passes through Ahlstrom Hollow along the north side of Bryce Canyon National Park extends east-west—directions very unusual for conspicuous displacements in the High Plateaus.

Compared with the faults that have substantially remodeled the landscape, the folds in the Paunsaugunt region have little interest. The region lacks representatives of such displacements as the Monument and Kaibab upwarps, the Sage Plain and Kaiparowits downwarps, the Waterpocket and Echo monoclines, and such laccolithic masses as the Henry, Abajo, and Navajo Mountains. In the place of these prominent structural features there were noted a few short, broad anticlines and flattened domes and several wavelike ridges isolated or associated with the major faults. Near the head of the Kanab Valley, beds on the western flank of a low anticline dip progressively from 2° to 6°, then steepen to 20° where the structure is faulted. Extending northwestward from the mouth of Sheep Creek an anticline that involves the Navajo sandstone and earlier formations has a northern dip of 2° to 3° and a southern dip of 8° to 10°. Doubtless precise topographic mapping would reveal many similar structural features and perhaps broad upwarps and downwarps of regional extent. The folds observed during the present survey are but local interruptions in the general regional dip and have had little influence in the development of topographic features. It therefore has seemed unnecessary to map them or to describe them in detail.

The structural features of the Paunsaugunt region illustrate the geologic unity and the essential stability of the plateau country through long periods of time. From the Devonian to the Tertiary period, sediments were laid down in the sea and on land and intermittently uplifted, eroded, and depressed in terms of hundreds, perhaps thousands of feet, but only near the end of the Cretaceous period was their attitude significantly changed. Slight structural disturbances are recorded in the Permian, Triassic, Jurassic, and Cretaceous formations of the plateau province, and probably in southern Utah broad bowings and regional tilts remain to be defined. Spieker [9] records for the northern part of the Wasatch Plateau profound orogenic movements between "the late Jurassic and the middle of the Cretaceous" and for the southern part of the plateau large displacements, probably in Montana time. Conclusive evidence of these movements has not been found in the Paunsaugunt region, but, as noted by Spieker, a later crustal movement, in the San Pete and northern Sevier Valley, is reasonably correlated with that which produced the monoclinal folds in south-central Utah—folds whose truncation marks the unconformable contact in places of Cretaceous with Jurassic and Tertiary beds. Local upwarps in the Wasatch formation point to structural disturbances in very early Tertiary time, but so far as known the earth movements conspicuously recorded in the Paunsaugunt region—the two great faults and perhaps all the minor faults and the folds—date from post-Eocene time; they have broken Eocene and Pliocene beds, and also post-Pleistocene lavas. As Dutton (1880, pp. 40–41) long ago remarked:

> The faults are very late occurrences in the history of the district. * * * It seems perfectly safe to say that if we carry back the faulting to the middle of the Pliocene we shall have dealt generously with anyone who may be disposed to push them back to the remotest possible epoch.

That the latest faulting was geologically recent is clearly shown by the topography. In places high cliffs stand close to the fault lines; some cliffs, in fact, are but the slightly modified faces of upthrown blocks. Furthermore, many drainage channels that cross the fault zone are youthful, and some are seemingly adjusting themselves to uplifts still in progress. The earthquakes recorded at Tropic and Panguitch in 1902, 1924, 1930, and 1931 may have had their focus in faults. Though probably not widely separated in time the movements along the various faults were not contemporaneous; activity was interrupted by periods of repose.

SEVIER FAULT

Along the western base of the Paunsaugunt Plateau the regional continuity of the lavas and sedimentary beds is broken by a fault that extends far northward

[9] Spieker, E. M., late Mesozoic and early Cenozoic history of central Utah: U. S. Geol. Survey Prof. Paper 205–D (1946); also letter dated March 13, 1939.

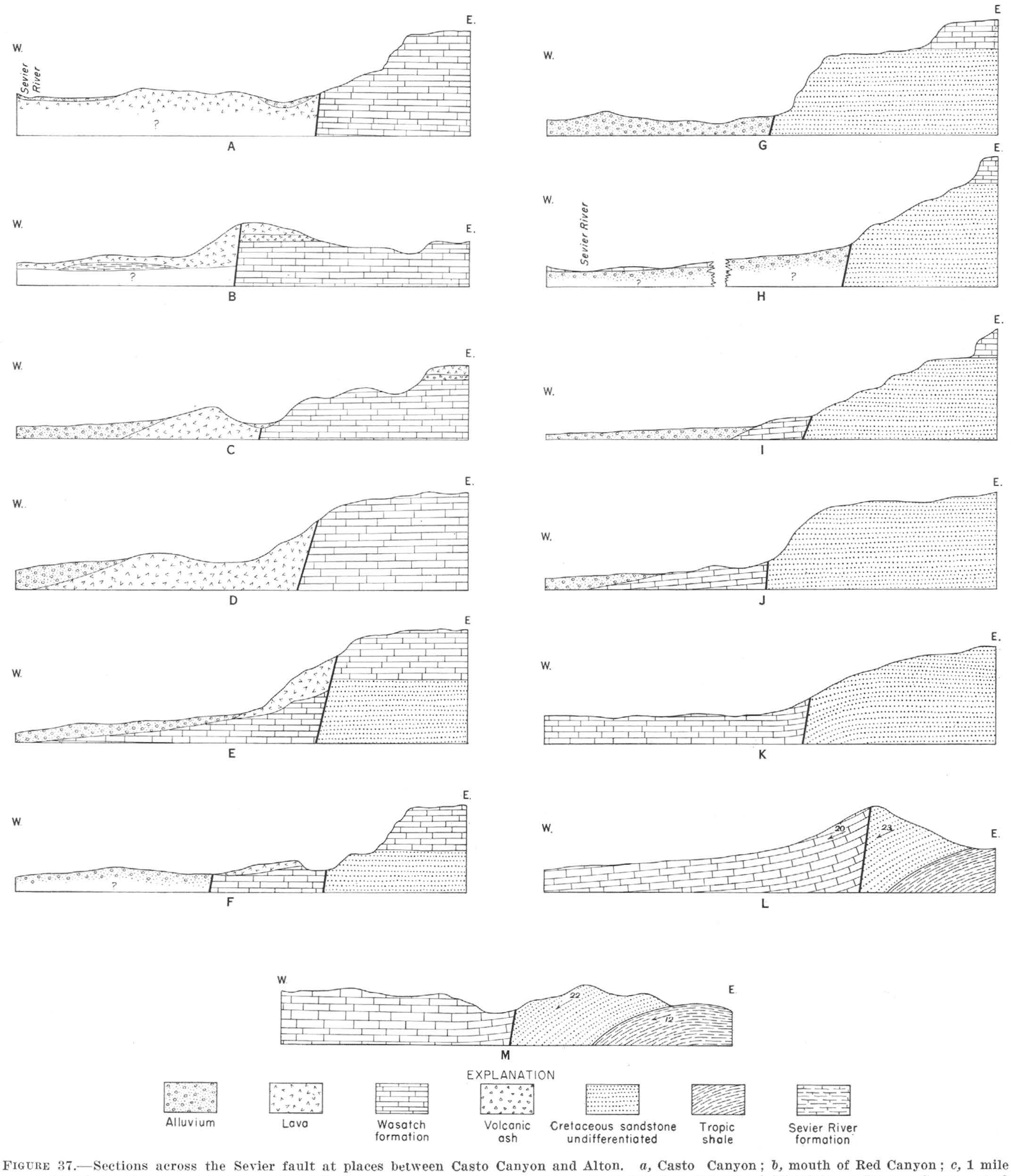


FIGURE 37.—Sections across the Sevier fault at places between Casto Canyon and Alton. *a*, Casto Canyon; *b*, mouth of Red Canyon; *c*, 1 mile south of Red Canyon; *d*, 2 miles south of Red Canyon; *e*, a quarter of a mile north of Hillsdale Canyon; *f*, Hillsdale; *g*, Proctor Canyon; *h*, 2 miles south of Proctor Canyon; *i*, 1 mile south of Big Hollow; *j*, 2 miles south of Spring Canyon; *k*, 3 miles north of Alton; *l*, 2 miles north of Alton; *m*, 1 mile north of Alton.

and southward beyond the limits of the Paunsaugunt region as a dominant feature in the structure of the plateaus of south central Utah. In length, amount of displacement, and topographic expression it is the peer of such fractures as the Hurricane and Paunsaugunt faults and also of the great monoclinal upwarps of the plateau province. Along its course it is the boundary line between plateaus and high terraces: east of it lie the Wasatch, Sevier, Paunsaugunt, and Kanab Plateaus and the Skutumpah and Wygaret Terraces; west of it the counterparts Gunnison, Tushar, Markagunt, and Uinkaret Plateaus and the Kolob and Moccasin Terraces. Though not mapped by the Wheeler Survey, Gilbert (1875, p. 49) recognized this huge structural feature as the Sevier Valley fault which, beginning in San Pete Valley and roughly paralleling the Sevier River, extends southward across Utah; "it was our good fortune to define its course for a distance of 225 miles without including either end." As the "Sevier fault" Dutton (1879, atlas sheet 4) mapped and briefly described a sinuous band of disturbed rocks between Moroni, Utah, and Pipe Springs, Ariz., a distance of about 180 miles.

For long stretches the Sevier fault is a simple fracture, an almost vertical cut through rocks otherwise little disturbed, but in places it is accompanied by short parallel linear faults or by curved faults that branch from the master fault and within short distances return to it. Throughout much of its length the position of the fault is shown in the topography. Along the south branch of the Sevier River and in the Paraunuweap Valley cliffs mark its upthrown (east) side, but in the vicinity of Alton and in places farther south erosion has brought the upthrown and downthrown sides to a common level. Near the Utah-Arizona boundary line the upthrown side of the Sevier fault is now much lower than the downthrown side (Gregory 1950).

Within the Paunsaugunt region the position and topographic effect of the Sevier fault are readily defined. From Casto Canyon southward to the upper branches of Spring Hollow the fracture marks the base of the Sunset Cliffs, and farther south across the divide between the Sevier and the Kanab drainage systems, where it is not expressed in the topography, its course is plainly shown by stratigraphic breaks and offsets. In consequence of faulting the rocks close to the plane of fracture have various attitudes. On the upthrown side the Tertiary and Cretaceous strata between Red Canyon and Spring Hollow retain their regional easterly dips of 1° to 3° and the tilted beds in the upper Kanab Valley seem not to have been disturbed by the movement. On the downthrown side the sedimentary beds lie in places nearly flat but generally have been bent. The amount of displacement along the fault cannot be determined with accuracy. On both sides of the fracture the thick formations are incomplete, and the form of the prefault surface on which the lavas were poured out is unknown; furthermore, in many places the fault trace is concealed by the gravel of alluvial fans. On the south side of Red Canyon, where the lavas on the cliffs lie above their probable westward extension, the stratigraphic throw is estimated as 900 feet; at Hillsdale Canyon, 850 feet, though at one place just north of this canyon it seems to measure only about 300 feet. Farther south, where the fault separates Cretaceous from Tertiary beds, the estimated displacement is 1,200 feet at Proctor Canyon and Big Hollow and 500 to 800 feet at places examined north of Alton. This range of displacement within relatively short distances is characteristic of the Sevier fault throughout its length; in stretches as short as 30 miles measurements of less than 100 feet and as much as 2,000 feet have been recorded. The significant features of the fault are illustrated in figures 37 and 38.

FIGURE 38.—Features of the Paunsaugunt fault in Campbell Canyon. Tropic shale (right) abuts against Wasatch formation (left). Displacement about 1,800 feet.

PAUNSAUGUNT FAULT

Comparable in dimensions and in topographic effect to the Sevier fault, which marks the western boundary of the Paunsaugunt Plateau, a fracture of north-south trend known as the Paunsaugunt fault outlines the east side.

The Paunsaugunt fault is the easternmost of the three great fractures that in large part have determined the regional structure and controlled the topographic development of southern Utah. Like the Hurricane and Sevier faults, which outline plateau blocks farther west, the Paunsaugunt fault is the line of separation between the Sevier and Paunsaugunt Plateaus and their eastern counterparts, the Aquarius and Kaiparowits Plateaus. But unlike its companions, which for long distances mark the base of lofty escarpments, the Paunsaugunt fault is poorly represented in the topography: it lies some distance from the plateau walls, crosses foothills and lowlands where its position is determined only by stratigraphic breaks, and for stretches of many miles is concealed beneath thick alluvium. Erosion along its course has largely destroyed its original features. In many places the upthrown and downthrown blocks have been reduced to a common level, but in the upper Paria Valley the surface of the upthrown block lies far above that of the downthrown block. (See fig. 44.)

Doubtless because they lack clear expression the features of the Paunsaugunt fault and related displacements were given little attention by the pioneer reconnaissance surveys. In their descriptions of the region south of the Sevier Plateau Gilbert (1875, pp. 51–52) and Howell (1875, pp. 291–293) made no mention of structural disturbances at the head of the Paria Valley. Dutton (1880, atlas, sheet 4) described the eastern edge of the Paunsaugunt Plateau as "a cliff of erosion. There is a fault a little distance from the eastern wall running north-northeast" (shown on the atlas sheet as the "Paunsaugunt fault"). As the oustanding structural feature in the Paria Valley Dutton mapped the "East Kaibab fault" as continuous from a point south of the Marble Canyon of the Colorado River northward through House Rock Valley and Cottonwood Canyon and along the west base of the Aquarius Plateau (Table Cliffs)—"the longest line of displacement of which I have ever heard." He described the Paunsaugunt fault "near the base of the plateau" as a relatively short branch of the "East Kaibab fault" that beginning at a point north of the abandoned village of Widtsoe extends south-southwest to the vicinity of Willis Creek.

Recent surveys show that the East Kaibab fault and the Paunsaugunt fault of Dutton are separate structures 15 to 18 miles apart and of different age; that the "East Kaibab fault"—a monoclinal flexure—decreases in amount of displacement northward and northwestward, and its eroded top is lost to view beneath the limestone of the Aquarius Plateau and the outlying Kaiparowits Peak (Gregory and Moore, 1931, pp. 122–124). In the monocline easterly dips of as much as 65° in the Kaibab upwarp and along Cottonwood Canyon are replaced by dips of 8° to 15° in Henrieville Creek, 6° to 8° at Kaiparowits Peak, 3° to 4° in the Table Cliffs, and less than 2° at the head of the Paria Valley. The surveys show also that Paunsaugunt fault is not a minor branch of some other break but the major line of displacement within the Paria drainage basin; that it extends the full length of the Paunsaugunt Plateau, passes southward through the White Cliffs and Vermilion Cliffs and onward across the northern Kanab Plateau, and may be represented by the faults at Big Springs and Ryan, on the west side of the Kaibab Plateau.

As shown on the map (pl. 1) the effects of earth movements along the line of the Paunsaugunt fault are plainly revealed in the discordance of sedimentary beds. Locally in upper Paria Valley uplift on the east side of the fault has brought the Cretaceous Straight Cliffs sandstones to the level of the Tertiary Wasatch formation. In places farther south the Dakota (?) sandstone and the Tropic shale—the lowermost Cretaceous beds—abut against the higher Cretaceous, the Upper Jurassic Carmel formation against Upper Cretaceous beds, and the Navajo sandstones against Jurassic beds that normally overlie it. Generally the contact of these displaced beds is readily recognized; crossing the fault implies stepping from pink rock to dark-gray rock, red to gray blue, white to tan, or brightly banded beds to beds of uniform color.

In the regional topography of south-central Utah the influence of the Paunsaugunt fault is clearly shown. Though immediately along the line of fracture erosion has largely destroyed the postfault landscape, earth blocks at discordant altitudes and angular crenulations in the trend of the White and Vermilion Cliffs remain as witnesses to large-scale differential movements. Thus the Paunsaugunt Plateau is the downthrown block and the Aquarius Plateau the upthrown block of the Paunsaugunt fault. As the result of faulting of originally continuous strata, the Wasatch formation at the east edge of the Paunsaugunt Plateau lies nearly 2,000 feet below corresponding beds in the Table Cliffs, about 8 miles distant. South of the rim of the plateau few places were found where the throw of the fault could be determined. Across the Tropic and the Upper Jurassic formations, its trace is generally smeared by debris from friable strata, and in the thick sandstones no limiting markers are definable. Where the fault breaks the rocks in the White Cliffs, its displacement is about 1,150 feet; on Willis Creek fully 1,500 feet; on Yellow Creek as much as 1,000 feet; and for other places field notebooks record estimates of 600 to 1,400 feet. In amounts of displacement within relatively short distances the Paunsaugunt fault duplicates the Sevier fault and also the Hurricane fault.

FIGURE 39.—Paunsaugunt fault at Findley Ranch. Fault follows west edge of upthrown block of Navajo sandstone capped by limestone of the Carmel formation (left sky line). West of it lies Carmel, Entrada, and Curtis formations (left center). Displacement about 1,300 feet.

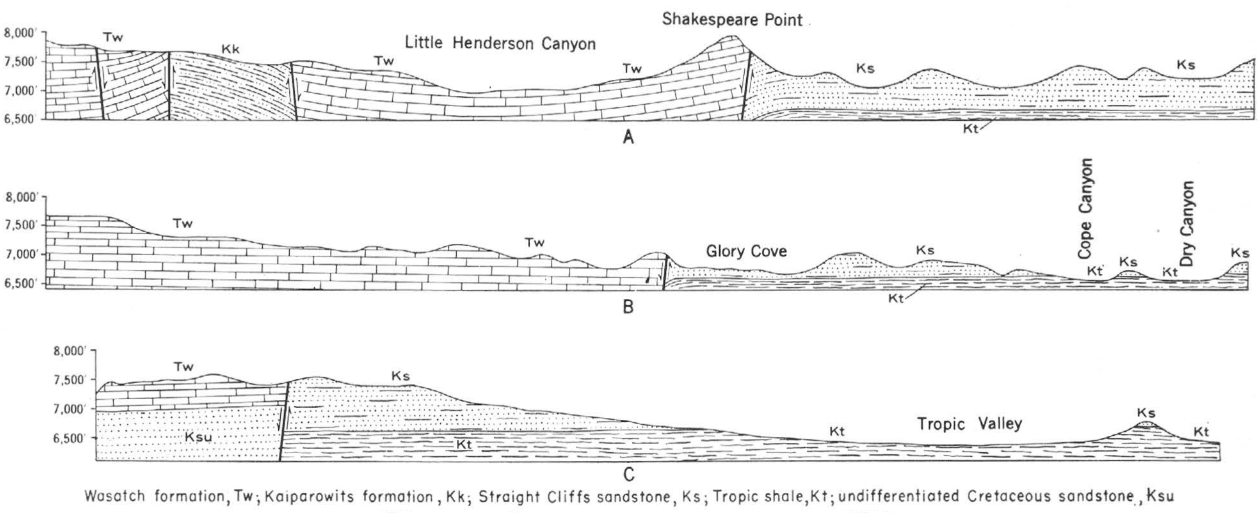


FIGURE 40.—Sections across the Paunsaugunt fault at the head of the Paria Valley. *a*, Across Little Henderson Canyon and Shakespeare Point; *b*, through Water Canyon and Glory Cove; *c*, a quarter of a mile north of the Sinking Ship, Bryce Canyon National Park. Topography drawn to scale 1 inch=2,000 feet.

Measured inclinations of the fault plane range from 67° to 87°—nearly all dipping westward. Features of the fault at selected places are shown in figures 39–42.

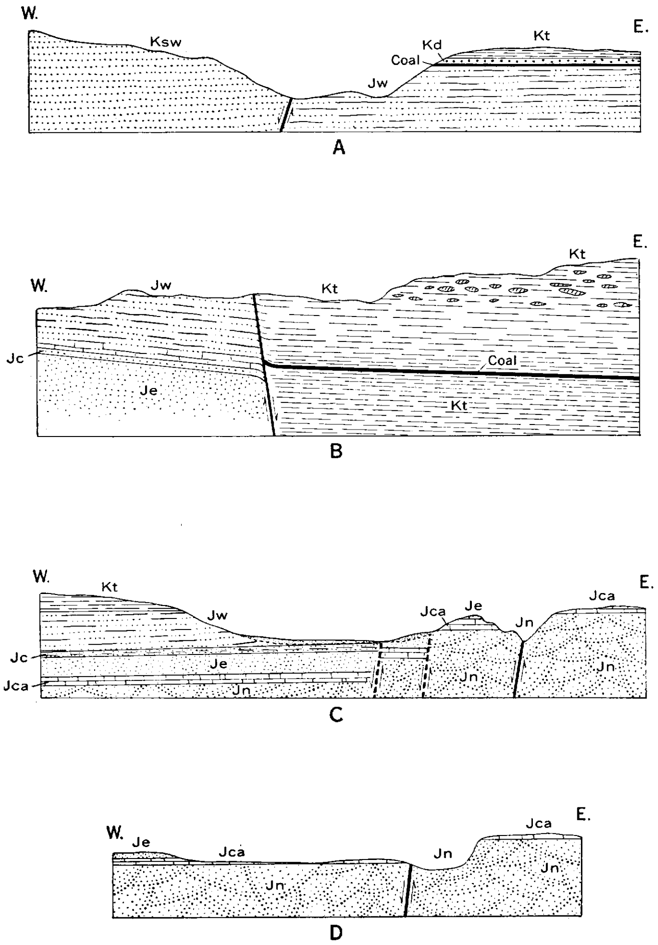


FIGURE 41.—Sections across the Paunsaugunt fault between Yellow Creek and the White Cliffs: *a*, Willis Creek near Upper Johnson ranch; *b*, South branch of Squaw Creek (recorded by H. S. Wood); *c*, Lick Wash above "the box"; *d*, Deer Spring (Meadow) Creek below Finley ranch (scale 1 : 63,360; displacement 1,150 feet). Jn, Navajo sandstone; Jca, Carmel formation; Je, Entrada sandstone; Jc, Curtis formation; Jw, Winsor formation; Kcl, Tropic shale; Ksw, Straight Cliffs and Wahweap sandstones undifferentiated.

MINOR FAULTS

In addition to the great Sevier and Paunsaugunt faults, which have profoundly affected the entire Paunsaugunt region and adjoining areas in southern Utah, faults of considerable length and throw have disturbed the rocks in Swallow Park, in the Skutumpah Terrace, in Gypsum Wash, and in Ahlstrom Hollow. Faults of smaller dimensions in many places have displaced some strata in all the formations exposed to view.

The Swallow Park fault crosses the floor and bounding ridges of Swallow Park and extends southeastward to No Mans Mesa and for an undetermined distance beyond. (See pl. 4.) At its northwest end in Podunk (Riggs) valley it joins the Paunsaugunt fault which appears to be younger, though the evidence is not conclusive. The actual plane of fracture is observable only for a short stretch, but its approximate position is shown by disrupted strata and topographic unconformities. In different places the Entrada sandstone abuts against beds in the Curtis,

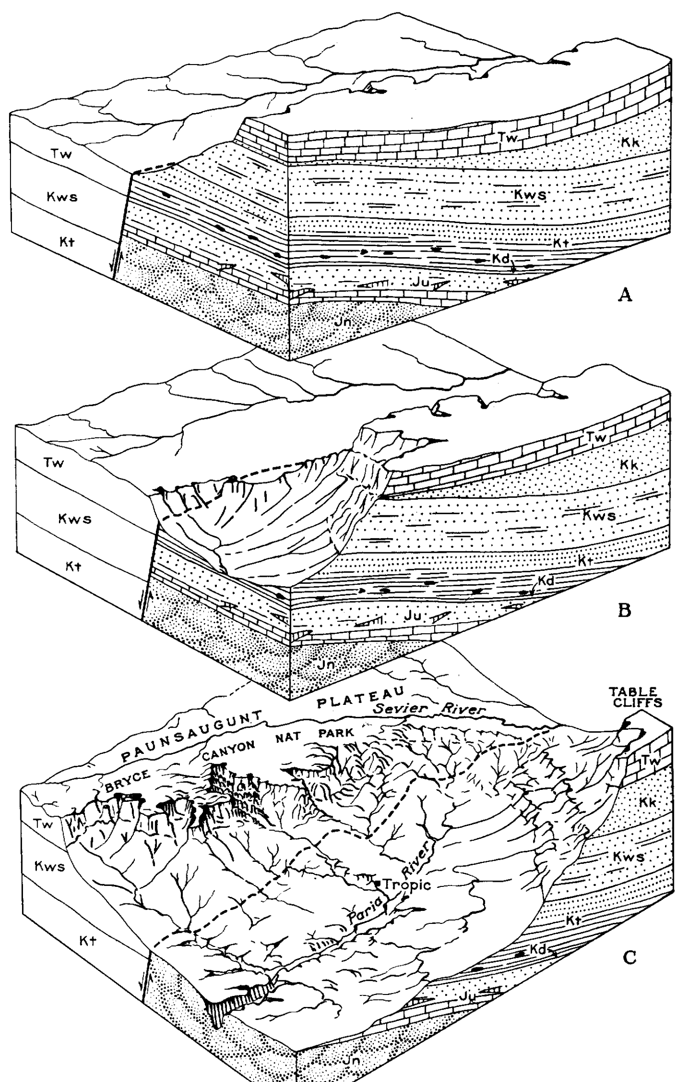


FIGURE 42.—Generalized diagrams showing the effect of faulting and erosion at the head of the Paria Valley. *a*, A short time after movement along the Paunsaugunt fault had raised the rocks on the east side about 2,000 feet above those on the west; the drainage was northward; *b*, the Paria River in eroding headward has begun the removal of the rocks on both sides of the fault but more on the higher east side; *c*, the Paria River and its steeply inclined tributaries have removed much of the Tertiary, Cretaceous, and Upper Jurassic rocks down to the massive Navajo sandstone, thus forming the present Paria Amphitheater. Jn, Navajo sandstone; Ju, Upper Jurassic Carmel, Entrada, Curtis, and Winsor formations; Kd, Dakota (?) sandstone; Kt, Tropic shale; Kws, Wahweap and Straight Cliffs sandstone; Kk, Kaiparowits formation; Tw, Wasatch formation—the Pink Cliffs. Reproduced in part from U. S. Geol. Survey Prof. Paper 164, figure 7.

the Winsor, and the Carmel, and on the western wall of Bullrush Hollow, near its mouth, a platform of limestone of the Carmel formation terminates abruptly against a wall of sandstone, then in a short distance reappears as the cap of a cliff 500 feet above. West of Adair Lake fault breccia forms the face of a cliff, and farther north a fairly even surface developed on formations of different ages is crossed by a low narrow ridge composed of partly consolidated fragments torn from the adjoining strata. No Mans Mesa owes its prominence to faulting. As indicated by discordant outcrops along its course, the estimated displacement along the Swallow Park fault increases from about 200 feet in White Ridge to fully 600 feet near the mouth of Deer Range Canyon. Doubtless in consequence of the fault, the dip of the strata in its vicinity is westward, though the regional dips are east and north.

The Skutumpah fault, which along its curvilinear course of about 7 miles breaks the continuity of the Navajo sandstone, the Carmel formation, the Entrada sandstones and the Curtis formation, is easily recognized in the trend of low cliffs, offsets, and color contrasts. Where the fault crosses Skutumpah Creek the limestone beds in the Carmel formation have the same altitude as the gypsum beds in the Curtis formation, indicating a displacement of 100 feet or more. Measurements in other places are 60 to 80 feet.

The fault that crosses Gypsum Wash cuts the Straight Cliffs sandstone northwest of Bald Knoll Crater and extends southward about 9 miles into Navajo sandstone of White Cliff. As mapped by Bronson Stringham it is the line of separation between the Winsor and the Tropic and between the Curtis and the Entrada, and its maximum displacement is about 70 feet. In the topography, the zone of faulting coincides with the trend of a branch of Gypsum Creek, and isolated low cliffs of resistant rock mark the upthrown (eastern) side.

The Ahlstrom Hollow fault trends east and west across the Paunsaugunt Plateau and is easily traced from the East Fork of the Sevier River westward through the Hillsdale Gap to the face of the Sunset Cliffs, where it meets the Sevier fault. East of the river for a distance of about 3 miles its presence is doubtful, but it seems to be represented by the east-west zone of fracture north of Water Canyon. Along much of its course the position of the fault is shown only by the sharp horizontal contact of Cretaceous and Tertiary strata—the Kaiparowits and Wasatch formations—and in places only by differences in color and content of surficial debris. In developing the broad postmature valley of the East Fork of the Sevier River the topographic inequalities that may have resulted from differential uplift have been reduced to a common level: even streams cross the fault without noticeable break in profile. The features of the Ahlstrom Hollow fault are best displayed in Hillsdale Gap, where the measured displacement is 535 feet. (See figs. 43 and 44.) Doubtless this gap, the only structural break in the long Sunset Cliffs, originated as a zone of disturbed rocks within which the steep headwater tributaries to Hillsdale Creek found favorable conditions for excavation.

The numerous minor faults, though many of them are clearly exposed, are so varied in trend, length, amount of displacement, grouping, and other features that systematic classification and mapping were found to be impracticable. Near the head of Tropic Canyon two faults that trend N. 30° W. and N. 3° E. cross the Wasatch limestone and include between them a slab of sandstone of the Kaiparowits formation, and in a tributary of Johnson Creek a small block of limestone of the Carmel formation has been faulted down into the Navajo sandstone, but generally the small faults have little or no stratigraphic significance. Few of them traverse thick sequences of strata, and many seem restricted to a single formation. Typical of the Paunsaugunt region are the faults examined in tributaries to the Paria River. In Lick Wash parallel vertical faults that trend N. 20° E. cut the Carmel and the Navajo into steps 80 to 100 feet high. In Everett Wash the Curtis and Entrada formations are vertically offset 60 feet by a fracture that trends N. 20° W, along which the beds are sharply bent down on the southeast. On Sheep Creek the Navajo sandstone is displaced 30 feet along a fault that trends N. 20° W. Of five faults exposed in the lowermost 4 miles of the Willis Creek Valley two trend northward, two northwest, and one northeast; one is within the Navajo sandstone, one brings the Carmel into contact with the Navajo, one breaks the continuity of the Entrada sandstone, one shows a vertical belt 3 feet wide of brecciated Tropic shale, and one (near the mouth of Squaw Creek) with a displacement of about 80 feet is bordered on both sides by Cretaceous strata that dip as much as 5°. In Bull Hollow three faults with throws of 6 to 20 feet are sharply curved. In Deer Spring Wash massive beds of sandstone are displaced as much as 100 feet without change in attitude. In Bullrush Hollow three faults trend along the crest of a narrow fold. At the head of Swallow Park a group of strike faults have comminuted the soft Jurassic beds into a mass of fractured rock. In many places the strata are displaced for a few inches along joints.

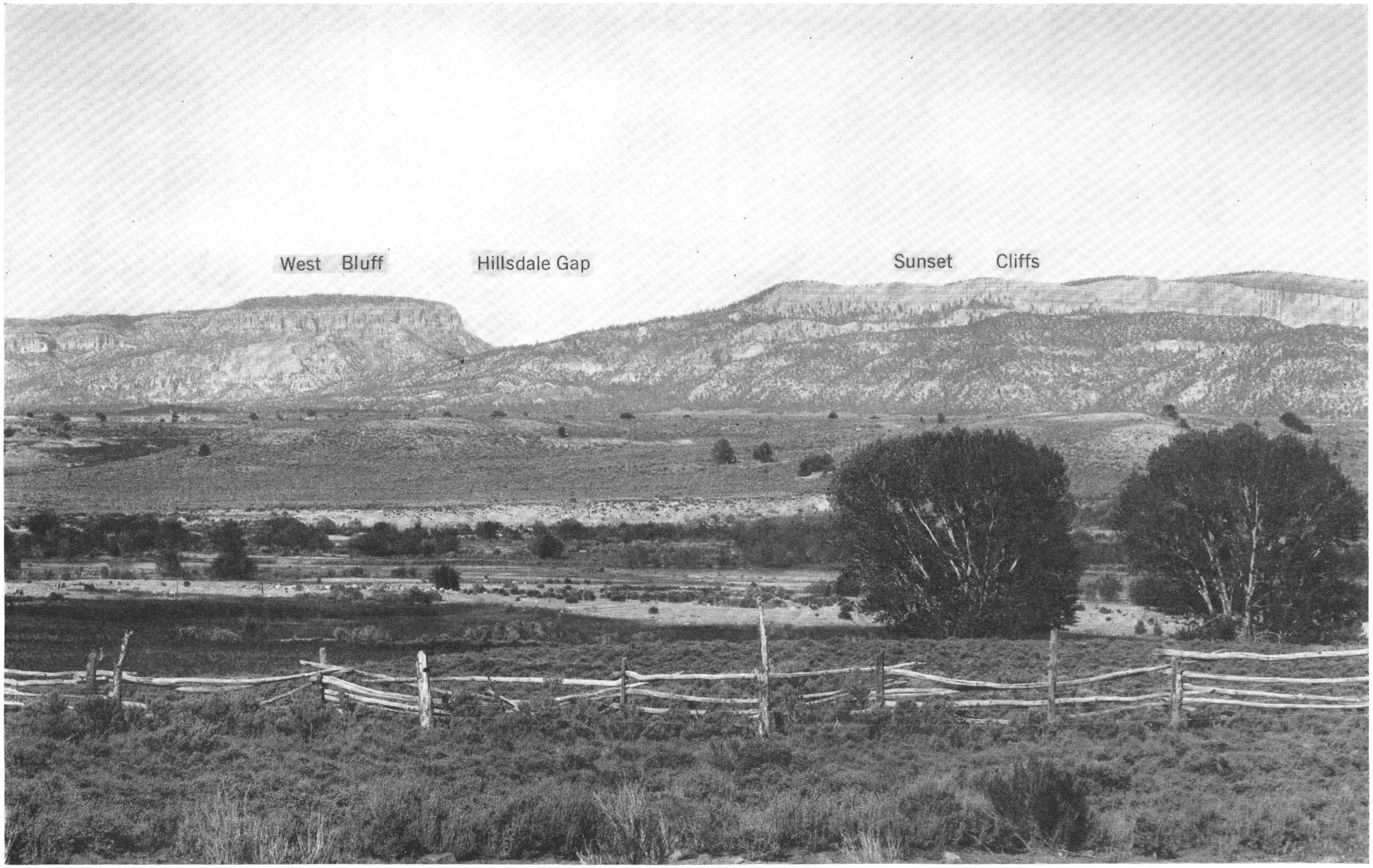


FIGURE 43.—The Pink Cliffs—walls developed in Wasatch formation. West edge of the Paunsaugunt Plateau, looking across the South Fork of Sevier River (foreground) and across alluvial fans toward Sunset Cliffs. Cretaceous and Tertiary strata (sky line), Hillsdale Gap and West Bluff upper left. Photograph by Fortieth Division Aviation, California National Guard.

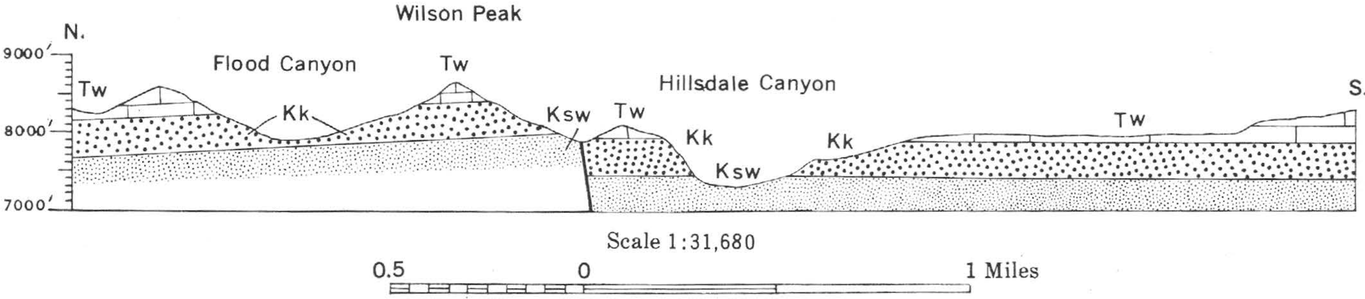


FIGURE 44.—Section across the Ahlstrom Hollow fault in Hillsdale Gap. Ksw, Straight Cliffs and Wahweap sandstones undifferentiated; Kk, Kaiparowits formation; Tw, Wasatch formation.

PHYSIOGRAPHY

REGIONAL TOPOGRAPHIC FEATURES

The Paunsaugunt region is a representative part of the widespread Colorado Plateau province, which covers more than 50,000 square miles on both sides of the Colorado River and within which the sedimentary rocks, the kind and date of diastrophic movements, the expressions of volcanism, and the form of the topographic features are generally alike. In fact, the correspondence is so close that much of the published material that relates to the adjoining Kaiparowits and Zion Park regions, the Navajo country, the San Juan country, and the Grand Canyon district applies also to the Paunsaugunt region. Outstanding differences of the Paunsaugunt from other large parts of the plateau province are the absence of great folds that on erosion produce hogbacks and sharp-crested ridges; the absence of laccolithic masses and extensive sheets of lava; and the presence of two long, roughly parallel faults of large displacement.

The topographic features in the plateau country are developed on a scale that in other regions would justify the term mountainous. In the midst of scores of lofty broad plateaus, deep, long canyons, and high continuous cliffs, the erosion forms that attract especial attention are relatively minor features. In a regional view Grand Canyon is but the deepest, the widest, and architecturally the most varied of the many gashes cut through the wide plateau; Zion Canyon is interesting chiefly for its marvelous display of the erosion forms everywhere characteristic of Triassic and Jurassic sandstone; and Capitol Reef is the eroded edge of the locally upturned Navajo sandstone. The Rainbow, Navajo, Bridges, Arches, and Cedar Breaks National Monuments owe their distinction to readily accessible and unusually attractive representatives of features displayed in many other places. The Paunsaugunt Plateau—the dominating topographic feature of the Paunsaugunt region—is but one of seven enormous flat-topped steep-sided highlands that give character to the landscape of south-central Utah, and the marvelous erosion forms that make of Bryce Canyon National Park a scenic wonderland are local features of a single widespread formation. Bryce Canyon itself is but a niche in a long, high, brightly painted wall.

As it appears today the plateau country is a region of plateaus, mesas, cliffs, and canyons. Except for such laccolithic masses as the Abajo, Carrizo, Navajo, and Henry Mountains and the volcanic San Francisco and Uinkaret Mountains, the highlands are flat or slightly inclined tables, benches, and steps bordered by precipitous cliffs; and the streamways are high-walled, flat-bottomed trenches. In distant views the plateau surfaces are conspicuous. Long stretches of sky line seem nearly horizontal, and platforms at different levels seem interrupted only by scattered buttes and mesas that rise above their surfaces. The canyons are lost in the general levelness. Unlike the graceful outlines of mountains and valleys in areas of humid climate, the landscape is bold and rugged; curves are replaced by angles. In further contrast the protecting cover of vegetation is largely lacking; the dominant grays and greens of humid regions give way to whites, reds, and browns—the colors of the rocks themselves.

In the development of the characteristic topography the stripping and recession of cliffs are major processes. The dominant stripping of weak formations from resistant formations has produced many surfaces that are essentially residuals of widespread postmature erosion surfaces. But unlike old-age surfaces developed under humid conditions, those produced by stripping tend to be flats in soft rocks and slopes that conform in steepness with the dip of the strata in hard rocks. Cliffs, as they weather back, maintain steep profiles; they are not transformed into slopes that decrease in declivity with age. The mural aspect of much of the plateau scenery is due to the fact that cliffs once formed retain the appearance of topographic youth until the canyons and mesas which they bound are entirely destroyed. (Gregory 1938).

PHYSIOGRAPHIC HISTORY

The physiographic history of the vast plateau country is essentially one of post-Wasatch erosion conditioned by climate, altitude, and tectonic deformation. The present topography records the latest structural changes and the nature of consolidated and unconsolidated sediments, and to a large degree it measures the progress of adjustment of drainage to structure and rock hardness.

The landscape of the Colorado Plateau province is not the work of a single cycle. The topography displays such discordant features as superimposed drainage, broken stream profiles, graded platforms adjoining deep canyons, entrenched meanders, local surfaces of erosion at several altitudes, alluvial terraces, gravel-floored rock terraces, and juxtaposition of old-age and youthful surfaces. The interpretation of these heterogeneous features involves the recognition of periods in physiographic history when dominant degradation was replaced by aggradation, uplift by stillstands, and humid by arid climate. In other words, when grouped and evaluated the seemingly unrelated surfaces, trenches, and walls serve to outline a series of long and short erosion cycles during each of which distinctive landscapes were developed. The two major periods of erosion in the plateau province generally have been recognized as the precanyon cycle and the canyon cycle—undefined stretches of time during which conditions were generally favorable for the destruction of high-lying land.

During the long precanyon cycle—the oldest cycle of which clear evidence is presented in the topography—most of the Tertiary sedimentary material, much of the Cretaceous, Jurassic, and Triassic, and some of the Permian were removed from southern Utah and northern Arizona. North of the Grand Canyon the differential stripping of the once extensive beds has produced the cliffs and slopes in the famous "rock stairway" that leads from the canyon rim to the top of the High Plateaus. During the precanyon cycle the topography of large areas, particularly along the major drainage lines, was reduced to the stage of postmaturity, but full development of the old-age erosion surfaces was inhibited by a regional uplift that initiated the canyon cycle of erosion.

As the term applies, the canyon cycle (the present major cycle) has been characterized by canyon cutting. Since its beginning the Colorado, the Virgin, the Kanab, the Paria, the San Juan, the Escalante, the Fremont, the Green, and other large streams have sunk deep trenches and, aided by hundreds of smaller streams, have carved the highlands and lowlands into the myriad topographic forms that give the plateau province its outstanding place among regions of marvelous scenery. For the precanyon cycle no subdivisions have been recognized; differences in altitude of the remnant erosion surfaces and in the degree to which inequalities of hard and soft rock have been obliterated greatly hinder definition. For the canyon cycle subdivisions are more readily established; evidence of intermittency in down cutting is clear and abundant. Canyons and interstream spaces record periods when normal vigorous erosion changed to deposition, and many features indicate rather recent rejuvenation. Regionally the major changes in stream habit in response to changes in climate and the renewal of uplifts are so clearly expressed that two epicycles within the canyon cycle may be defined—the inner canyon epicycle, during which a pause in dominant down cutting provided conditions favorable for aggradation of streamways, and the terrace epicycle, during which renewed degradation has stripped the canyons of their alluvial fill or cut it into terraces that border the present streams.

In brief, the probable main stages in physiographic evolution in the Paunsaugunt region, in the adjoining Kaiparowits and Zion Park regions, and probably throughout the plateau country are as follows:

1. A period of regional uplift associated with widespread folding—end of the Cretaceous.
2. A period of extensive erosion—Cretaceous-Tertiary interval.
3. A period of differential warping associated with deposition of fresh-water sediments and possibly with regional depression—early Tertiary.
4. A period of regional uplift accompanied by or closely following large-scale faulting—post-Eocene.
5. A period of widespread and long-continued erosion—the precanyon cycle.
6. A period of regional uplift associated with faulting and profound erosion—the canyon cycle, probably post-Pliocene.
7. A period of alternating aggradation and degradation, regional in scope, possibly initiated by tectonic movements—inner canyon and terrace epicycles, Pleistocene and Recent.

The stages as outlined are characterized by unmistakable features, and their relative place in the series of progressive events seems established, but the evidence at hand is insufficient to date satisfactorily the beginning, the end, or the duration of the periods of vertical uplift, differential warping, and stillstands, or to determine the rate and amount of cyclical erosion. The events that preceded the deposition of the early Tertiary strata (periods 1, 2, 3) are clearly recorded in the present topography: marine rocks and terrestrial rocks of Cretaceous age lie high above sea level, their structural inequalities have been greatly reduced in places to a general level, and upon them fresh-water

Tertiary strata occupy broad basins. The tectonic movements (period 4) that followed the deposition of the limestones of the Eocene Wasatch formation and the clays and agglomerates assigned to the Pliocene are also clearly expressed: between prominent faults of large displacement, broad sheets of sedimentary rock originally near sea level now cap the plateaus at altitudes above 8,000 feet. Erosion of this high-lying land (period 5) was an outstanding event in the phsysiographic history of the Colorado Plateau. During the long precanyon cycle denudation proceeded so far as to reduce fault cliffs, deep drainage channels, and outcrops of hard and soft rock to a surface where the valleys and hills were relatively inconspicuous: remnant peneplains witness the elimination of topographic inequalities. In consequence of the uplift that initiated the canyon cycle (period 6) the streams that were flowing in meandering courses on gentle slopes were given power to entrench themselves deeply and to cut headward into the heart of the plateaus that had escaped the general denudation of the precanyon cycle. As erosion progressed a landscape characterized by old-age surfaces, low talus-clogged cliffs, broad, shallow valleys, and unreduced highlands became a land of canyons—the present land—sunk into plateaus, terraces, and plains. Before the vigorous streams of the canyon cycle had reduced their courses to grade and worn away the interstream lands, further deepening was inhibited by a pause in dominant down cutting, introducing the inner canyon and terrace epicycles (period 7), during which many canyons were so completely filled with alluvium that their rock bottoms were converted into sand and gravel floors at a high level. Since it was first deposited the valley fill has intermittently been partly or wholly removed and replaced; its physical features record alternate periods of aggradation and degradation, in consequence of climatic changes and possibly of tectonic movements. At present degradation is in progress: the alluvium is being removed at a rapid rate. Vigorous stream trenching accelerated by human activities is converting the once unbroken valley floors into a system of vertical-walled, flat-topped terraces.

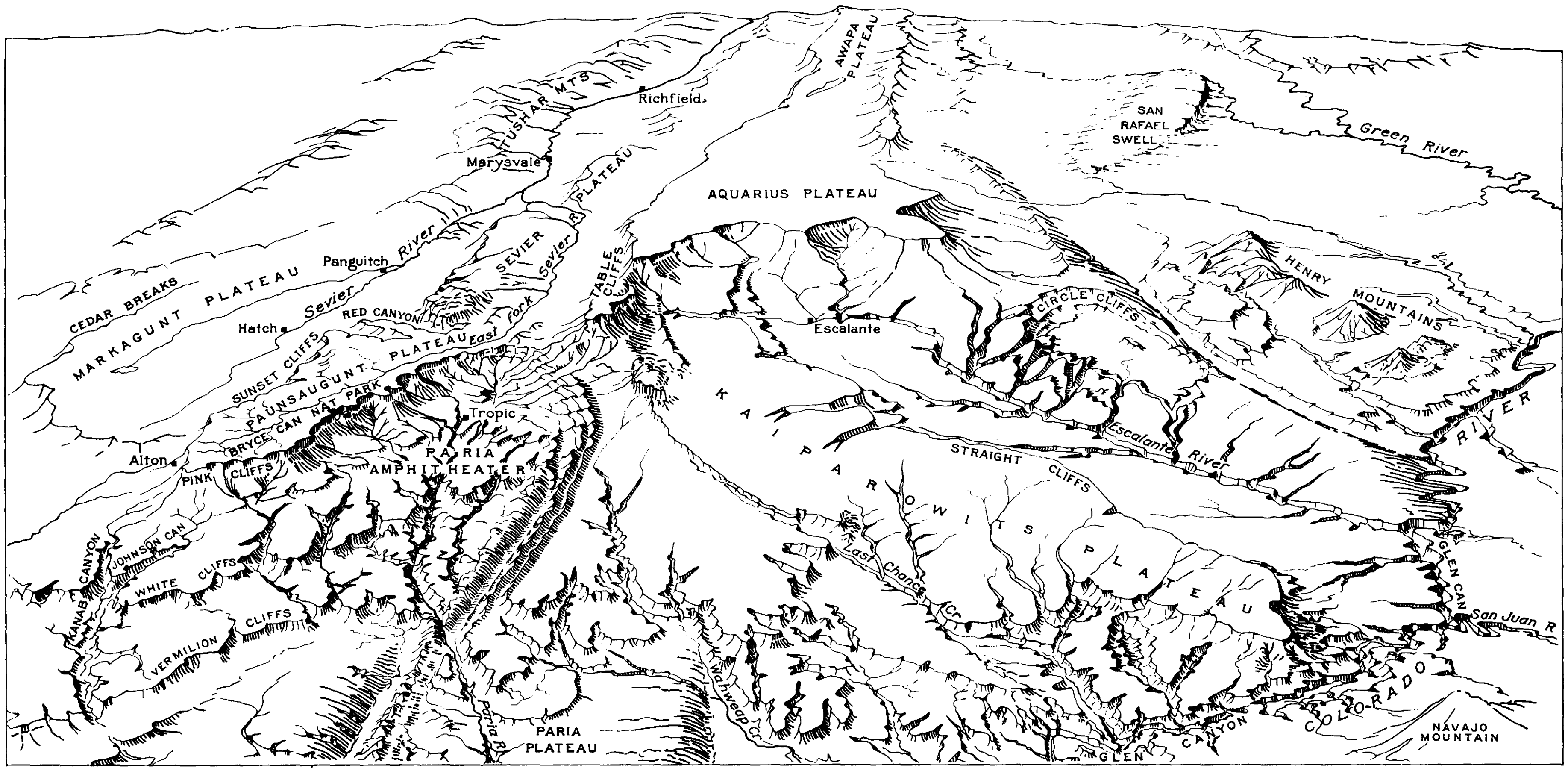
THE PAUNSAUGUNT LANDSCAPE

The setting of the Paunsaugunt region with reference to neighboring parts of the plauteau province may be visualized from selected viewpoints. Thus from Powell Monument, on the crest of the Table Cliffs, the Paunsaugunt Plateau, 2,000 feet below, appears as a cliff-bound expanse of flat land that on the north abuts against the Sevier Plateau and on the west across a narrow lowland adjoins the Markagunt Plateau. (See pl. 5 and figs. 1, 48.)

Everywhere at their rims the generally flat plateaus appear to give way to regions of rough topography, difficult to penetrate. As far as the eye can reach, the cliff faces and foothills present innumerable topographic forms, seemingly displayed without order and on a scale so vast as to obscure features that in other regions would attract particular attention. It is an unparalleled scene of plateaus, gorges, cliffs, mesa walls, sharp-edged ridges, and volcanic piles within a radius of nearly 100 miles on both sides of the Colorado canyons. The extreme ruggedness of the Paunsaugunt landscape is apparent in views along the "rim road" in Bryce Canyon National Park. Beginning abruptly at Sunset Point, meandering trails lead steeply downward along trenches between serrated walls to the floor of the Paria Valley, 2,000 feet below. Beyond this flat land appear interlocking ridges, trenched by narrow, deep canyons, more than 20 of them in a mile, that carry water to the Paria or directly to the Colorado. The rim of the lofty Kaiparowits Plateau is cut by innumerable notches at the heads of innumerable canyons and stands on the sky line carrying the view southeastward to the domelike Navajo Mountain, beyond Glen Canyon, 90 miles away. From Sunset Point northeastward the details of the amazing landscape are dwarfed by the towering plateau headlands that stand 2,000 feet above the rim of the Paunsaugunt Plateau and 4,000 feet above the Paria. As viewed from Rainbow Point, the country descends southward in an orderly succession of terraces miles in width, separated by cliffs hundreds of feet high, across the White Cliffs and the Vermilion Cliffs to the Kanab Plateau, 40 miles distant and 4,000 feet below. (See figs. 45–48.) The terraces are trenched by deep gorges, and from their floors rise small mesas, platforms, and towers, and such prominent erosion remnants as No Mans Mesa and White Cone (Tabetimp).

The rough topography that characterizes the east and south flanks of the Paunsaugunt Plateau ends at the Kanab Valley. Northward along the west base of the plateau, ridges give way to a flat land in which the stream channels are few and inconspicuous (Figs 43, 49). The view westward from the crest of the Sunset Cliffs or from the top of the outlying Wilson Peak reveals the broad plain and slopes gently downward toward the South Fork of the Sevier River, then gently upward into the Markagunt Plateau.

Ever since the Utah plateaus attained their present altitudes, the eroding streams have been active. In some places their work is nearly finished; in other places



GENERALIZED SKETCH OF SOUTH-CENTRAL UTAH, SHOWING THE TOPOGRAPHIC SETTING OF THE PAUNSAUGUNT PLATEAU.

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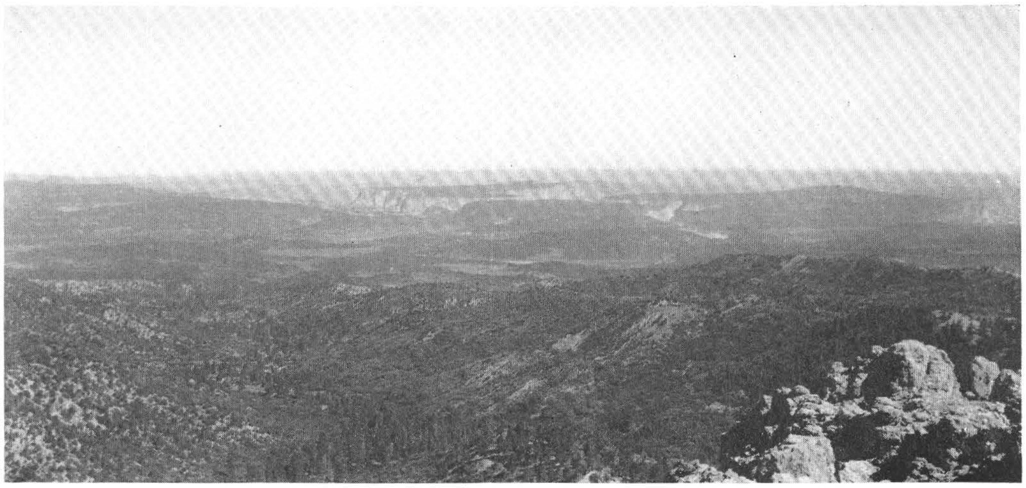

FIGURE 45.—View from Rainbow Point across foothills of Paunsaugunt Plateau showing roughly dissected highlands.

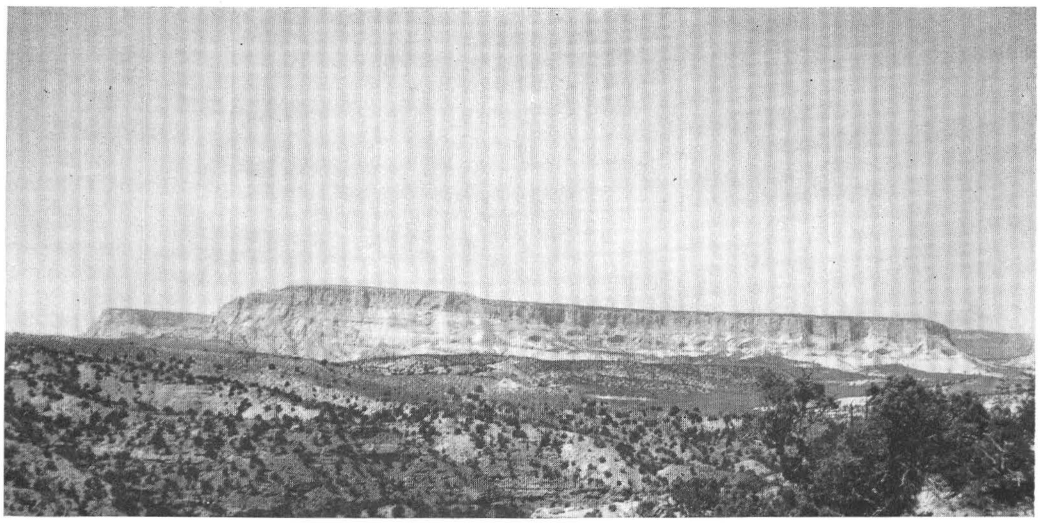

FIGURE 46.—No Mans Mesa, an outlier of the White Cliffs (Navajo sandstone) capped by limestone of the Carmel formation.

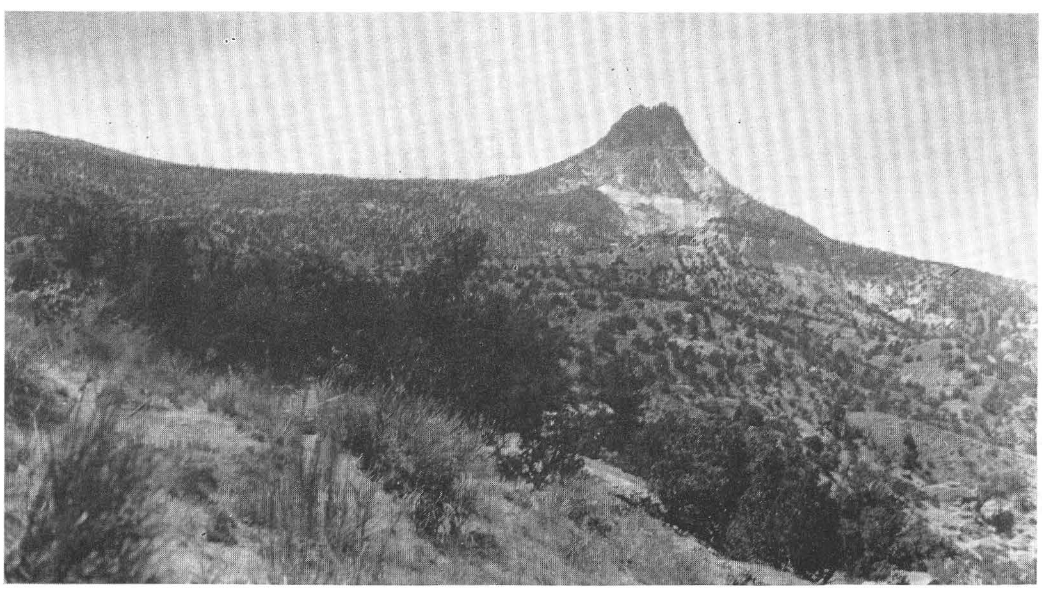

FIGURE 47.—White Cone, an isolated remnant of Navajo sandstone impregnated with iron.

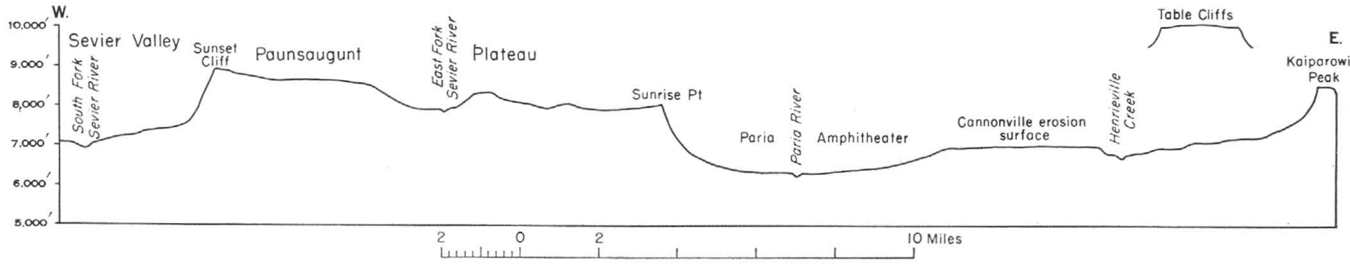

FIGURE 48.—Surface profile from South Fork of Sevier River near Hatch across Paunsaugunt Plateau to Kaiparowits Peak.

it is vigorously in progress, and in still other places barely begun. As a result, the Paunsaugunt landscape consists of three unlike parts—a vertical wall, a nearly flat highland above it, and a rugged lowland. The wall is the Pink Cliffs; the highlands is the top of the Paunsaugunt Plateau; the lowland is the much-dissected foothill belt that includes canyons, ridges, and such relatively flat lands as the Paria Amphitheater, the Alton Amphitheater, Skutumpah Terrace, and the alluvial plain that borders the South Fork of the Sevier River.

In topographic prominence, the Pink Cliffs rank first among the great walls that give the scenery of southern Utah its unique expression. They are the longest and most continous of all the plateau escarpments and the most extensively and intricately carved. As the rim rock of the High Plateaus they extend with few interruptions from Cedar City eastward to the Paria River and northward to the Fremont River, a distance of more than 150 miles, and within the plateau area they border the Sevier River for nearly 50 miles. They entirely surround the Paunsaugunt Plateau. As the top step in the series that includes the Chocolate Cliffs, the Vermilion Cliffs, the White Cliffs, and the Gray Cliffs, the Pink Cliffs are perched high in the air, on the sky line as seen from most viewpoints in northern Arizona

FIGURE 49.—South Fork of the Sevier River south of Hatch River. Flows on alluvium along edge of fans that extend westward from the base of the Sunset Cliffs (skyline).

and southern Utah. From a distance the Pink Cliffs appear as a continous escarpment, but from the highway through Gravel Pass, Hatch, Hillsdale, and Panguitch, from roads through Alton, Skutumpah, and Swallow Park, and from trails along the back slopes of the White Cliffs their architectural design is revealed: on a dark-colored sloping base rests a brightly colored crenulated wall that includes massive buttresses, huge square towers, deep angular recesses, broad circular grooves, and narrow high-walled portals—in the words of Dutton, "the glory of all rock work." Viewed near at hand these strong, bold features of the cliffs display carving beautiful in design and color. (See figs. 24, 49, 60.)

At the heads of Paria and Kanab Valleys erosional indentations in the Pink Cliffs are exceptionally developed; they appear as broad, relatively flat-floored steep-sided depressions—the topographic features termed "amphitheaters" by the pioneer geologists of Utah. The large Paria and Alton Amphitheaters and their smaller companions are substantially alike in form, are made of the same kinds of rock, and have the same physiographic history.

As seen from the rim of the Paunsaugunt Plateau the Paria Amphitheater appears as a broad, semicircular valley bordered on the north and west by broken slopes that terminate in cliffs and on the south and east by low ridges and terraces that form the borders of the flat land immediately along the Paria River. (See figs. 50, 51.) The grandeur of this vast rugged structure is best appreciated while standing on its floor, easily reached by the trails or by the automobile road down the "breaks of the Paria" and on through Tropic to Cannonville. From this viewpoint the flat land is but a band of gravel cut into deep, narrow gullies; the ridges, inconspicuous from above, are mesas and headlands faced by cliffs; and the drainage system that from the rim of the plateau seems to consist of a main channel and a few orderly disposed branches is in reality a plexus of waterways—scores of ephemeral streams, hundreds of tributaries—all within canyons. Northward from the fields about Cannonville and Tropic the land along the Paria and its chief branch, Henrieville Creek, rises in steps cut into soft drab shale and hard yellowish thick-bedded

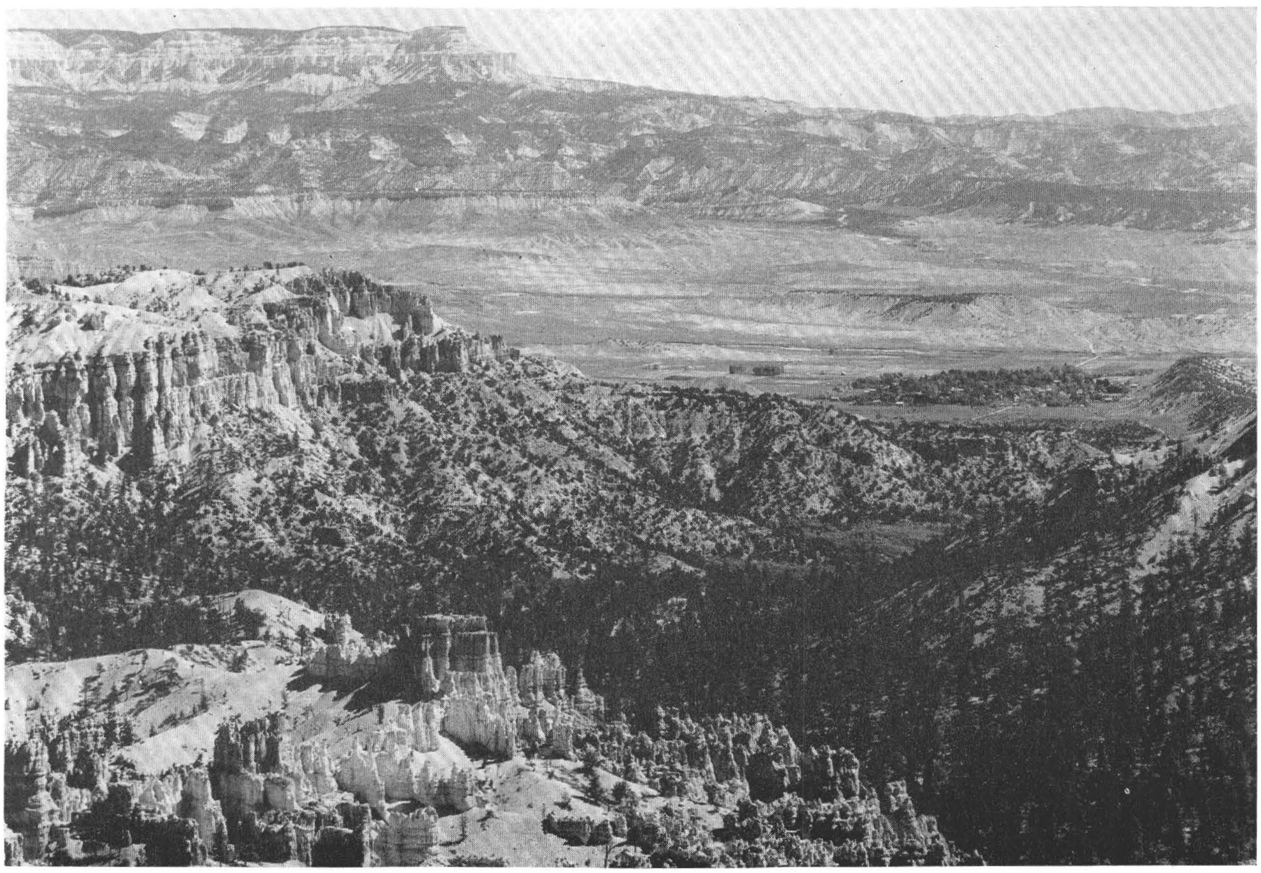

FIGURE 50.—View looking northeast from Inspiration Point on rim of Paunsaugunt Plateau across floor of Paria Amphitheater (eroded in Cretaceous shales) and bordering benches (cut in Cretaceous sandstones) to the rim-rock (Wasatch formation) exposed in Table Cliffs. The village of Tropic (right center) stands near the junction of Bryce Creek and Paria River. Photograph by National Park Service.

FIGURE 51.—Paria Amphitheater, showing a flat part of the amphitheater used for farming. Photograph by National Park Service.

sandstone to the base of an unscalable wall of limestone whose top lies more than 4,000 feet above the floor of the arena at Cannonville. The highest tier in the amphitheater is Table Cliffs—walls fully 1,000 feet high that rise sheer from their bases except where supported by steep buttresses, indented by niches, or broken into decorative columns.

In strong contrast to the intricately dissected, brightly colored, nearly bare Pink Cliffs and the topographically complex amphitheaters, the surface of the Paunsaugunt Plateau back of the rim is generaly flat, dull-colored, forested, and devoid of conspicuous cliffs, canyons, sharp-cut gullies, and terraced hills; a remarkable landscape in a region of rugged topography. (See figs. 52–54). Even the few high benches that stand immediately on the plateau rim have rounded tops and gently sloping sides. In place of the short, swift, cliff-bound streams that carry water from the plateau rim to the Paria, the Kanab, and the South Fork of the Sevier, the plateau top is drained by the slow-moving East Fork of the Sevier River, which wanders across the surface in a broad, shallow valley between inconspicuous rounded ridges. The divide between the two drainage systems is sharply drawn. From the plateau rim, rain water goes southward by short cuts to the Colorado River and northward along a circuitous route to the desert flats of the Great Basin. It is interesting to note that the northward-trending valleys are incomplete. They begin in broad swales (passes) that are abruptly terminated along the southern plateau rim. (See p. 97.)

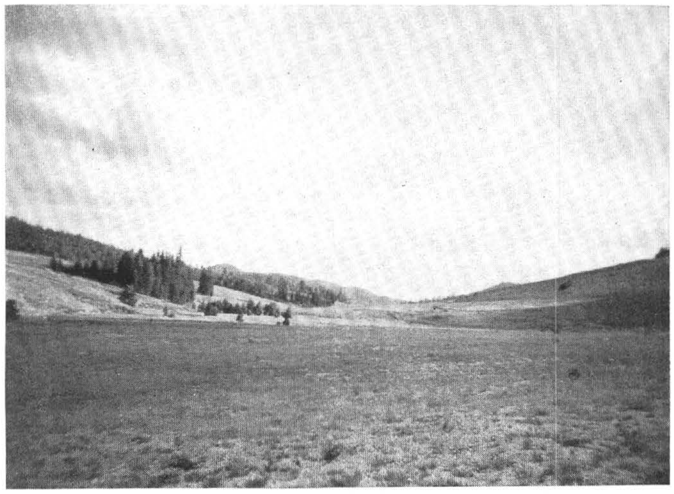

FIGURE 52.—East Fork of the Sevier River about 2 miles from its source, on the Paunsaugunt Plateau, near the mouth of Podunk Creek.

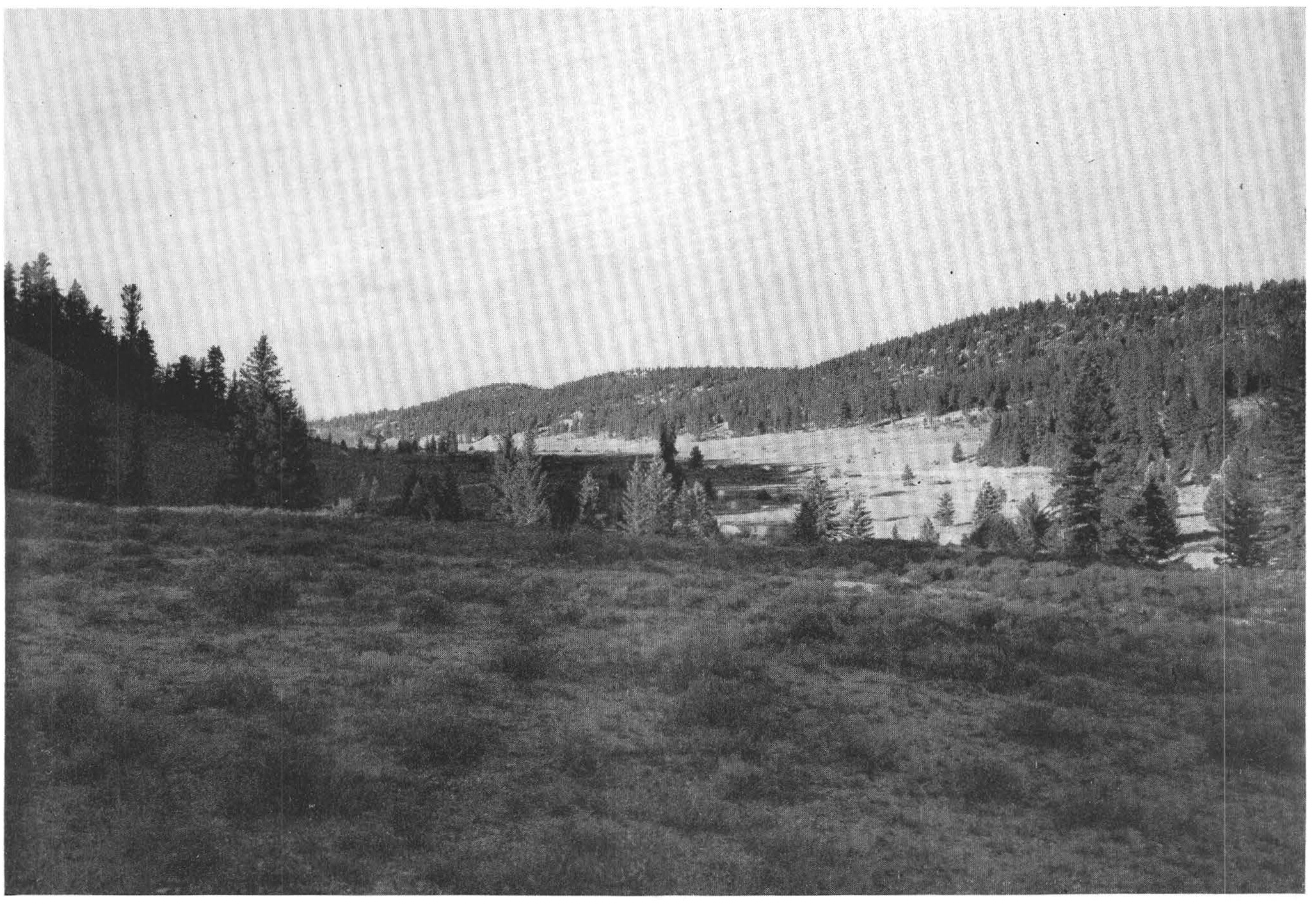

FIGURE 53.—East Fork of the Sevier River on Paunsaugunt Plateau, near Blubber Creek.

FIGURE 54.—Valley of East Creek, on top of Paunsaugunt Plateau, west of Bryce Canyon Lodge.

The surface of the Paunsaugunt Plateau marks the stage reached in the erosion of a high-lying land that probably has been undisturbed by major tectonic movements since the beginning of the canyon cycle. As erosion progressed the land was lowered, the inequalities were removed, and the drainage channels became less steep, until finally the main streams were unable to cut deeper grooves and were barely able to carry away the small amounts of rock debris brought in by their tributaries. On the Paunsaugunt Plateau, most of the weathered rock now remains where it is formed, and, unlike the bare rock in much of the surrounding region, the surface is mantled with soil. In geologic parlance, the surface of the plateau has attained postmature age, and its bordering lands are youthful.

FACTORS THAT INFLUENCE EROSION

CLIMATE AND RUNOFF

Though the Paunsaugunt region as a whole is semiarid, meteorologic records show wide variation in precipitation and temperature with respect to amount, time, and topographic position. On top of the Paunsaugunt Plateau near the administration building in Bryce Canyon National Park the average annual precipitation is 19.08 inches, heaviest in winter. In the upper Kanab Valley at Alton (altitude 7,000 feet) the combined rainfall and snowfall is 19.07 inches, also heaviest in winter. In the valley of the upper Sevier at Hatch (altitude 6,916 feet), the precipitation of 11.44 inches is heaviest during July, August, and September. At Panguitch (altitude 6,700 feet), in a broad flat valley bordered by mountain slopes, the annual precipitation is 9.69 inches, and the rainy months are July, August, and September. In the Paria Valley at Tropic (altitude 6,296 feet), the annual precipitation of 11.88 inches is heaviest in the summer and lightest in the spring. (See fig. 2, *a*, *b*.)

If evenly distributed in time the total rainfall and snowfall is sufficient to maintain a small, regular flow in the more favorably placed streams, but under the prevailing conditions the drainage channels at unpredictable places and times carry flood waters, rivulets, rills, or no water at all. The intermittency and volume of precipitation are reflected in the behavior of the streams.

Thus the South Fork of the Sevier River below the mouth of Asay Creek, the East Fork of the Sevier above Widtsoe, and Kanab Creek are perennial and except during long-continued dry periods the Paria River and its larger branches—Yellow Creek, Sheep Creek, Willis Creek, and Meadow Creek—are throughflowing. In their upper parts Thompson, Tenney, and Mill Creeks, tributary to Johnson Creek, also Proctor, Hillsdale, and other creeks that head in the Sunset Cliffs, flow throughout the year, being fed chiefly by springs. Though the number of perennial throughflowing short streams is relatively greater than in most other parts of the Colorado Plateaus the characteristic stream in the Paunsaugunt region is intermittent, and, as expected in a region of semiarid climate, hundreds of its minor tributaries are ephemeral. Though instrumental measurements are wanting, casual observations show that the amount and the proportion of precipitation represented directly by runoff vary commonly with topographic position. On the faces and immediate back slopes of the White Cliffs, Pink Cliffs, and escarpments made of Cretaceous sandstone and Jurassic limestone, where bare rock, steep declivities, and sparse vegetation are favorable, the falling rain hurries away. In the rough foothills, where bare rock and steep slopes are less common, considerable of the rain and especially the water from melting snows sinks into the ground. On the relatively flat, forested Paunsaugunt Plateau, where more than half of the precipitation is in the form of snow, soil absorption utilizes perhaps a third of the total precipitation.

As regards erosion, the most significant feature of the rainfall is the violence of the showers. In the Paunsaugunt region, as generally in the plateau province, the typical rain is a short-lived torrential downpour that covers a few square miles. In most showers the water comes so suddenly and in such volume that little of it sinks into the ground. It gathers at once into existing channels, or if these are too small or too few, it flows across the surface as a sheet of water that temporarily comes to rest in some depression. During its short life each of these vigorous ephemeral streams sweeps from the surface all the disintegrated rock within reach and, in combination with other streams of like origin, carries to the larger channels great volumes of swiftly flowing debris-laden water, thus providing optimum conditions for tearing up and transporting rock waste. So effective is this process that with no change in the character of rainfall a reduction half the present annual precipitation probably would cause little diminution in the rate of erosion. The rapidity of accumulation and the sharp localization of floodwaters is remarkable and in the human affairs of Utah has large meaning.

The effect of violent rains may be illustrated by the "great wash-out" in Proctor Canyon in 1921. At the mouth of the canyon the farm of D. H. Evans comprised 74 acres, and another farm farther downstream 150 acres of fertile farm lands "irrigated by a permanent shallow clear stream meandering slowly through willows, alders, cottonwoods, and grassy meadow lands." For more than 40 years crops had been regularly planted and harvested undisturbed by floods, and Proctor Creek rose to flood stage "only once in a while" and the irrigation ditches needed little attention. Mr. Evans recalls that at noon on July 13, 1921, during a "cloudburst," water in the stream bed "rose 20 feet above the banks" and "rivers" flowed down the canyon walls. While the water was rushing in torrents across the surface the saturated alluvium within the canyon began to move downstream and out over the cultivated fields as "a wall of snaky mud as high as the house." "Trees moved along standing straight up like shipmasts." The barns and corrals were "twisted around and buried in the mud." A second "wall of mud" submerged the house just after the family of 8 children had escaped to higher land, and passing to the sides of the first mud flow deeply buried land farther down the valley. In it were rolled along "mud balls bigger than horses." In consequence of this flood, which "lasted about an hour," the land at the mouth of Proctor Canyon was completely remodeled. The place of the original fields of level arable agricultural soil has been taken by rough-surfaced barren gravel on which lie slabs of sandstone weighing as much as 5 tons, nearly half a mile from their source. Proctor Creek, which once flowed to the Sevier River in a clearly defined broad channel, now appears and disappears among mounds of the jumbled gravel. The former canyon is represented by terrace remnants 40 feet above the stream, and the intake of the present irrigation ditch is 20 feet below its former position.

Frost is an active agent. As recorded in the meteorologic tables (p. 77), temperatures below the freezing point are recorded for 6 months of the year in upper Kanab Valley, 7 months in the Sevier Valley and Paria Valley, and 10 months on top of the Paunsaugunt Plateau. During these months the daily variation is so great that alternate freezing and thawing may be many times repeated. Each year at all places in the Paunsaugunt region ice forms on streams and reservoirs, and the ground is frozen to depths exceeding 1 foot. The innumerable joint cracks permit the entrance of surface water that on freezing quarries blocks of various sizes from bare rock ledges and breaks into finer fragments the partly disintegrated subsurface rock in areas coated with soil. Though most of the fragments detached from canyon walls, from cliffs of thick-bedded limestone and sandstone, and from steep slopes in thinly stratified rock are soon swept away by rapid and powerful streams, piles of coarse talus lie here and there at the base of high walls and on the flanks of steep ridges. Many of the rock mounds that stand above the general surface of the Paunsaugunt Plateau are coated with talus, and in favorable places on flatter lands, frost supplies each spring a thin coat of disintegrated rock ready for removal by the torrential rills of summer.

VEGETATION

In the Paunsaugunt region the effectiveness of vegetation as a factor in erosion varies widely from place to place. In the forests on the plateau top, where the glades between stands of pine, spruce, and fir are carpeted with grass and annual herbs, runoff is obviously retarded, and much of the water from snow and rain sinks into the ground. At the boxlike heads of many canyons rising in the plateau and locally on flat-topped ridges and mesas, thickets of shrub and a ground cover of litter tend to prevent the formation of gullies. On the slopes at lower altitudes the scattered covering of rather stunted trees and of sagebrush takes little part in checking erosion. Over large areas trees, shrubs, grass stalks, flowering annuals, and introduced weeds rise as individuals from a floor of rock or alluvium; even in the places most fully covered by vegetation, matted grasses and sod are rare. (See p. 12.) In recent years the destruction of soil binders incident to overgrazing and intensive agriculture has greatly accelerated erosion. (See p. 15.)

GROUND WATER

In the Paunsaugunt region, as elsewhere in the plateau province, deep trenching by streams has exposed the many aquifers in the sedimentary beds and thus facilitated the emergence of ground water. Innumerable canyon walls provide exits for streams and seeps in bedding planes, along zones of jointing, and within the massive porous sandstones. Generally the unconformity between the Winsor formation and the Dakota (?) sandstone is marked by seeps and in many places the sandstones immediately overlying the shales and coal of the Tropic shale, also the sandstones at their contact with shales in the Straight Cliffs and Wahweap formations are saturated. At the base of the Wasatch formation moist rock, night-time seepages, and perennial springs are common. Here the abundant water supplied by melting snow on the plateau above percolates downward through joints and solution channels and finds a suitable exit in the loosely compacted conglomerate and porous sandstone that mark the Cretaceous-Tertiary unconformity. Another conspicuous spring zone is the contact of valley fill with the irregularly eroded rock surface below. Marking places near to bedrock, seeps and in places large springs emerge from the base of alluvial terraces. Except for a short time after showers, Red Creek and other streams that flow across the alluvial fans of the Sevier Valley are dry where their floors are above bedrock but flow in considerable volume where bedrock is exposed. Springs that rise on the floor of the creek supply about 0.5 second-foot of water to irrigation ditches. This widespread, thoroughly saturated zone supplies abundant water for wells. (See p. 112.) Among factors that influence the rate and manner of erosion in the Paunsaugunt region, ground water is subordinate only to stream scour. It disintegrates the rock on cliff faces and canyon walls, widens the canyons that streams have deepened, and greatly facilitates the removal of valley fill. Perennial seeps have produced many recesses in walls and thus have removed large quantities of rock inaccessible to other agencies. In the cliffs and ridges at the heads of canyons the larger springs have developed flat-floored, steep-sided alcoves acres in extent and supply the water that gives abrasive power to the streams running during dry periods. The efficiency of ground water as a factor in erosion is further shown by landslides.

STREAM GRADIENTS

Most streams in the Paunsaugunt country have steep gradients. (See fig. 55.) Of the two through-going tributaries to the Colorado, the Paria River descends 7,000 feet in 75 miles (93 feet to the mile) and Kanab Creek 6,500 feet in 90 miles (72 feet to the mile). The gradients of Meadow, Kaibab, and Johnson Creeks are roughly 100 feet to a mile. The upper stretches of these streams and of their shorter companions that drain the south flank of the Paunsaugunt Plateau fall at rates of 500 to 1,500 feet to a mile: their heads are essentially steep rapids. On the west side of the plateau, Proctor Creek, Hillsdale Creek, Red Creek, and other tributaries to the upper Sevier, which head in the highlands at altitudes of 8,000 to 9,000 feet above sea level, pass through the Sunset Cliffs on slopes as steep as 500 feet to a mile, then continue on gradients of 30 to 50 feet to a mile. In striking contrast to the normal steep gradients of streams that flow southward and westward, the streams flowing northward—streams that constitute the upper part of the Sevier River system—have generally low gradients. Except for a mile of steep slopes at its head the South Fork of the Sevier River from Gravel Pass to Panguitch falls 25 feet to the mile, and throughout a course of 53 miles, from Crawford Pass to the head of its first canyon, 8 miles north of Widtsoe, the East Fork of the Sevier descends at the rate of about 24 feet to the mile. For about 15 miles of the distance through Emery Valley (the "Panguitch Hayfields" of the Wheeler Survey) the gradient of the East Fork is less than 10 feet to the mile, and at times its channel expands into ephemeral lakes. The short branches of the East Fork as represented by Podunk, East, Daves, Blubber, and Ahlstrom Creeks have gradients of 10 to 15 feet to the mile. In contrast the Colorado River in Glen Canyon has average gradients of about 2 feet to the mile and even in Grand Canyon only about 8 feet to the mile, in the steeper portions 10 to 20 feet to the mile. The average gradient of the Virgin River in its 200-mile course is approximately 40 feet to the mile.

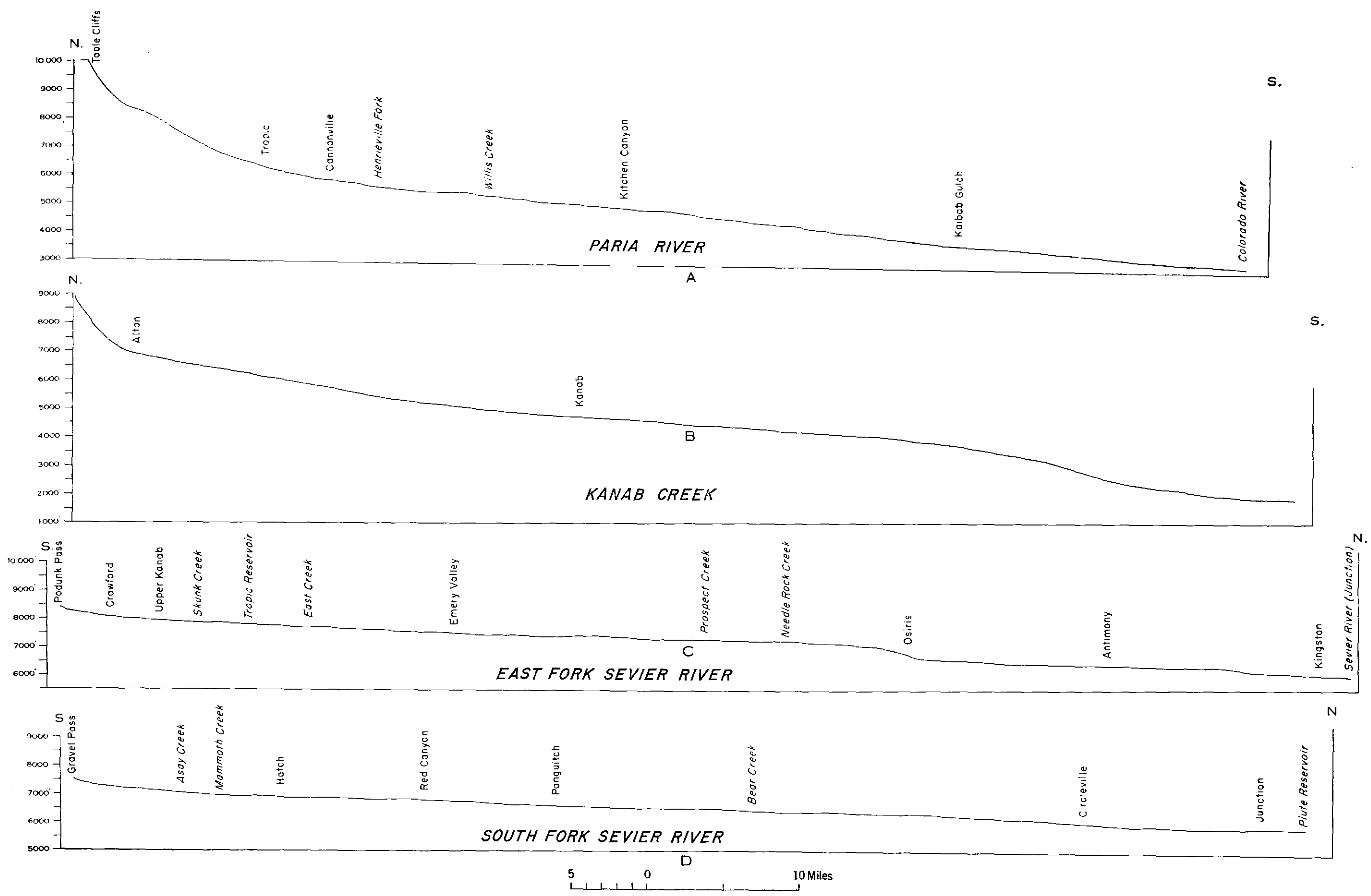

FIGURE 55.—Generalized stream profiles. *a*, Paria River; *b*, Kanab Creek, streams flowing from the rim of the Paunsaugunt Plateau southward across the tilted edges of Tertiary and Mesozoic strata; *c*, East Fork of Sevier River; *d*, South Fork of Sevier River, streams flowing down the dip slopes of Tertiary strata and lavas.

Because of their generally steep gradients the streams of the Paunsaugunt region are obviously capable of tearing up their beds and side walls and transporting almost unlimited amounts of rock waste. Traverses of valleys show a succession of waterfalls, rapids, and relatively smooth water in accordance with the distribution of bare rock, thin sheets of gravel and sand, and deep alluvial valley fill. At stages of low-water channels on steep gradients, particularly those cut into freshly scoured rock, are generally clear, but in the more level stretches they are clogged with sand, gravel, boulders, and huge angular blocks through which the tiny streams find their way. During the frequent flood stages all the rock waste seems to be in motion; the debris temporarily lodged on the valley floor is pushed along across steep and gentle slopes alike, and with it the material freshly supplied by upstream sources and from the immediate banks. From season to season alluvial floors are sunk to rock, rock floors are covered with gravel, boulders accumulated in the main channels find new places, and the mouths of tributaries are cleared or so jammed with boulders as to permit passage only by climbing. Measurements show that during a single flood grooves as much as an inch deep may be cut into previously smooth rock and trenches 1 to 4 feet deep in alluvium. Widening of the streamways by slumping of their walls is also conspicuously in progress. On the floor of Swallow Park and in places along Skutumpah, Sink, Meadow, Lick, and some other creeks, where rock attitude, structure, and composition have favored the development of flats on soft rock, so much of the energy of the meandering stream is utilized in transportation that down cutting is secondary to widening.

BEDROCK

A feature of erosion in the plateau province, fully represented in the Paunsaugunt region, is the control exercised by the composition, texture, and attitude of the rocks. On the Paunsaugunt Plateau and on some broad platforms and benches formed of single beds of sandstone or limestone, where the inclination of the streamways is in accord with the dip of the rock, the streams are chiefly engaged in carrying away the waste produced by weathering: the reduction of the rock

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surface is slow. Likewise after their development by headwater erosion or faulting, the cliffs in the hard limestone and thick-bedded sandstone are nearly immune from scour by established streams: they retreat in consequence of spalling induced by frost and ground water and of disintegration under the direct impact of rain. On slopes of the weakly consolidated Winsor formation and on some highly friable beds among the Cretaceous formations the falling rain immediately forms close-spaced rills that widen and lengthen and, almost regardless of frost, ground water, and vegetation, rapidly carry the bedrock away. Likewise exposures of the soft Entrada sandstone, where not protected by gypsum beds, seem literally to melt away under the attack of heavy sudden downpours. On outcrops of shale and thin-bedded sandstone streams supplied with the products of weathering tend to develop gently undulating surfaces uniform in slope over wide areas. On rocks of this kind steep slopes are progressively worn to gentle slopes with relative rapidity, then to flats until the more resistant underlying rock is exposed. But at all stages of the process the slope of the valley floors and of interstream spaces is broken by low steps that mark the position of thin hard beds. On the bare surfaces of such relatively massive rocks as the Navajo sandstone, the limestone in the Carmel formation, the gypsum in the Curtis formation, and the sheets of basalt, streams originally guided by joint cracks and local variations in rock texture expend their energy in cutting clearly defined isolated trenches with a rapidity that makes the work of frost and of direct rain impact seem almost static. Likewise in the development of alluvial terraces vertical and lateral stream abrasion far outdistances the erosion by other agents. So persistent is the relation of rock types to the style and rate of erosion that, with a general knowledge of the regional stratigraphy, the form and position of cliffs and canyon walls and of steep slopes, gentle slopes, and flat lands can be fairly well predicted and with a detailed topographic map in hand a generalized geologic map could be constructed without field study. In fact, the excellent reconnaissance maps of the Wheeler and Powell Surveys represent little local observation: their drafting seems to have been influenced by the belief that the major stratigraphic units retained their characteristic thickness and composition over large areas.

RATE OF EROSION

At the present time most of the streams in the Paunsaugunt region are vigorously eroding their beds. Those flowing on rock are scouring their floors, and those flowing on sand and gravel are rapidly cutting downward and sideward. Erosion in the present cycle added to that in previous cycles has given the Paunsaugunt landscape its distinctive features and made of it a representative part of the plateau country.

Regionally the amount of land removed by erosion since the plateaus were uplifted is measured in large terms. On the reasonable assumption that the strata now capping the Paunsaugunt Plateau once extended southward to the Colorado River the rock removed from the narrow strip between the Sevier and Paunsaugunt faults would form a block of Eocene and Mesozoic rocks measured roughly as 20 miles wide, 110 miles long, and 2 miles thick—about 4,400 cubic miles of consolidated sediment. To this total there should be added the large but unknown amount of rock worn away from the top of the plateau. Comparable estimates for the much larger areas of denuded rock in southern Utah and northern Arizona give figures of astonishing size and mark the stripping of the plateau lands as a major event in the geologic history of North America.

Of the streams that carry waters from the eastern and southern flanks of the Paunsaugunt Plateau the present baselevel of erosion for Kanab Creek is the Colorado in Grand Canyon and for the Paria River the head of Marble Canyon. By cutting deep gorges these tributaries meet their master stream at grade and thus near their mouths are no longer actively deepening their channels. In their steeply inclined upstream stretches their erosive power is unchecked, and aided by their many branches they are not only transporting the waste supplied in the present epicycle but are removing the waste deposited in previous cycles and cutting into the rock beneath.

No figures are available for the amount of rock waste annually removed from the Paunsaugunt region by the Paria and Sevier Rivers and Kanab Creek, but rough estimates may be obtained by comparison with streams that traverse similar regions and whose silt load is known. Thus for the San Juan the estimated annual silt load is 1 acre-foot a square mile (U. S. Reclamation Service, 1919, p. 404) and for the Virgin River the amount of suspended silt is reported to range from "a trace to 42.2 percent of the volume of discharge." The amount of material removed from the rim and upper flanks of the Paunsaugunt Plateau is shown by Christiansen (1936, pp. 33–35) whose study of run-off during nine storms led to an estimate of 800,000 tons of material carried annually by Bryce Creek from an area of about 3 square miles. These figures for the rate of regional erosion based on estimates of suspended silt are supported by observation of the rates of disintegration of various types of rock in various topographic positions. Records obtained by Christiansen show that each 100 pounds of "flood material" (silt, gravel, water) stripped from limestone of the Wasatch formation in Bryce Canyon during a heavy storm contains "71.904 pounds of solid matter and 0.0139 pound of matter in solution." For the Winsor formation, calculations based on the rate of deepening of 32 rills showed an annual loss of surface material nearly 2 inches thick over an area of approximately 1 acre. Likewise steep slopes in the Kaiparowits formation and the weakly cemented parts of the Entrada sandstone annually lose 1 to 2 inches of surface debris, and each year exposures of Tropic shale, especially where gypsiferous and carbonaceous, are appreciably worn down. On the Navajo sandstone chalk marks, the impressions of hobnails, and shallow dents made by picks are generally obliterated by each storm. On the Straight Cliffs sandstone pick marks may last a year—two dents half an inch deep on a fine-grained bed showed no appreciable change after 3 years of exposure. Likewise because of its heterogenous make-up, the Dakota (?) sandstone offers only moderate resistance to weathering and stream work. The rocks that decompose most slowly are the thin, dense limestones of the Carmel and Curtis formations, which, except as broken by frost, show little change from year to year, and to a somewhat surprising degree massive gypsum finds its place among the "hard" or resistant rocks.

In general it may be said that on canyon bottoms and on rounded bare surfaces of weakly cemented sandstone erosion is remarkably fast; in canyons cut in alluvium it is spectacular. On canyon walls and cliff faces it is much slower, and on pedestals and similar small erosion remnants it is not noticeable. Though only such terms as "rapid," "moderate," "slow," and "unappreciable" can be applied with assurance as measures, years of observation leave the impression that the rate of denudation in the Paunsaugunt region matches those for the Zion Park region and the San Juan country—rates faster than those in other large areas in the plateau province and in most humid regions. And there seems no reason to doubt that erosion in the present epicycle is as fast or even faster than at any time since the present drainage system was established.

POSITION AND FORM OF VALLEY

In their outstanding features the major stream channels in the Paunsaugunt region follow a common pattern. Their prevailing trends disregard faults and the regional attitude of the strata; their local alinement is controlled in large part by fractures; their form is determined chiefly by the composition and texture of the rocks; and with very few exceptions they are the runways for superposed streams. In the region where the strata in all the formations exposed dip northward and northeastward (in few places eastward) the streams flow southward, southeastward, westward, and northwestward, up the dip. Kanab and Johnson Creeks and their tributaries flow generally southward across the northward-tilted strata of Skutumpah Terrace and go their way across small faults and low anticlines with seeming unconcern.

Tropic Creek, Bryce, Creek, Yellow Creek, Sheep Creek, Willis Creek, Meadow Creek, and other western tributaries to the Paria flow southeastward from the downthrown to the upthrown side of the Paunsaugunt fault without deflection, and the streams that emerge from the Sunset Cliffs have graded their courses up dip slopes and across the Sevier fault. Even the faults of large displacement have so little modified the lines of drainage that a study of streams is of slight value in tracing zones of fracture. The one important exception to this general trend is the course of the East Fork of the Sevier River, which for about 30 miles flows down structural slopes, but even this stream crosses a fault without change in form or direction, and its eastern tributaries flow opposite to the direction of dip.

Obviously the streams so completely out of accord with regional slopes originated on surfaces not now represented in the landscape. On the reasonable assumption that the northward dipping Jurassic, Cretaceous, and Tertiary strata in southern Utah once extended far south of the present rim of the Paunsaugunt Plateau, the ancestral Sevier River, consequent on northward-tilted strata, drained the country now in the drainage basins of the Paria River and Kanab Creek.

Despite structural features that normally would favor the development of great bends, the valleys of the larger streams are generally straight for long stretches. For 90 miles the Kanab Valley, everywhere inclined opposite to the regional dip, varies little from a north-south course, and for nearly 50 miles the Paria Valley, cut across tilted strata, faults, and folds, departs less than 2 miles from a south-southeast course. Likewise in most valleys of intermediate size miles of generally straight courses lie between bends. Many of the smaller valleys are sinuous where they cross flat lands developed on weak rock or alluvium and sharply angular where they flow on interbedded soft and hard rocks. Along most canyons the extent of right and left curvature is surprisingly uniform; the tangents to the larger curves are for long distances nearly parallel. But between these outer limits many of the valley stretches are crooked to an extreme degree, particularly where they traverse thick beds of strongly jointed sandstone. Through the Navajo sandstone the Paria

River, Sheep Creek, Willis Creek, Lick Creek, and other waterways follow angular bends and curves of short radius so closely spaced that views along stream beds are cut off at distances of 100 to 500 feet. As the present streams are engaged chiefly in down cutting, and the transportation of waste and lateral corrosion are thus negligible, the great angular and curved recesses in the outer canyon walls are not matched in size or position by the meanders in the stream below. Some of these meanders, especially those in open valleys, are normal features of stream development, but the close-pressed curves and zigzags followed for considerable distances by scores of perennial, intermittent, and ephemeral streams are discordant features in the regional topography. It is believed that the meandering canyon streams of the Paunsaugunt region developed their courses while flowing on a graded surface which stood above the present canyon rim, and that an uplift enabled them to sink their beds deeply without greatly altering their courses. Their history is thus that recorded by the more prominent entrenched meanders of the San Juan, the Escalante, the Virgin, and the Colorado in Glen Canyon, as elsewhere related in detail. (See Gregory 1917, pp. 126–127; Miser 1925, pp. 67–71; Gregory and Moore 1931, pp. 135–138; Baker 1936, pp. 80–82.)

The inheritance of stream channels from a previous cycle is well illustrated by the behavior of Park Wash. Near its head this stream, after traversing the flat floor of Swallow Park, enters Adair Lake, from which it dives abruptly into a wall of Navajo sandstone and after following a deep canyon for about a mile emerges with equal abruptness onto another area of flat land. (see pl. 4.) Similar remnants of entrenched meanders used by other streams and in places abandoned meanders are traceable on canyon walls. In the Paria below the mouth of Sheep Creek a lone rock island, once part of a projecting spur, marks the position of a cut-off meander bend (fig. 63).

In contrast with the typical valleys whose alinement is discordant with the regional tilt of the strata and with the inclination of ancient erosion surfaces, some valleys for short stretches follow minor faults and groups of joints and most of the abrupt changes of alinement in canyons are in accord with zones of fracture. Particularly on bare surfaces of the Navajo and Straight Cliffs sandstones, of the gypsum in the Curtis formation, and of the limestone in the Carmel formation, the ephemeral streams follow parallel grooves and receive water from other grooves nearly at right angles, and this pattern of trellised drainage channels also appear here and there on shales. The position, form, and size of the alcoves sunk into thick beds of limestone and sandstones and the angular projections and reentrants in the Pink Cliffs and the White Cliffs are determined chiefly by joints. Whiteman Bench, Boat Mountain, and Wilson Peak, on the Paunsaugunt Plateau; No Mans Mesa, White Cone, "the throne" and the "square tower" in the Paria Valley, and other great sculptured blocks owe their individuality to the headward cutting of canyons in the fractured rock that surrounds them. Innumerable small-scale architectural features have the same origin. Joints singly or in groups are characteristic of horizontal and vertical surfaces. In fact, to a large degree the topographic sculpture of the Paunsaugunt region seems to have been predetermined; erosion has been guided by a network of crisscross fractures.

In longitudinal profile the floors of canyons in the Paunsaugunt region are very uneven. Not one of the many perennial, intermittent, and ephemeral streams traversed during surveys is graded throughout its course, and few of them for any considerable distance. Commonly the profile of the streamway is a series of steps of various width, height, and spacing, over which the stream progresses by rapids and waterfalls, separated by stretches of steep or flat gradient. In most valleys the steps are more numerous and higher near their heads and near their mouths, thus making the generalized stream profile a curve, steep at both ends. The branches of the Kanab and the Paria meet their master streams at grade, many of them at grades so flat that in times of flood in the main streams the lower ends of side streams are drowned. But commonly at short distances back from their mouths ramps and steps of bare rock cross their floors. Also near their heads the channels of the larger streams are commonly marked by rock steps, and the stairlike longitudinal profile continues up minor tributaries. Many canyons head in boxlike alcoves, bounded by steeply inclined or vertical walls, into which water from poorly defined hanging valleys on the rim descends as narrow streams and sheets. Boxes also appear along the course of streams where the contact of resistant rock with friable rock is exposed. They are particularly prominent where streams have worn their way through the limestone of the Carmel formation into the Navajo sandstone; the hard Carmel resist erosion, while the much softer Navajo yields. The result is a progressively deepened and widened canyon walled by sandstone into which fall the streams from a flat-floored broad valley above. (See fig. 61.) Where it first reaches the Navajo sandstone the Paria River suddenly drops into a slot about 70 feet deep and 30 feet wide and Willis Creek into a crooked groove half a mile long, 100 to 300 feet deep and 8 to 20 feet wide. In Lick Canyon a similar "box" is but 6 feet wide.

In cross profile the prevailing type of stream channel is a narrow, vertical-walled, flat-bottomed, deep gorge. Many of the wider canyons are also flat-floored and steep-sided, and most valleys in alluvium conform to this pattern.

The form of the canyon walls measures chiefly the relative durability of strongly jointed sandstones, shales, and limestones where, as the result of stream trenching, they are exposed to weathering in a semiarid climate marked by torrential rainfalls and wide range in temperature. The climatic conditions in the present physiographic cycle favor the development of walls steep, regular, and closely spaced in hard rock, less steep and less uniform in soft rocks, and a sequence of cliffs and slopes in alternately hard and soft rocks. Because of the dominance of hard rocks narrow V-shaped valleys and broad open valleys are uncommon. Especially rare are valleys in which the sides continuously bevel the strata upward to clearly defined divides.

The valleys in the Paunsaugunt region are thus representative of a class characteristic of the topography of all southern Utah and northern Arizona. As long ago noted by Powell (1875, pp. 4–5), not only the Colorado and its big tributaries occupy canyons but also "every lateral creek has cut a canyon; every brook runs in a canyon; every rill born of a shower, and born again of a shower, and living only during these showers, has cut for itself a canyon; so that the whole upper portion of the basin of the Colorado is traversed by a labyrinth of deep gorges."

A prominent feature of the valley system in the Paunsaugunt region is the instability of divides between the master drainage basins— the Sevier and the Colorado—and between innumerable tributary basins. The relocation of divides in consequence of stream capture and readjustment of streams to rock exposed by down cutting in newly occupied channels is going on progressively and rapidly. The conditions are substantially duplicates of those in the Zion Park region (Gregory, 1950).

Except on the postmature erosion surface where southward-flowing tributaries of the Kanab meet the northwestward-flowing tributaries of the South Fork of the Sevier along a somewhat indefinite zigzag line, the demarcation between the Colorado and the Sevier drainage systems is the crest of the Pink Cliffs, which form the continuous rim of the Paunsaugunt Plateau. (See fig. 56.) Here the divide is sharply marked. From a belt of generally bare rock, in places as little as 5 feet wide, about half of the run-off goes to the Pacific Ocean by way of the Colorado and the other half to an inland lake by way of the Sevier River. In competition for drainage the streams flowing down the cliffs have an overwhelming advantage. The headwater tributaries to the East Fork of the Sevier River flow on gradients of 5 to 30 feet to the mile; those to the Paria, the Kanab, and the South Fork of the Sevier fall as much as 500 feet to the mile. From a common source at 8,000 feet above sea level the East Fork of the Sevier reaches its mouth at an altitude of 4,400 feet after a traverse of more than 200 miles; the Paria descends an equal amount in about 40 miles. Because of their steep gradients, the southward- and eastward-flowing tributaries to the Paria and the Kanab, rapidly growing in number and efficiency, are able to cut headward with relative rapidity and to add to their drainage basins the headwater valleys of the unfavorably placed northward- and eastward-flowing branches of the Sevier—a procedure in vigorous progress. The eventual capture of the East Fork of the Sevier by the Paria has been anticipated by the construction of the Tropic irrigation ditch. (See p. 18.)

On top of the Paunsaugunt Plateau fully developed valleys terminate abruptly at the crest of the Pink Cliffs and appear as rounded notches in an otherwise continuous wall, hundreds of feet high. Vigorous young southward-flowing streams have worked their way upward into the notches and interlaced their tiny branches with the headwater rills of the older northward-flowing streams. Consequently, from the little-dissected groovelike floors as much as 300 feet wide and bordered by sloping walls 200 to 600 feet high, water flows in opposite directions. These openings in the Pink Cliffs are the "passes" that permit access to the top of the Paunsaugunt Plateau from the lowlands about Swallow Park, Skutumpah, Alton, Hatch, and Hillsdale. For some years wagon roads were maintained through Podunk Pass and Crawford Pass, and some of the passes are still in use as routes for pack trains and for livestock. Seemingly, the pioneer stockmen thought of the passes, the steep valleys that led up to them, and the gently inclined valleys that led downward from them as a continuous valley, regardless of the direction of stream flow. Thus in accord with local usage, Kanab Creek and other streams are shown on maps of the United States Land Office and Forest Service as flowing northward across the plateau top and also southward down the plateau face. On a less conspicuous scale, tributaries to Kanab Creek are competing with tributaries of Johnson Creek, and water once carried by the upper Johnson now flows through Thompson Creek. Likewise Bullrush Creek and the many-branched Bull Creek are encroaching on the drainage basins of Riggs (Podunk) Creek and Willis Creek. On the flat lands and low slopes about Skutum-

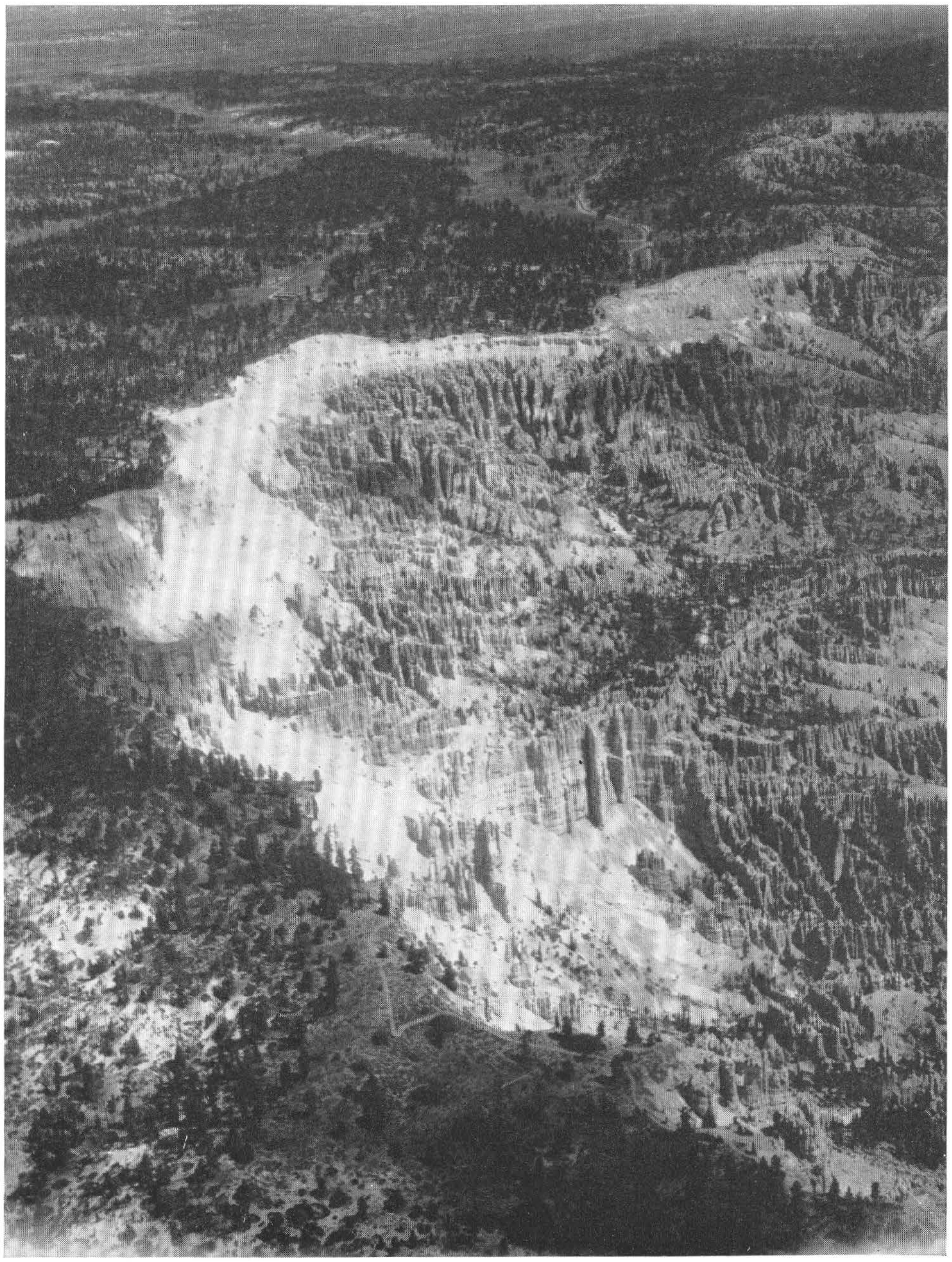

FIGURE 56.—The rim of Paunsaugunt Plateau at head of Bryce Canyon, showing narrow divide between streams (foreground) tributary to Paria and Colorado Rivers and streams that flow northward across Utah (background). Photograph, U. S. Army Air Corps.

pah and the Findley ranch and in the intricately dissected areas bordering Sheep Creek and Yellow Creek the drainage lines are curiously interlaced. Among the low mounds that characterize surfaces of Navajo sandstone, only observation after rainfalls could determine the ultimate goal of flood waters.

The relation of rock hardness to valley form is illustrated by all the stream channels. The Paria Valley, everywhere out of accord with the structure and attitude of the sedimentary strata, is a succession of broad, uneven floors bounded by stepped slopes of moderate inclination, flat floors between precipitous walls, and narrow, deep gorges. Near its head the valley is a broad bowl-shaped structure excavated in soft Cretaceous shales—the Paria Amphitheater (p. 87). For about 10 miles below the town of Tropic it is broad where cut into the friable Winsor formation, in which the flat lands about Cannonville are developed, and relatively narrow in the more resistant Curtis, Entrada, and Carmel formations. At "the box" the generally open valley abruptly changes to a canyon cut deeply into the massive Navajo sandstone and continues between meandering walls as much as 500 feet high. In its relation to type of rocks along its course, the Kanab Valley substantially duplicates the Paria Valley. On the easily eroded Cretaceous rocks at its head lies the broad-floored Alton Amphitheater; farther downstream the valley alternately widens and narrows in accordance with the relative hardness of the strata in the San Rafael group and with obstructions produced by lava flows; and across outcrops of Navajo sandstone capped by limestone of the Carmel formation it is deep, narrow, and straight-sided. The longer valleys tributary to the Paria and the Kanab follows the patterns of their master channels. In their upper courses they are wide or narrow, shallow or deep, straight or meandering, in accord with the varying stratigraphic sequence in the Cretaceous and Upper Jurassic formations; and through the Navajo sandstone they are deep, crooked canyons that head in "boxes," generally too rough-floored and too narrow to permit traverse on horseback. Streams that rise on the western rim of the Paunsaugunt Plateau flow for short distances on steep gradients through deep rock-walled canyons, then abruptly emerging from the face of precipitous cliffs, continue for long distances in shallow, gently inclined valleys across sheets of sand and gravel. The valley of their master streams, the South Fork of the Sevier, is also broad and shallow; its bottom and sides are made of alluvium. (See fig. 49.)

Deer Range Canyon is cut entirely in Navajo sandstone. From a flat floor 20 to 300 feet wide, its intricately jointed, bright-colored, almost vertical sandstone walls rise 800 to 1,200 feet to a cap rock of limestone of the Carmel formation. The generally bare rock floor of the canyon is incised by potholes ("water tanks") 3 to 10 feet across and 2 to 15 feet deep. They are especially numerous in the tributary Tank Canyon, where, during dry seasons, they serve range cattle as watering places.

To a large degree the width and depth of valleys in the Paunsaugunt region record their age, but valley form is so largely the expression of local differences in hardness, thickness, and grouping of stratigraphic units that classifications based on age have meaning only in a broad sense. In terms of the prevalent nomenclature, valleys of youthful form predominate, and next in order are the valleys on the plateau tops and broad erosion surfaces that have reached the stage of late maturity or postmaturity, in places, old age; valleys ordinarily classed as mature are restricted to small areas on the flat-topped highlands. Gradational forms are substantially absent; in a topography as defined by types of streamways, youthful features are in juxaposition with features of old age.

EROSION SURFACES

GENERAL FEATURES

On the Shivwits, Uinkaret, Kanab, and Coconino Plateaus, in the San Juan, Escalante, Paria, Kanab, and the Little Colorado Valleys, and in other parts of the plateau province surfaces of erosion of varied extent and degree of evenness are conspicuous features that derive special interest as records of events in physiographic history. Dutton (1882, pp. 223–224) thought that these surfaces were remnants of a province-wide platform that for many miles on both sides of the Colorado River "was flat and destitute of deep canyons and valleys such as now exist there, and therefore destitute of great hills or buttes or mesas." Dutton inferred that at the time these features were formed the streams of the plateau country had reached a general base level of erosion, where their down cutting substantially ceased, and that power to cut the present canyons was given by a regional uplift.

In line with the conclusions of Dutton, Huntington and Goldthwait (1904, p. 227), outlined an area of "some 20,000 square miles."

In a broad sense the significant generalization of Dutton has withstood the attack of critics and is the basis for the recognition of a precanyon cycle and the canyon cycle—periods of profound regional degradation and aggradation.

In the Colorado drainage basin the extension of lowland plains at the expense of the rugged highlands during late Tertiary time is readily demonstrated, and it is highly probable that favored by intermittent uplift, regional and local, streams of the precanyon cycle developed postmature surfaces at different altitudes and in different positions, but there is good reason to doubt the existence at any time of a "Tertiary peneplain" coextensive with the plateau province. The widely scattered old-age surfaces in Utah and Arizona stand at altitudes between 3,000 and 9,000 feet, and so far as known their positions are not the consequence of tectonic movements. Many of them are undoubtedly local features closely related in origin and preservation to the varying position of drainage lines and to the type of rock exposed.

In the Paunsaugunt region erosion by innumerable close-spaced vigorously youthful streams of the present cycle has left few expanses of land that attained their form in a previous cycle. Areas in which the topography presents features of old age or even of maturity are not prominent. They are remnants of once more extensive surfaces, some of them isolated, others so placed as to permit projection across gorges and around salients in cliffs. On the divides between Kanab Creek

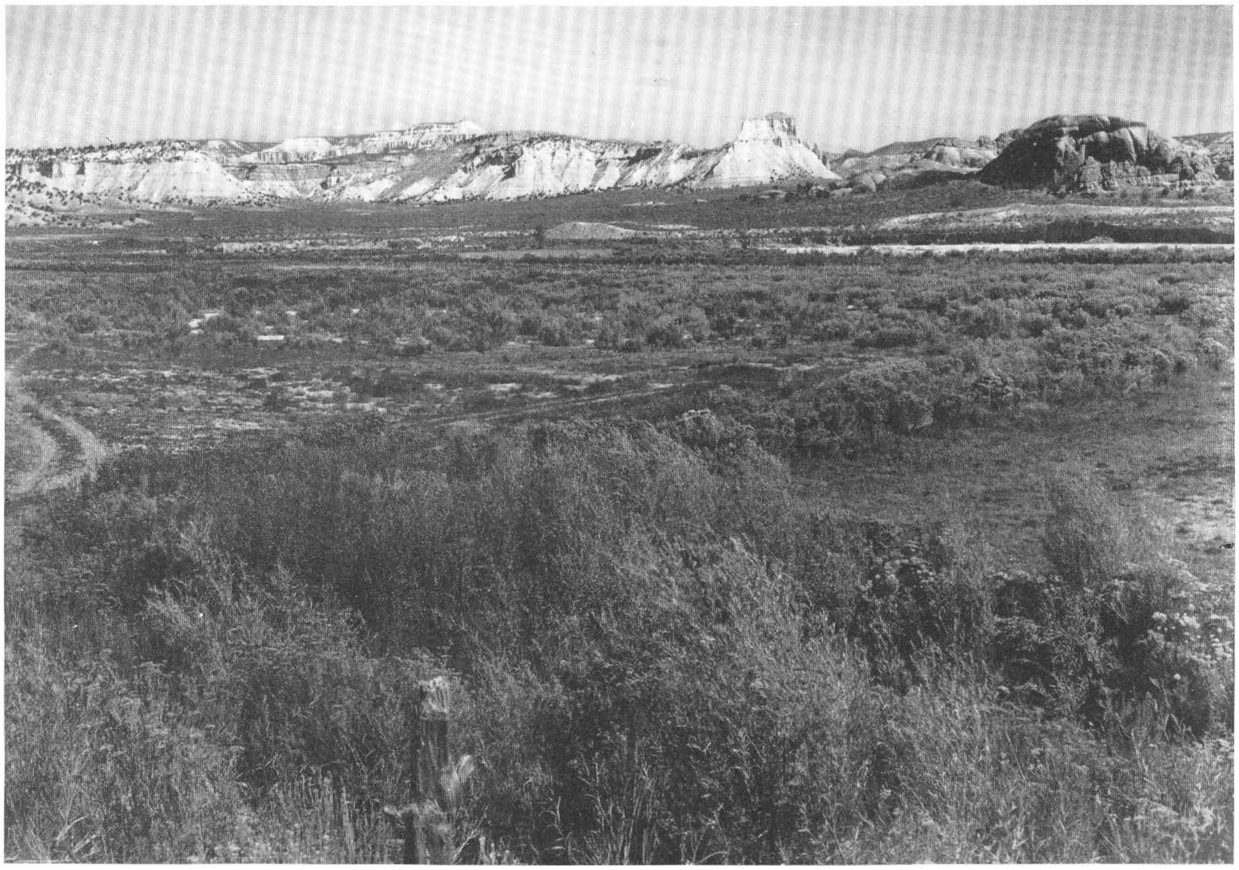

FIGURE 57.—Valley of Paria River (center) south of Cannonville, a broad surface across the tilted edges of Upper Jurassic strata, Winsor formation (lowest white cliffs), and Wasatch formation (sky line).

and the South Fork of the Sevier River, between the head of the Paria and the East Fork of the Sevier River, between Red and Casto Canyons, and in the Paria Valley above the mouth of Yellow Creek (fig. 57), postmature surfaces cover areas of a few square miles, and on the sides and on the top of the Paunsaugunt Plateau and about Cannonville and Skutumpah the restoration of much larger surfaces is possible. Some of these surfaces that antedate the present cycle are developed on hard strata with which they roughly coincide; others bevel the edges of tilted rock. None of the surfaces are even-floored and none are uniformly gentle slopes. Long-continued weathering and corrasion have produced many inequalities—flats on soft rocks, slopes on local dip planes, and ridges on hard rock. The most extensive and least broken of the postmature surfaces that approximately correspond in attitude with the rock strata are those developed on the resistant Carmel formation by the removal of the friable Entrada, Curtis, and Winsor formations and those on the Wasatch formation from which the soft younger Tertiary beds have been stripped. (See pp. 89–101.) Other old-age surfaces, in places covered with stream gravel and talus, are displayed as rock terraces along the Paria, the Kanab, and other streams where their floors coincide substantially with the Dakota (?) sandstone or with the hard strata in the Curtis formation and the Straight Cliffs sandstone. Particularly conspicuous is the old-age surface developed on limestone of the Carmel formation, which crops out widely on the back slopes of the White Cliffs east of Johnson Canyon. Here the surface is so persistently smooth and the canyons that cross it are so narrow and steep-walled that distant views give the impression of an unbroken expanse of bare rock too recently exposed to show the effects of stream work. All these flat or slightly inclined surfaces of rock outlined by cliffs and canyons are essentially base levels to which local ephemeral streams are so adjusted that that water from rains and melting snows flows in poorly defined channels of very slight gradient. Some of the streams that drain them are too weak to move the debris in their beds or the soil on their divides. Most of the surfaces of hard rock doubtless were parts of a regional old-age landscape that is now being cut to pieces by powerfully eroding streams. Obviously under existing conditions these surfaces are long-lived; they can be destroyed only by widening the canyons that surround or cross them.

In addition to those old-age surfaces that substantially parallel the bedding of the harder sedimentary rocks the topography of the Paunsaugunt region presents others that indiscriminately bevel nearly horizontal soft and hard rocks and also the strata displaced by faults and folds. Such surfaces are expressed in the topography about Cannonville and Skutumpah and on the south flanks of the Paunsaugunt Plateau.

CANNONVILLE EROSION SURFACE

In the upper Paria Valley about the little towns of Cannonville, Tropic, and Henrieville an old erosion surface planes rather smoothly across the Jurassic and Cretaceous rocks, generally at a pronounced angle to the bedding. Northeast of Tropic the surface is represented by remnants developed on the soft Tropic shale. Near Cannonville it transects the tilted beds of the Dakota (?) sandstone and Winsor formation and farther south the massive Navajo sandstone. Parts of the erosion surface are minutely dissected by shallow, steep-sided gullies and along the Paria River and its larger tributaries its continuity is broken by broad valleys and canyons exceeding 500 feet in depth, but over considerable areas this ancient graded plain is protected from rapid destruction by a thick coating of stream-borne sand and gravel. As pointed out elsewhere (Gregory and Moore 1931, pp. 133–134, pl. 25) the Cannonville erosion surface slopes southward toward the Colorado River and may be represented by areas of postmature topography at an altitude of about 5,000 feet near the abandoned settlement of Paria. Northward and westward it continues as a slope on the flanks of the Paunsaugunt and Aquarius Plateaus. It is interpreted as a feature developed in the precanyon cycle.

SKUTUMPAH TERRACE

The Skutumpah Terrace, one of the great rock steps that lead from the Colorado River to the crest of the High Plateaus, is a surface of erosion generally well shown in the topography. (See figs. 58, 59.) With little essential variation in form it extends from the crest

FIGURE 58.—Skutumpah Terrace looking eastward across upper Kanab and upper Johnson Valleys. Surface developed on Upper Jurassic strata and Navajo sandstone on crest of White Cliffs (sky line, right).

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of the White Cliffs northward to the foothills of the Paunsaugunt Plateau and from the Sevier fault in Parunuweap Valley eastward to the cliffs along the Paunsaugunt fault. Regionally it is the counterpart of the Kolob Terrace, into which the canyons of the Virgin River are cut. On this broad surface the streams flow in various directions and except for very recent trenching occupy wide valleys of low gradient—valleys that contrast sharply with the steeply inclined canyons that come to this old-age land from the north and with the precipitous channels that trench its southern border. The terrace is exceptional in that its surface in part coincides with the dip of strata in the Carmel formation and in part is the result of low-angle truncation of beds in the Entrada, Curtis, and Winsor formations above the Carmel. Over considerable areas the divides between washes have been planed off; the relief is less than 100 feet and is marked by meadow lands, swales, and ephemeral swamps. In places along their courses across the erosion surface Riggs Creek, Lick Creek, and other meandering streams that head in the Pink Cliffs lose their valleys; their floors widen and flatten to such an extent that even in flood season it is difficult to trace them (See fig. 59.)

The Skutumpah Terrace is the site of ranches and cultivated fields, reached by almost hill-less roads. It provides the only east-west route feasible for wagons through the belt of cliffs and canyons 130 miles wide between the base of the Vermilion Cliffs and the back slopes of the Pink Cliffs.

SLOPES OF PAUNSAUGUNT PLATEAU

Composite profiles drawn on the divides between streams tributary to the Paria River and the Kanab Creek, especially on those that have not been sharpened or much reduced in altitude by recent denudation, serve to outline a broad erosion surface that extends southward from the rim of the Paunsaugunt Plateau. The narrow divides, though locally cut into steps as high as the thickness of individual strata, have a fairly uniform, moderately steep slope in directions opposite to the tilt of their component rocks. The broad interstream spaces show remnants of an anciently graded plain strewn with well-rounded cobbles and boulders obviously not deposited by streams of the present cycle. Observations at many places leave the impression that between Kanab Creek and the Paria River a well-graded, steeply graded, postmature surface of a former cycle is now being dissected by a drainage system in the youthful stage of development. Most of the larger present streams are merely deepening and steepening their ancient courses, but some have abandoned their former runways and are flowing in new channels, steeply inclined and markedly ungraded. In places ancient gravel-filled channels on divides may be traced to the edge of present canyons where they abruptly terminate. Doubtless during the development of the erosion surface on the plateau flanks the plateau top was slowly receding, and it seems possible that in the precanyon cycle the rim cliffs were merely the steepest part of a general steep slope. In any event the dissection of erosion surfaces of a previous cycle

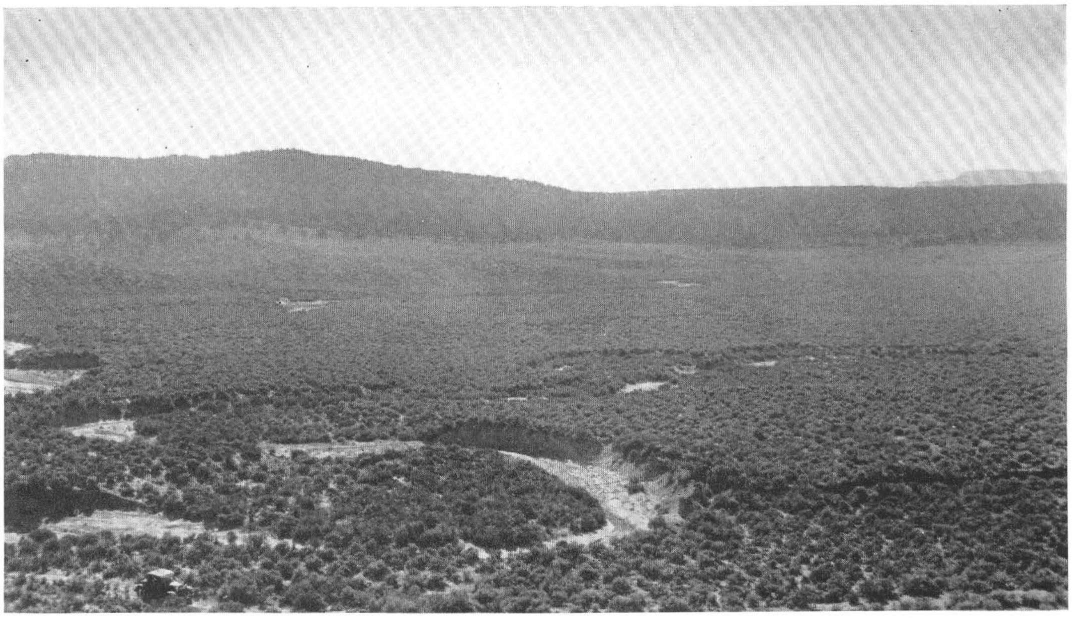

FIGURE 59.—Meandering stream on Skutumpah Terrace.

by the rejuvenated streams of the present epicycle has been accompanied by a sharpening of the cliff profiles and a retreat of the plateau fronts.

ALLUVIAL FILL AND TERRACES

Most of the streams that head in the Paunsaugunt Plateau and carry their waters to the Paria River, the Johnson Creek, Kanab Creek, or the South Fork of the Sevier River flow between walls of alluvium. Typically they occupy a two-storied valley—an inner gorge bounded by walls of alluvium and an outer gorge whose walls are of rock. Streams on the top of the plateau—the East Fork of the Sevier and its tributaries—likewise flow on alluvium but in wide open valleys. These features are considered evidence of three stages of valley history: the original canyons were sunk deeply into rock, then partly filled with alluvium, then again trenched to their present form. (See p. 83.) The alluvial fill is a feature of lowlands and highlands alike—of all places where the pre-fill topography permitted the transport of material by streams. In the valleys it appears as narrow strips between high rock walls and as sheets as much as half a mile wide. On the plateau tops and in the foothills it occupies depressions of various dimensions. Much of the fill, especially that near the heads of such creeks as Willis, Meadow, Tenney, and Proctor, has been little disturbed and in stretches of low gradient along the larger streams remains substantially intact. Thus the valley of the East Fork of the Sevier River for some miles south of Widtsoe is a broad expanse of alluvium. In dry seasons the stream crosses this flat land in shallow meandering channels through swamps and meadows. In wet seasons the area is occupied by the body of muddy water mapped by the Wheeler Survey as "Little Red Lakes." On top of the Paunsaugunt Plateau much of the alluvium deposited in rock depressions remains in place. It is the saturated filling of rock-bottomed and rock-bordered swales—an important source of potable water. For the region as a whole the valley fill is in process of rapid destruction: it is being cut into slices, detached blocks, and broad terraces by streams that have been effective in accordance with their size, their gradient, and the number of violent showers that fall within their drainage basins. In general the terraces are increasing in length by headward erosion and in height by down cutting.

In some places, particularly across wide alluvial flats and near the heads of small branch streams, the two terraces that border a channel are separated by a deep vertical trench narrow enough to be jumped; in other places they are far apart and even may appear as flat-topped embankments pressed against the rocks of opposing canyon walls. Some streams have cut trenches entirely through the valley fill, revealing the rock bottom of the old canyon. In the narrow parts of Sheep, Willis, and some other canyons the fill has been entirely removed, and its former position is shown by the relative freshness of the rock which it once covered. Because down cutting is much more rapid than surface weathering the fronts of most terraces are vertical walls of various dimensions. (See fig. 30.) To climb them is no easy task. As exposed along canyons the terraces consist chiefly of interbedded sand, gravel, clay, and silt that vary widely in thickness, extent, and coarseness. In places they include strings and dislike accumulations of well-worn pebbles and thinly laminated calcareous beds. Lateral overlaps and erosional unconformities are common. Obviously such an arrangement of material is the work of streams of fluctuating volume flowing in valleys of so low gradient as to permit the formation of ponds and swamps.

ALCOVES

A distinctive feature of valley form in the Paunsaugunt landscape is the system of canyons cut into the Pink Cliffs that abruptly terminate the Paunsaugunt Plateau. All along the plateau rim the major streams rise in gorges, slots, and transepts, each with its peculiar alinement, shape, and sculpture; and in scores of tributaries to the Paria and Sevier Rivers and Kanab Creek the spreading headwater branches combine in gouping out amphitheaterlike alcoves, a few hundred feet deep and wide. Though in accord with prevailing usage these rock-walled alcoves are mapped as canyons, they lack the long high sheer walls, the flat floors, the box heads, and the deep angular reentrants characteristic of the canyons in southern Utah. Their floors slope unevenly outward, and their sides are sloping and irregularly concave. Dutton calls them "terraced and rock-walled glens." Some of the great recesses resemble bowls in which for a short space the side has been broken down to permit the escape of its contents. (See fig. 56.)

The alcoves are an outstanding illustration of local erosion. It might naturally be supposed that they had been carved by waters pouring down from the plateau above. But the high lying streams contribute nothing; from the very rim of the plateau they flow in an opposite direction. The sculpturing agents are the snow and the rain that fall directly into the canyon and the frost and atmospheric acids. The transporting agents are intermittent and ephemeral streams of short length.

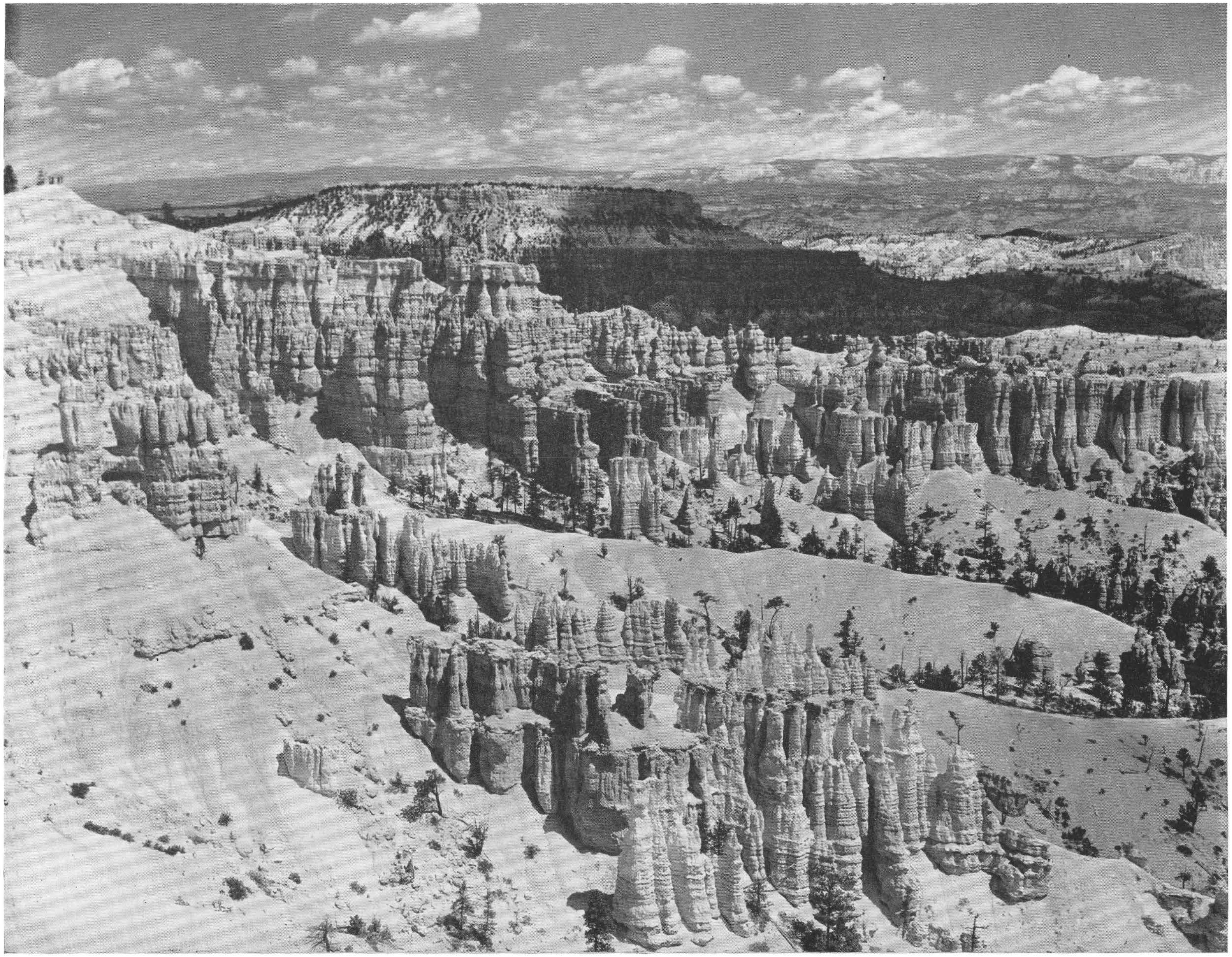

FIGURE 60.—Carving of Wasatch formation in the Pink Cliffs. View looking across head of Campbell Canyon toward Boat Mesa (upper left). Photograph, National Park Service.

From the bottoms of the alcoves cut into the Pink Cliffs rise spires and ridges, and many of them are filled to the brim with literally hundreds of towers, needles, cathedrals, narrow mesas, and myriads of fantastic figures that stand alone or are grouped about buttresses of the enclosing walls, which themselves are decorated with windows and niches of many shapes. Every erosional feature possible to make in rocks of this kind seems to be represented by innumerable examples. (See fig. 60.)

In the forestlike array of erosional forms, individual components at first go unnoticed; they seem to be lost in the amazing landscapes. Yet their wealth in numbers is matched by richness of architectural form. Some pinnacles are ribbed and fluted so symmetrically as to seem to be the work of powerful lathes; some are rounded like huge stalagmites, others are nearly square; some rise from the canyon floor, but most have been carved in the sides or at the top of the walls; some are isolated, others are grouped in companies; some terminate as flat caps; some form domes, others extend upward as spires and minarets. Some of the larger towers are bordered by sheer walls, but commonly they are horizontally grooved and decorated with bosses and statues.

Like the form, the color of the architecture ranges widely. The top beds are white, gray, or cream-colored; those below are dominantly red of various shades, grading into delicate pink and orange, more rarely into yellow, pale lemon, purple, or brown. Intergrading and strongly contrasted interbanding are common, and in places one color is thinly overlaid by another. The color changes tone with passing clouds, with the direction of illumination at sunrise, sunset, and noonday, and when wet by infrequent showers. Days of wandering in the canyons and along their rims give the impression that in the morning when sunlight strikes directly against the walls the mass tone is orange and yellow, at noon grades into pink, and in the shadows of sunset is an inspiring display of delicate reflected lights. In moonlight the coloring of the wierd "ruined cities" is fascinating.

LANDSLIDES

In the Paunsaugunt region the conditions favorable for the production of landslides are generally lacking. In few places do thick accumulations of talus, long sliding surfaces, and persistent ground water appear in combination. Except immediately at the base of walls made of lava, of thick limestones, and of single beds of sandstone, talus covers little ground, and even in these situations much of it is displayed as ribbons, detached piles, and scattered boulders that rest on bare rock. Very few continuous bands of talus mark lines of feasible ascent of the lofty cliffs. Commonly the water that falls on the slopes from light rains and melting snows and sheet floods disappears before the surface rocks are saturated, and the water from torrential showers sweeps from the ledges all but the coarsest debris. The fresh, sharp, angular profiles of mesas, ridges, and canyon walls and the extensive areas of bare rock indicate clearly the prompt removal of weathered and disintegrated rock.

WINDOWS AND ARCHES

In addition to the pinnacles, columns, and bizarre forms that decorate the alcoves in the Pink Cliffs, the architectural features displayed in the Paunsaugunt region include windows, "sky holes," incomplete arches on canyon walls, and natural bridges that span ephemeral streams. For making these erosion forms the composition and bedding of the Cretaceous and Upper Jurassic formations are generally unfavorable; of the Wasatch formation and the Navajo sandstone, favorable. In the Wasatch formation the walls made of dense, nearly pure limestone are decorated by small pits and broad shallow recesses that mark the position of relatively friable rock that has crumbled in response to atmospheric weathering, locally aided by ground-water seepage. A decrease in the purity of the limestone or the replacement of limestone by sandstone is accompanied by an increase in the number and size of cavities, and where beds of weakly cemented sandstone lie between beds of resistant limestone their exposed edges are worn backward and on cliffs are represented by detached angular openings or continuous grooves. In constructing the "Cliff Caves" at the head of Bryce Canyon, water entering through cracks in the overlying limestone made its way along porous sandstone beds and so completely dissolved the lime cement about the quartz grains that the rock crumbles to sand, easily removed. On some of the narrow vertical limestone walls that separate deep gorges weathering guided by differences in rock hardness has produced cavelike indentations—"bore holes" and "cliff pockets"—most of them shallow and irregular in form. In places erosion directed inward from opposite surfaces and along a common axis has perforated the walls, thus producing such attractive structures as the famous Wall of Windows and the high-perched "sky holes" in Bryce Canyon. At the heads of Bridge Canyon and Agua Canyon differential erosion within the Wasatch formation, aided by ground-water seepage through meander spurs, has developed natural bridges (see fig. 61) of small dimensions.

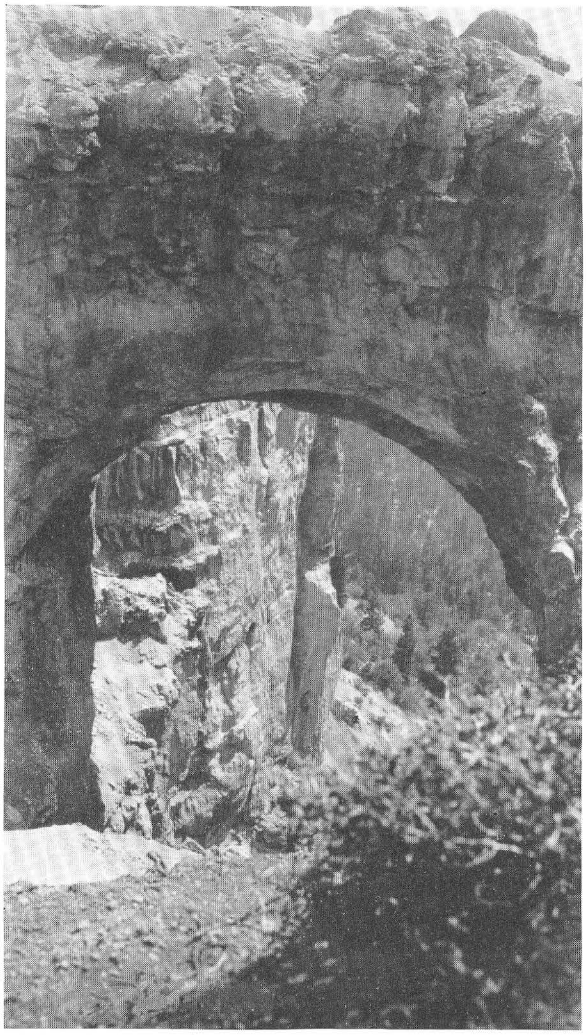

FIGURE 61.—Natural bridge developed in limestone of Wasatch formation at head of Bridge Canyon. Photograph by C. C. Presnall.

The arches, windows, and similar erosion forms that add scenic interest to the Wasatch formation are even more fully developed in the Navajo sandstone. Though in the Paunsaugunt region exposures of the Navajo include no huge natural bridges or broadly expanding arches and few conspicuous windows, they display the rough carvings and delicate tracery that characterize this great bed of rock everywhere in the plateau country. The composition and texture of the sandstone, its curved and tangetial cross-bedding, and its intricate jointing combine in facilitating the production of rounded recesses, flat arches, steep arches, domes, circular indentations, cliff caves with bowlike roofs, cups, "owl holes," and niches (figs. 62, 63). In this sculpture of canyon walls, curved surfaces in both horizontal and vertical directions dominate, almost to the exclusion of angular forms.

ALLUVIAL FANS

In the valleys of the major streams and in some of their tributaries alluvial fans lie at the base of cliffs and spread thinly outward to a junction with the valley fill. Most of them cover small areas, obtain no great depth, and are steeply inclined. However, the nearly flat floor of the East Fork of the Sevier River just north of the Bryce Canyon National Park is generally bordered by fans of very low slope, and extending outward from the Sunset Cliffs to the South Fork of the Sevier a composite fan covers about 50 square miles (fig. 49). This South Fork fan is of special interest in that it is a broad plain of deposition in a region where most large areas of flat land are either stripped surfaces of resistant strata or erosion surfaces inherited from a previous physiographic cycle.

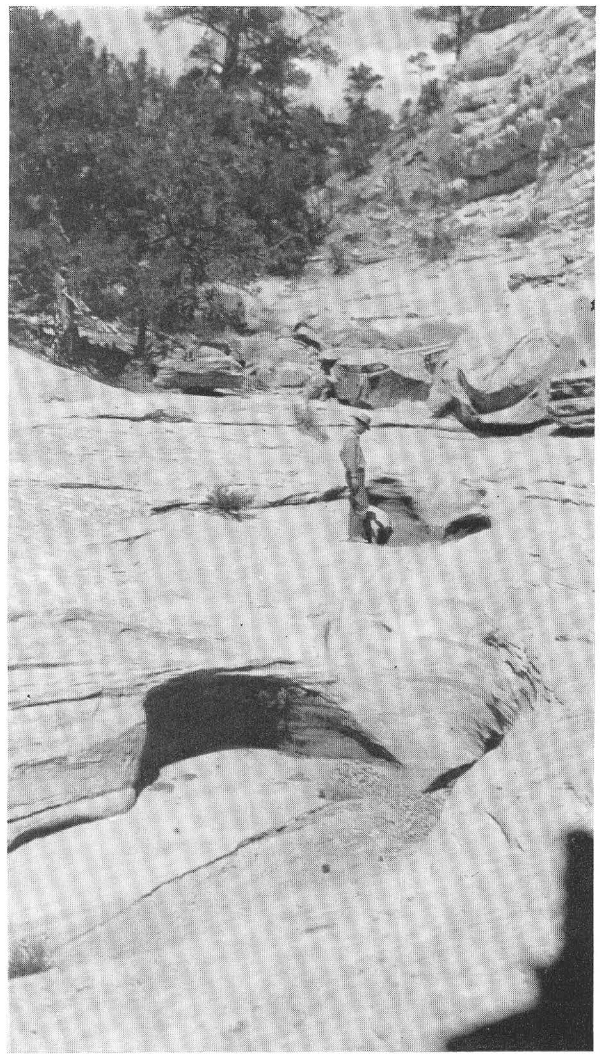

FIGURE 62.—Pothole in Navajo sandstone on floor of Tank Canyon.

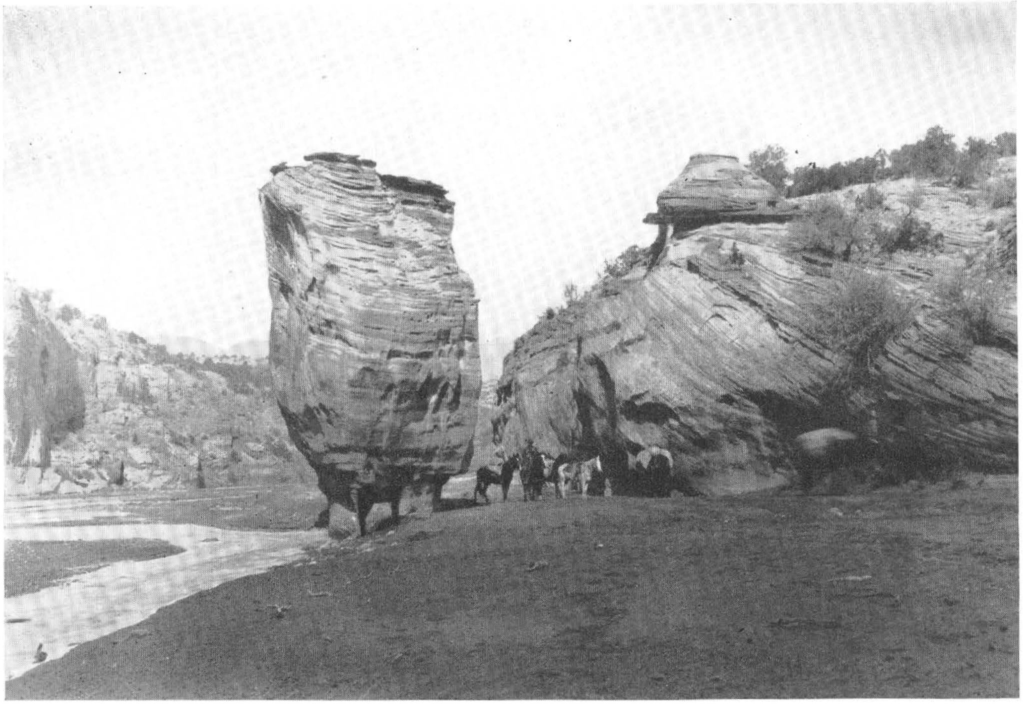

FIGURE 63.—Remnant of Navajo sandstone cut from an ancient meander spur in Paria Canyon.

In the Paunsaugunt region few new fans are now being built, and the long-lived fans are not appreciably growing in thickness or length. In fact, all the fans observed are in process of destruction; some of them have been entirely removed, leaving only bare rock and stranded boulders. Fan building is believed to have been a prominent feature of the aggradation that during the inner-canyon epicycle filled rock-floored canyons with alluvium, built slopes from cliff faces to streamways, and generally reduced the angularity of the landscape that characterized the large parts of the canyon cycle.

ECONOMIC GEOLOGY

Though the rocks about the rim of the Paunsaugunt Plateau are exceptionally well exposed and have been thoroughly prospected, no metalliferous deposits of economic value have been discovered. Metamorphic rocks, pegmatities, and igneous intrusives—usually characteristic features of metalliferous districts—are absent, and the sedimentary rocks are mineralized only to a slight degree. Small amounts of low-grade copper ore appear here and there about abandoned prospect holes in the Navajo sandstone, and a recently worked "mine" near Skutumpah has yielded specimens of malachite, bornite, and chalcocite. Copper, carnotite, and silver are reported from rocks of the San Rafael group, and a petrographic analysis of the Entrada sandstone revealed a tiny fragment of free gold. So far as observed the copper minerals are restricted to short, narrow lenticular areas within which they constitute 0.5 to 3 percent of the grains and locally give a black, green, or yellow tone to the host rock. They appear in the associations made familiar by the published descriptions of scores of similar deposits in Utah, Arizona, Colorado, and New Mexico, and as recently pointed out by Fisher (1937, pp. 906, 949), they present interesting problems of ore genesis rather than of mining.
Survey, as follows:

At the base of the Dakota (?) sandstone in the Paria Valley, deposits of clay (bentonite) in sheets a few inches to 2 feet thick have been mined to a small extent. The material from a mine near Henrieville (Widow No. 1) is described by Clarence S. Ross, of the Geological

The sample from Paria Valley appears to be a bentonite, although the volcanic-ash structure is not well retained. Mr. Nutting has tested its oil-clarification property and found it to be so low that it will probably have no usefulness for that purpose. It is the Wyoming type of swelling bentonite rather than the more normal type. The swelling bentonites (that are sodium-bearing) have only a limited usefulness compared with the other type, and abundant supplies are available in the Wyoming-Dakota region. There is several percent of angular quartz and sodic plagioclase associated with the clay material.

For building, the Tertiary limestones and the Cretaceous sandstones are everywhere abundant, and, particularly in the Sevier Valley, clay is available for making bricks. Gypsum in thick beds is widely exposed, but material for making satisfactory cement is rare. A search for petroleum would involve expensive deep drilling and doubtless would repeat the unsatisfactory results of explorations in the nearby Butler Valley, where a well sunk to a reported depth of 3,840 feet yielded no oil. In addition to the indispensable water the one deposit of economic value is coal, which is a persistent feature of the Cretaceous sandstones and shale.

COAL

OCCURRENCE

Surveys show that nearly everywhere along the base of the Paunsaugunt Plateau coal beds are included in the Cretaceous sedimentary rocks. On the "west fork of the Paria Creek" Gilbert (1875, pp. 159, 297), measured eight beds of coal 4 inches to 4 feet thick, and "near the town of Paria" Howell (1875, p. 297), noted four beds, the thickest 18 inches. Richardson (1909, pp. 398–400), reported coal beds in the Kanab Valley, and Gregory and Moore (1931, pp. 148–153), called attention to the commercial value of the coal deposits of the Kaiparowits region, including the upper Paria Valley.

Coal is a characteristic feature of the Dakota (?) sandstone, the Tropic shale, and the Straight Cliffs sandstone, and earthy lignite is sparsely distributed in the Wahweap sandstone and the Kaiparowits formation. In the Dakota (?) most of the coal beds are too thin, too irregular, and too poor in quality to justify exploitation. Thick coal beds of good quality are restricted to the Tropic and Straight Cliffs formations and it is interesting to note that as sources of commercial coal these formations replace each other in their extension across southern Utah. In the Paria Valley coal in the Tropic has little value; the beds selected for mining are in the Straight Cliffs sandstone, and eastward in this stratigraphic position they become more numerous, thicker, and of better quality. In contrast, from the Paria Valley westward the coal in the Tropic increases in amount and value and that in the Straight Cliffs decreases, until in the Kanab Valley and generally westward all the coal mines are in the Tropic. To the north in the Sunset Cliffs, measured sections of the well-exposed Straight Cliffs sandstone include no coal and but few other carbonaceous beds.

In the vicinity of Alton the coal of commercial value is in the Tropic shale 30 to 100 feet above the Dakota (?)

sandstone, though about a mile south of Alton a bed 4 feet 5 inches thick about 200 feet higher is exposed in an abandoned prospect. Coal of considerable thickness exposed in the upper Johnson Valley apparently thins out eastward. Between the Johnson Valley and Meadow Creek Valley no coal of workable thickness was found. For several miles northeast of this area of relatively barren rocks the Tropic includes carbonaceous shale, lignite, and disconnected beds of coal at two or more horizons, all seemingly of little value.

In the Paria Valley the coal in the Tropic shale, though unsuitable for mining, is conspicuous in the topography: as a dark band above the white sandstones of the Jurassic Winsor formation it follows the indentations of canyons, open valleys, and headlands. Southwest of Cannonville, in sec. 12, T. 38 S., R. 4 W., the lower part of the Tropic shale includes three beds of coal, one about 5 feet thick, in a vertical interval of 98 feet. (See section 3.) On Sheep Creek, in sec. 25, T. 37 S., R. 4 W., corresponding beds consist of bone and shale interstratified with five coal beds, one of them 2 feet thick. This great change in the mass character of the carbonaceous parts of the Tropic within distances of 3 to 4 miles is duplicated on a smaller scale within the coal-bearing units themselves; traced along the strike single coal beds, in places a series of beds, are replaced within a few hundred feet by fossiliferous marine sandstone or by coarse terrestrial sediments entirely free of bituminous materials. Obviously the conditions favorable for the making of coal in the Tropic varied widely in time and in place.

Unlike the coal in the Tropic shale along the base of the Paunsaugunt Plateau, which is of highly varied thickness and somewhat sporadic distribution, the coal in the Straight Cliffs sandstone in the Paria Valley and eastward along the Kaiparowits Plateau in many places is thick enough for profitable mining and continuous enough to justify mapping of four beds that in stratigraphic sections lie 300–310, 460–480, 495–500, and 600 feet above the base of the Straight Cliffs sandstone. The mines and most of the prospect holes about Tropic, also across the Aquarius Plateau at Escalante, and eastward at Warm Creek and Last Chance Creek, are in one or another of these beds. (See Gregory and Moore 1931, p. 151.)

The stratigraphic arrangement of coal beds in the Paunsaugunt region is illustrated by the following sections. Sections in adjoining regions have been published elsewhere. (Lee 1907, pp. 359–375; Richardson 1909, pp. 389–399; Gregory and Moore 1931, pp. 148–153; and Gregory 1950.)

1. *Section of coal at the Alton mine, sec. 19, T. 39 S., R. 5 W.*

[Jacob Sorensen, operator. In the Tropic shale]

	Ft.	in.
Shale and thin sandstone.		
Lignite and carbonaceous shale	8	
Drab clay shale	4	
Gray fossiliferous shale	3	
Coal	17	2
Shale impregnated with iron.		
Total coal	17	2

2. *Section of coal at Bald Knoll mine, in upper Johnson Valley*

[In the Tropic shale]

	Ft.	in.
Brown gypsiferous sandstone	3	
Yellow sandy shale	3	
Carbonaceous shale	4	6
Coal	4	3
Shale, dense, gray		2
Coal	8	
Carbonaceous shale	1	
Coal	5	8
Sandy shale	6	
Coal		3
Sandy shale	7	
Black shale, plant fragments	6	
Coal (a lens)	2	4
Carbonaceous sandstone	1	5
Conglomerate, Dakota (?)		
Total coal	20	6

3. *Section of coal at Johnson prospect, sec. 25, T. 39 S., R. 6 W.*

[Measured by G. B. Richardson in 1907. In the Tropic shale]

	Ft.	in.
Shale, drab.		
Coal	1	6
Bone		3
Coal	1	
Bone		1
Coal		7
Limestone		3
Coal	3	11
Shale, carbonaceous.		
Total coal	7	

4. *Section of coal at mine in Henderson Canyon, sec. 5, T. 36 S., R. 2 W.*

[In Straight Cliffs sandstone]

	Ft.	in.
Shale, carbonaceous, sandy; forms roof of mine.		
Coal, of fair quality	1	5
Shale, carbonaceous		7
Coal, of good quality	1	2
Sandstone, light yellowish brown		5½
Coal, of good quality	3	9
Shale, carbonaceous		7
Bone and thin streaks of coal		6
Coal, of good quality	4	
Total coal	10	4

5. *Section of coal beds in sec. 12, T. 38 S., R. 4 W.*

[In the Tropic shale]

	Ft.	in.
Shale and sandstone.		
Coal	2	
Shale	88	
Coal, including several partings of bone and sandstone	7	
Shale		5
Coal	1	
Shale and coarse sandstone.		
Total coal	10	5

6. *Section of mine about 6 miles east of Tropic in sec. 8, T. 36 S., R. 3 W.*

[Lewis Ray, operator. In Straight Cliffs sandstone]

	Ft.	in.
Sandstone, massive.		
Clay shale.		
Coal	13	8
Sandstone, argillaceous, nodular.		

7. *Partial section of the Straight Cliffs sandstone at the head of Deer Spring Wash*

	Feet
11. Tan shale and thin sandstones	17
10. Drab sandy shale; includes four stringers of carbonaceous shale	10
9. Carbonaceous shale: includes thin lens of coal	2
8. Red and yellow friable sandstone; thin lenses of macerated plants	14
7. Coal, lignite in part	2½
6. Drab shale; abundant plant remains	5
5. Yellow sandstone	3
4. Drab shale	7
3. Coal, of fair quality	3½
2. Drab shale, gypsiferous	12
1. Gray sandstone, compact, resistant	1
Total	77

QUALITY, VALUE, AND USE

The coal exposed to view along the rim of the Paunsaugunt Plateau may be classed as lignite, subbituminous, and bituminous. The lignite is generally an indefinably bounded laminated mass of carbonized shale, macerated plant remains, and lenticular sheets of pure coal too thin for profitable mining. The common subbitminous coal and the rarer bituminous coal form single beds of fairly uniform quality 1 to 6 feet thick, in a few places 7 to 14 feet thick, but most outcrops show two to six thin beds separated by inches or a few feet of carbonaceous materials or sandy shale. The three classes of coal are not regionally segregated; in fact, all of them are present in certain outcrops. In general the coal exposed in mine entries is plainly bedded in series of thin alternately bright and dull layers or in thick, massive dark layers. Much of it is compact, has a fairly bright luster, and is moderately resistant to weathering. Some of it is very hard, has a conchoidal fracture, and remains comparatively fresh and unslacked after exposure for several years in natural outcrops and on mine dumps. The prevalent jointing is roughly columnar but in places is so arranged as prominetly to outline subcubical blocks.

For use in the present report no laboratory analyses have been made of the coal in the belt of Cretaceous rock between the Paria River and Kanab Creek. However, the study of hand specimens and ignition tests in camp fires showed that in number and thickness of beds, in the widely variable composition, and in marked local variations, the coal in this area is comparable to that in the immediately adjoining Kaiparowits region, on the east, and the Zion Park region, on the west, where detailed studies of the physical and chemical properties have been made. They also showed that most of the coal beds in the Tropic shale contain more harmful impurities than those in the Straight Cliffs and that in this respect the Dakota (?) coal is inferior to both. The combined analyses of air-dried coal samples from the Tropic shale and from the Straight Cliffs sandstone, selected as representative, are given in the following table. To them is added the analysis of an interesting bed in the Dakota (?) sandstone.

Analyses of coal samples from southern Utah

	Tropic shale [1]	Straight Cliffs sandstone [2]	Dakota (?) sandstone, Paria River [3]
Moisture	3. 58–16. 64	4. 07–15. 30	6. 20
Volatile matter	33. 91–37. 38	37. 13–41. 23	44. 00
Fixed carbon	38. 90–45. 42	37. 07–50. 20	44. 95
Ash	6. 53–13. 99	4. 25–10. 50	4. 85
Sulfur	1. 25– 6. 82	. 47– . 82	. 87
British thermal units	8, 202–11,120	8, 366–12,190	12, 240

[1] Richardson 1907, p. 397; Gregory 1950. Six samples represented in analyses.
[2] Gregory and Moore 1931, p. 153. Seven samples represented in analyses.
[3] Coal sample collected from "the Dakota (?), sec. 33, T. 42 S, R. 1 W. a 4-foot seam of good coal." Material "as received" analyzed by Curtis and Thompkins, Ltd. Data supplied by Byron Davies, of Cannonville, Utah.

As the analyses show, the Tropic shale yields medium low-grade bituminous coal that on account of its high ash and sulphur content ranks below the coal in most other parts of Utah: users complain of "disagreeable smell" and "iron clinkers." Much of the coal in the Straight Cliffs sandstone is also of relatively low grade, but in the higher grades the moisture, sulfur, and ash are relatively low, the fixed carbon high, and the heating value satisfactory. The best of it ranks in desirability with that extensively mined in Carbon County, Utah, in southeastern Wyoming, and in Colorado. Thus the average proximate analyses of 19 samples of coal from the Wasatch Plateau and Book Cliffs, which supply about 96 percent of the coal mined in Utah, show fixed carbon 44.7 to 60.4 percent, ash 1.4 to 11.13 percent, and heat British thermal units 12,400 to 16,595. This coal is obtained chiefly from the Mesaverde formation, which is equivalent in part to the Straight Cliffs sandstone (Spieker 1931, pp. 64–71, 201–204; Lupton 1916, pp. 31–33).

Coal mining in the Paunsaugunt region is an industry of slight importance. Small local demands and distance from other markets make large-scale operations impracticable. Mining occupies the time of a few men during the winter season, when farms and stock herds need little attention. Since the settlements at the southwest base of the Paunsaugunt Plateau were established, some coal has been obtained from at least 10 outcrops in the Kanab and Sink Valleys, and for several years coal from the Bald Knoll mine, in the Johnson Valley, was carried by truck to Kanab and Fredonia. At present the only coal recovered in this region comes from the Sorensen mine (see sec. 1), an inclined tunnel 130 feet long, 6 feet deep, and 8 feet wide. From this mine about 100 tons of coal was taken in 1939 and readily marketed at Alton.

Of the several mines developed from time to time in the upper Paria Valley only the Ray mine is now operated. In this mine a main drift and branch drifts extend for a distance of about 400 feet along a seam that averages about 13 feet in thickness and consists almost entirely of minutely stratified coal of fairly good quality. In 1939, 400 tons was mined, and the owner estimates that an annual output of 2,000 tons is feasible.

In the Paunsaugunt region coal is used almost exclusively for domestic fuel. Selected parts of it "burn well in the forge," but most blacksmiths use coke or coal from outside sources. The amount mined is ample for the demands at Alton, Tropic, and Cannonville; a little is shipped by truck to Hatch and Panguitch. However, piñon and juniper wood brought in from the surrounding hills and driftwood in the large washes remain the chief local source of fuel, and for use in hotels and Federal establishments in Bryce Canyon National Park coal is imported from Castlegate, Utah.

SURFACE WATER

The top of the Paunsaugunt Plateau and the lands about its base are supplied with surface water ample for livestock but insufficient for large-scale irrigation. The East Fork of the Sevier River is perennial from its source to the Tropic Reservoir, and at times during most years it carries water much farther. Its larger headwater tributaries are likewise perennial, and many of the smaller ones flow for short distances throughout the year. The chief upper tributaries to the Paria River that head in the Paunsaugunt Plateau—Yellow Creek, Sheep Creek, Willis Creek, and Birch Creek—are through-flowing during most years. Farther west the branches of Meadow Creek, Deerspring Creek, Buckskin and tributaries to Johnson and Kanab Creeks are continuously supplied with water. On the west side of the Paunsaugunt Plateau, where they emerge from the Sunset Cliffs, Big Hollow, Proctor, Hillsdale, and Red Creeks are reliable sources of water, and the Sevier River, fed chiefly by its western tributaries (Asay Creek and Mammoth Creek), has an annual flow at Hatch of 94 to 249 second-feet. Below the rim of the plateau from the head of the Paria to the mouth of Red Canyon—a distance of about 60 miles—water is available in no less than 30 tiny streams spaced from half a mile to 3 miles apart. During the floods that follow heavy showers or the melting of snow these streams perennial near their heads, carry large volumes of water throughout their courses. If additional supplies were needed for livestock, water for storge is ample.

The driest lands in the Paunsaugunt region are parts of the Skutumpah Terrace between the Kanab and Johnson Valleys and eastward toward Deer Creek Canyon. Here the drainage channels head in open country, and the rain that falls on the slopes back of the White Cliffs feeds only ephemeral streams. In some years the only water available for stock is in potholes.

As regards irrigation, which is neecssary for most crops in southern Utah, surface water though abundant is so distributed as to be unsatisfactory. For the fields about Tropic and Cannonville the Paria River and its small upper tributaries produce an inadequate supply. For the farms at Tropic water is carried in canals and along canyon floors from an artificial reservoir on the East Fork of the Sevier. From this source the normal annual supply is 12 to 17 second-feet; in some years the yield is as much as 20 second-feet and in some less than 10. At Cannonville water for irrigation comes mainly from seeps in the bed of the Paria River. Ranches along Yellow Creek, Willis Creek, Meadow Creek, Skutumpah Creek, Thompson Creek, and Sink Creek are supplied by short ditches. At Alton a canal about 3 miles long carries about 7 second-feet of water from upper Kanab Creek to conveniently placed reservoirs, and a ditch of smaller capacity heads in a tributary valley. At Hatch an irrigation ditch 7 miles long, from Mammoth Creek, carries an average of 9.62 second-feet (in the spring about 15 second-feet), and another from the Sevier River carries 2 second-feet. Hillsdale is supplied by ditches from the Sevier that yield 4.37 second-feet. The outlying farms in the upper Sevier Valley obtain water from the perennial headwaters of tiny streams that rise in the Sunset Cliffs and along the east base of the Markagunt Plateau.

GROUND WATER

SPRINGS

The Paunsaugunt region is well supplied with perennial springs. In fact most of the scores of tributaries to the Paria, the Johnson, the Kanab, and the Sevier, head in well-defined springs or in swamp lands about seeps. On the steep upper slopes of the Paunsaugunt Plateau most of the water emerges at the base of limestone of the Wasatch formation, at the base of thick porous beds in the Straight Cliffs and Wahweap sandstones, and at the contact of the Dakota (?) sandstone and the Winsor formation. A few springs rise at the Paunsaugunt fault. The smaller springs and some of considerable yield are utilized only as sources of stock water and are frequently used by stockmen as sites for field camps and "holding corrals." Water from many springs is now carried in pipes to villages and farms that in earlier days received their supply from streams and irrigation ditches. For household use at Cannonville 11 gallons a minute comes from a spring in the bank of Paria River, 3 miles distant. Tropic receives about 38 gallons a minute from two springs in Bryce Canyon, and Alton receives about 15 gallons a minute from a pipe 3 miles long that leads from springs west of the village. On top of the Paunsaugunt Plateau springs issue from the lips of alluvium-filled swale-like depressions which are so thoroughly saturated as to form swamps in wet seasons and wet land at all seasons. From sumps sunk into a marshy swale about 7 acres in extent in East Creek, the Utah Parks Co. pumps 90 gallons a minute for Bryce Canyon Lodge and from the same source 35 gallons a minute seeps into the Tropic irrigation canals. Rubey's Inn at the entrance of the park obtains water from a nearby depression filled with saturated gravel. At Panguitch, 1,800 people derive water for household use and garden irrigation from a 10-inch pipe line leading from a group of springs 8 miles distant. This source provides 4.08 cubic feet a second of excellent water.

WELLS

To an extent unusual for southern Utah wells in the Paunsaugunt region are used to supplement the water taken from streams and springs. Hatch obtains its household water from 41 wells sunk 18 to 35 feet into the coarse alluvium that borders the Sevier River. Their estimated average yield of 8 gallons a minute fluctuates but slightly in response to seasonal change in rainfall. The wells are near the Sevier River and the level of the water table is maintained by underground flow from the stream. In situations similar to those at Hatch, Hillsdale has dug 3 wells, each of which yields approximately 6 gallons a minute—sufficient for the population of 22 people. Farther down the Sevier River on ranches near Panguitch 19 wells sunk to depths of 16 to 24 feet yield water amply sufficient for domestic use. In surface wells at Tropic and Cannonville alkali rendered much of the water unfit for household use.

For deep drilling in the hope of obtaining flowing wells the geologic conditions in the Paunsaugunt region are generally unfavorable. Though the regional dip of the alternating pervious and impervious beds is persistent, the exit of water is facilitated by innumerable canyons cut below the usual water-bearing beds. In the Paria Valley the Dakota (?) sandstone, usually a source of water, is above inhabited areas and the common water horizons—the base of the Navajo sandstone and the base of the Shinarump conglomerate—are about 2,000 and 3,000 feet below. Even at these horizons the deep "oil wells" in the nearby Butler Valley encountered little water. Similar conditions prevail all along the south base of the Paunsaugunt Plateau. In the upper Sevier Valley the conditions are more favorable. Here the conglomerate beds of the Wasatch formation and the overlying volcanic sands and agglomerates are porous and, as shown by springs and seeps, contain water. As these beds dip from the high Markagunt Plateau eastward beneath the Sevier Valley to their termination in the Sevier fault deep drilling might result in flowing wells. Round about Panquitch 13 wells drilled to depths of 60 to 90 feet have a listed average yield of 70 gallons a minute. They derive water from coarse alluvium below relatively impermeable layers of clay silt which in turn is the lower limiting bed of the saturated sands from which water in surface wells is obtained. In most of these wells the water rises to within about 16 feet of the surface where it is easily drawn off by pumps.

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