

# GEOLOGY OF PART OF THE PAVANT RANGE, MILLARD COUNTY, UTAH\*

GEORGE B. MAXEY.

**ABSTRACT.** Rocks of Paleozoic, Mesozoic, and Cenozoic age crop out in the Pavant Range in central Utah. Some unrepresented time intervals in the geologic section were periods of emergence, whereas other unrepresented time intervals resulted from removal of rocks by later erosion or burial by younger sediments. Exposed rocks of Paleozoic age are the Tintic quartzite (Lower Cambrian), approximately 3,000 feet thick; a group of limestone and shale beds over 2,200 feet thick, conformably overlying the Tintic, and probably of Cambrian age; and the Kaibab limestone, over 300 feet thick and of Permian age. The Mesozoic era is represented by a sequence of limestone and shale approximately 470 feet thick that is assigned to the Moenkopi formation; 80 feet of pebble-conglomerate and sandstone assigned to the Shinarump conglomerate; and over 2,000 feet of sandstone, tentatively correlated with the Chinle and Navajo formations. Rocks of Cenozoic age fall into two classes: (1) older, well-consolidated and tilted beds of the Wasatch formation of Eocene age and the Sevier River formation of questionable Pliocene age; (2) relatively recent, poorly-consolidated, undeformed alluvial and lacustrine deposits of Pleistocene and questionable Pliocene age that crop out at the base of the mountains and in Pavant Valley. The Wasatch formation ranges from a feather-edge to well over 4,000 feet thick. The total thickness of the Sevier River formation and the younger unconsolidated deposits in the Pavant area are unknown.

Pavant Valley was inundated by Lake Bonneville during the Intermediate Bonneville, and Provo stages, and for a short time following the Provo stage. Evidence indicating a change in the direction of prevailing winds in the Pavant area preceding the Bonneville stage is presented.

A plate composed of rocks of earlier Paleozoic age, was thrust over the Mesozoic and Permian rocks following late Jurassic time and not later than earliest Eocene time. Most of the folds in the area are probably related to the thrusting and in some instances may indicate the direction of movement of the thrust plate. Block-faulting occurred along the front of the range during Tertiary time, and possibly in early Pleistocene time, but no evidence was found of normal faulting since early in the Pleistocene epoch.

## INTRODUCTION.

**D**URING an investigation of the ground-water resources of the southern part of Pavant Valley by the United States Geological Survey in coöperation with the Utah State Engineer, a detailed reconnaissance of the geology of the valley and of the west side of the Pavant Range was made. The ground-water investigation was initiated in November 1942 and

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is in progress at the present time. Prior to the present investigation little geologic work had been done in the area and published reports are limited to the early surveys of Wheeler and Dutton. The material presented in this report is the result of field work done from November 1942 to October 1943.

The writer expresses his appreciation for suggestions and help which he received from P. E. Dennis, geologist in charge of ground water investigations in Utah, and H. E. Gregory of the U. S. Geological Survey. Many thanks are due also to organizations and residents of the area who coöperated in furnishing facilities and facts which speeded the progress of the investigation.

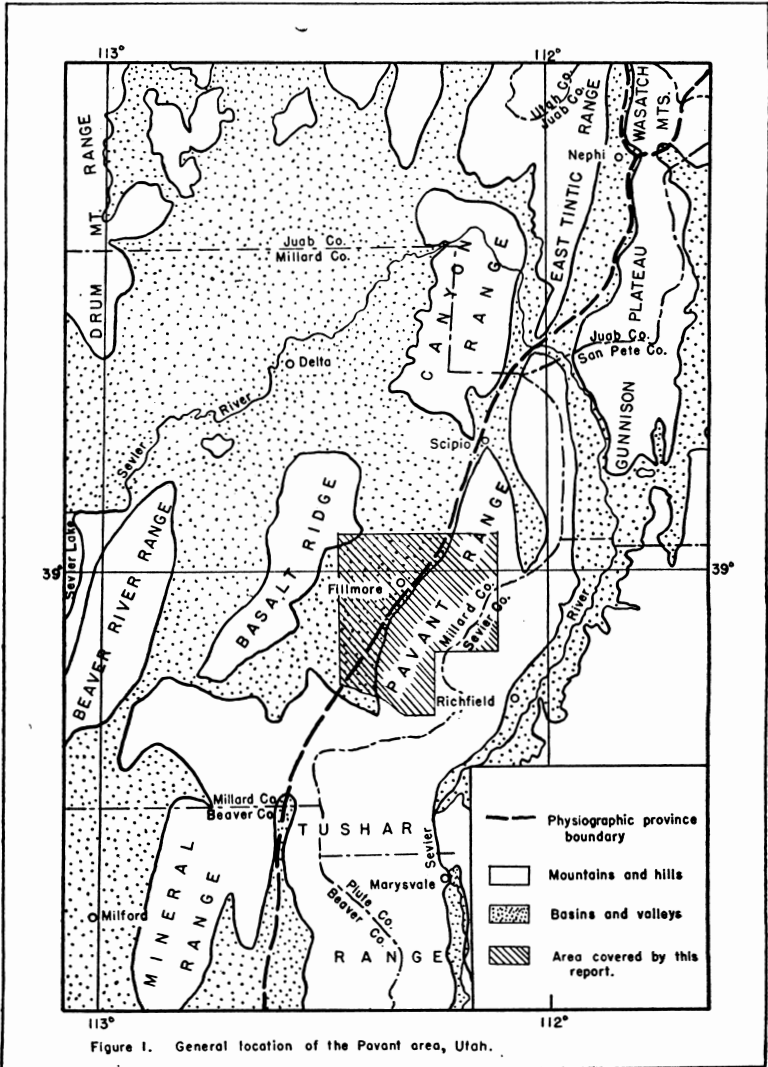
#### GEOGRAPHY AND PHYSIOGRAPHY.

The Pavant Range lies in Millard and Sevier Counties about 150 miles south and 20 miles west of Salt Lake City, Utah. It bounds the southeastern margin of the Sevier Desert in eastern Millard County. According to Fenneman<sup>1</sup> the western base of the Pavant Range is the eastern boundary of the Basin and Range Province and the range has thus been included in the High Plateaus of Utah which lie to the east of it. The Sevier River Valley lies between the Pavant Range and the other plateaus. The southern arm of the Sevier Desert extends westward from the Pavant Range to the Beaver Range which is 30 miles distant. The central part of the southern arm of the Sevier Desert is a low irregular ridge which has been built up in the recent geologic past by a succession of lava flows. This volcanic ridge divides the arm of the Desert into two valleys, the eastern one being Pavant Valley. South of the Pavant Range are the Tushar Mountains which rise to elevations in excess of 10,000 feet. The northern extremity of the Pavant Range is a low pass just south of Scipio. Northwest of this pass are mountains known as the Canyon Range (Fig. 1).

The area covered by this investigation includes the western slopes of the Pavant Range between Corn and Pioneer Creeks and the southern part of Pavant Valley. This area lies between the parallels of latitude 38° 45' N. and 39° 02' N. and the meridians of longitude 112° 10' W. and 112° 28' W.

<sup>1</sup> Fenneman, N. M., and others: 1927, Physical Division of the U. S.: Association American Geographers Annals, 6, 19-98, map.

and includes all of Ts. 21, 22 and 23 S. and portions of Ts. 20 and 24 S., Rs. 3, 4, 4½ and 5W., Salt Lake base and meridian. Fillmore, the largest town in the area, lies on the alluvial slopes at the mouth of Chalk Creek and has a popu-



lation of 1,785 (1940 census). Kanosh and Meadow, the other villages in the area, are at the mouths of Corn Creek and Meadow Creek and have populations of 422 and 526, respectively.

The main perennial streams in the Pavant Range are Chalk Creek, Corn Creek and Meadow Creek. They are small and water from them sinks into the alluvial apron a short distance from the base of the range. There are many intermittent streams; the most important ones are Pioneer, Dry, Pine, Sunset, and Cottonwood Creeks.

## GEOLGY.

### GENERAL RELATIONS.

Sedimentary rocks representing large intervals of Paleozoic, Mesozoic and Tertiary time are present in the mountain areas tributary to Pavant Valley, and both sedimentary and igneous rocks of Tertiary and Quaternary age occur on the alluvial apron and valley floor. No rocks of pre-Cambrian or Cretaceous age are known in the area, and the middle Paleozoic and most of late Paleozoic are unrepresented between Pioneer and Corn Creeks. Some unrepresented time intervals probably were periods of emergence when no sediments were deposited in the area; rocks deposited during the other unrepresented time intervals have been removed by later erosion or buried by younger sediments.

The important structural features include late Mesozoic over-thrusting, Tertiary block faulting of the Basin and Range type which may have continued into early Quaternary time, and minor faulting and folding which were probably synchronous with and immediately related to both the over-thrusting and block faulting.

Early in the course of the investigation the writer found that the areas in which the geology is intimately related to the hydrology are those which are underlain by the geologically recent sediments and those affected by geologically recent structural movements. Geologic formations and structures formed relatively early in the history of the area were subjected only to reconnaissance study, emphasis on detail being reserved, generally, for study of the mountain front, the bajada, and formations and structures in the valley floor.

### STRATIGRAPHY.

#### IGNEOUS ROCKS.

The low, irregular ridge which forms the west side of Pavant Valley is made of late Tertiary and Quaternary basalt

flows. The earliest, or Pavant flow, extends from the southern end of Pavant Valley to Pavant Butte at the northern extremity of the valley and is more than 5 miles wide. The lava beds of the Pavant flow are horizontal, underlie Pleistocene Lake beds and Recent deposits and were extruded probably in late Pliocene or early Pleistocene time.

The Tabernacle flow, approximately 7 miles west of Meadow, covers a relatively small area and overlies the Pavant flow. Lake deposits of Bonneville age do not occur on its surface and the Provo shoreline notches its edge. The evidence indicates, therefore, that it was extruded in late Pleistocene time, probably during the later part of the Bonneville stage or during the Provo stage of Pleistocene Lake Bonneville.

A later small basalt flow, the Ice Springs Craters flow, about 8 miles west of Fillmore, occurred subsequent to the disappearance of Lake Bonneville and probably at a time well into the Recent epoch. It covers a small area on the eastern edge of the Pavant flow.

One small outcrop of rhyolite occurs at White Mountain about 7 miles west of Meadow, Utah. The rhyolite is deeply weathered and eroded and its base is covered by the Pleistocene Lake beds. It is obviously much older than the basalts and may be correlated with the pre-Bonneville alluvial fans which contain numerous rhyolite boulders especially in the area south of Kanosh.

Excellent detailed descriptions of the igneous rocks in the area are included in Gilbert's discussion of Lake Bonneville.<sup>2</sup>

#### SEDIMENTARY ROCKS.

##### *Paleozoic sequence.*

Rocks of Paleozoic age crop out along the eastern and southern margins of the mountainous section of the area. These outcrops contain rocks assigned chiefly to formations of the Cambrian and Permian periods. The Cambrian rocks which occur in the eastern part of the area and possibly also the Permian rocks which crop out in the southern part of the area are contained in one or more thrust sheets which moved eastward over the Mesozoic sediments which now underlie

<sup>2</sup> Gilbert, G. K.: 1890, Lake Bonneville: U. S. Geological Survey Mon. 1, 319-322.

them. The rocks of these thrust sheets are Lower Cambrian quartzites overlain by Middle Cambrian limestones and shale which in turn are overlain by limestones of probable Cambrian age. Unconformably overlying and deposited upon this thrust sheet is the Tertiary Wasatch formation. Thus, the Paleozoic section in the area is limited in thickness and extent by structural conditions, as it is cut off at the base by a thrust fault and covered unconformably at the top by early Tertiary sediments.

The chief exposures of Paleozoic rocks lie high up along the west side of the Pavant Range in the vicinity of Corn Creek and Chalk Creek but near Pioneer Creek they extend to the base of the range front. The outcrop belt is from 1 mile to 4 miles wide and extends from beyond the north boundary of the area south to Corn Creek. Other exposures of Paleozoic rocks including Carboniferous strata occur south and southwest of Kanosh.

#### CAMBRIAN SYSTEM.

##### TINTIC QUARTZITE.

The Tintic quartzite is a thick, white and pink, massive to medium-bedded, fine to coarse-grained metaquartzite, which grades into darker, red and purple, olive-green to dark-green and gray, medium and thin-bedded quartzites interbedded with some olive-green, green, and tan shales at the top of the formation. Throughout the formation are thin layers containing massive to medium beds of pebble and cobble conglomerates. The quartzite beds are characteristically hard and weather to high, light-colored, blocky ledges and cliffs. The shale beds at the top of the formation are usually metamorphosed and hard but there are some fissile beds. Usually the shale beds contain much mica along the parting planes. They weather to slopes and saddles between the underlying quartzite and the overlying limestone beds both of which are characteristic ledge-formers. Much hematite and limonite is disseminated throughout the formation and along the bedding planes. *Scolithus* (worm-borings?), ripple-marks, and cross-bedding are common.

The thickest exposure of the Tintic quartzite in the Pavant Range is on the north-facing slope of the valley of the North Fork of Chalk Creek. It is estimated to be well over 3,000

feet thick and the base is not exposed. The beds of the formation are generally nearly horizontal along the face of the range and for a distance of one-fourth to one-half mile back into the range, but the easternmost exposures near the center of the range dip  $25^{\circ}$  to  $45^{\circ}$  to the east. As the quartzite is the basal formation in the thrust sheet it is usually much shattered, especially along and near the thrust plane; and small flexures and faults within the formation are common. South of Kanosh the Tintic outcrops are chiefly honeycombed masses of fault breccia.

A basal Cambrian formation of quartzite with interbedded shales at the top usually overlain by a fossiliferous shale formation is commonly found in the adjoining Great Basin Province wherever Cambrian rocks crop out.<sup>3</sup>

In areas adjacent to Pavant Valley<sup>4</sup> the Cambrian quartzite is of proven Lower Cambrian age and is called the Tintic quartzite. The limestones occurring above the quartzites in the Pavant Range bear fossils of early Middle Cambrian age. Therefore, the quartzites in the Pavant Range are probably synchronous with the basal Cambrian quartzites found in adjacent regions and they are referred to the Tintic quartzite. Although there are shaly beds at the top of the Tintic quartzite in the Pavant Range they are neither abundant nor well exposed, and do not represent the typical Ophir shale.<sup>3</sup> Shale beds also occur in the limestone overlying the Tintic quartzite and the limestone contains fossils of Ophir age. It is probable that a part of the basal limestone and a part or all of the shale beds in the quartzite are the same age as the Ophir shale.

### CAMBRIAN AND YOUNGER (?) SYSTEMS.

#### UNDIFFERENTIATED LIMESTONES.

An area of limestone varying in width from 300 feet to three-fourths of a mile overlies the Tintic quartzite conform-

<sup>3</sup> Wheeler, H. E.: 1943, Lower and Middle Cambrian Stratigraphy in the Great Basin Area: Geol. Soc. America Bul., 54, No. 12, 1781-1822, Dec. 1.

<sup>4</sup> Lindgren, Waldemar and Loughlin, G. F.: 1919, Geology and Ore Deposits of the Tintic Mining District, Utah: U. S. Geol. Survey Prof. Paper 107, 23.

Eardley, A. J.: 1932, Stratigraphy of the Southern Wasatch Mountains, Utah: Mich. Academy Science, Arts, and Letters, 18, 314.

ably, and forms the upper third of the outcrop belt and thrust sheet of Paleozoic rocks in the Pavant Range. It is overlain unconformably near the crest of the range by the thick Wasatch formation. The maximum exposed thickness of the limestone is estimated to be more than 2,500 feet. In general, the limestones are light to dark-gray, thin to medium-bedded, rarely massive, and compact to medium-crystalline. The lower part of the sequence contains many thin, nodular, fossiliferous beds interbedded with a few layers of tan to olive-green, generally fissile and rarely fossiliferous shales. The upper two-thirds of the formation is composed of dark to medium-gray, medium to massively-bedded, unfossiliferous, uniform limestone interbedded with some dolomitic limestone and dolomite. No evidence of significant breaks in sedimentation were observed in the limestone and the lithologic composition of the total sequence of beds is strikingly similar. The limestone beds are jointed and locally faulted and folded, but generally much less so than the underlying Tintic quartzite. The limestone is conformable with the underlying quartzite and is involved in the same structures. It weathers to ledges and cliffs or to steep block-covered slopes. Most of the beds, particularly the thin ones, contain silty and sandy partings which weather in relief to reddish-tan and light-tan, rough surfaces.

The following detailed section was measured on the north slopes and along the bed of Pioneer Creek Canyon in the northern part of the mapped area where one of the thickest sections of the limestone in the area occurs. The base of the section is in the NE  $\frac{1}{4}$  sec. 3, T. 21 S., R. 3 W., Salt Lake base and meridian, at the contact of the Tintic quartzite and the overlying limestone, approximately 600 feet up the north slope of Pioneer Creek Canyon and one-half mile east of the mouth of Teeple's Canyon. The line of the section runs eastward up to the top of the ridge and down into Pioneer Canyon, thence east along the bed of Pioneer Creek to the contact of the limestone with the overlying Wasatch formation. The section was measured with a steel tape; bearings and the attitude of the beds were determined with a Brunton compass. *Section of the Paleozoic limestones in Pioneer Creek Canyon in secs. 2 and 3. T. 21 S., R. 3 W.*

## Tertiary system

## Eocene series

## Wasatch formation

Conglomerate, red, composed chiefly of quartzite boulders, cobbles, and pebbles cemented with red clay and silt; well-consolidated, massive beds; weathers to high ledges or to steep rough slopes; in unconformable contact with underlying limestones.

## Unconformity

## Cambrian and younger (?) systems

Limestone, thick- to thin-bedded, light- to dark-gray, compact to medium-grained; interbedded with a few thin- to medium-bedded, light- to medium-gray dolomitic limestone and dolomite layers. The lower part of the formation contains many thin beds of medium- to coarse-grained oolitic limestone, also some cherty beds. Where thin-bedded the limestone beds are argillaceous and separated by shaly partings. The limestone weathers to prominent ledges and steep, block-covered slopes, and where surfaces of outcrops are weathered they are rough with many small projections due to differential weathering of pure limestone and limestone with concentrations of silt and clay. No fossils were found in this unit. Thickness . . . . . 1870 feet

Shale, olive-tan, lumpy, calcareous with many argillaceous, fine-grained, lenticular, dark-gray limestone lenses which are fossiliferous. Weathers to poorly-exposed slopes and low yellowish-gray outcrops. Only fossils observed were unidentifiable fragments of brachiopods.

Thickness . . . . . 65 feet

Limestone, thin-bedded, dark-gray, fine-grained to compact; interbedded at top of unit with massive to medium-bedded, unevenly bedded, fine-grained limestone. Weathers to light- and dark-gray banded outcrops and relatively gentle plate-covered slopes. Unfossiliferous.

Thickness . . . . . 115 feet

Limestone, thin- to medium-bedded, medium- to dark-gray, fine-grained nodular, fossiliferous, with many shaly partings; interbedded with oolitic, medium-bedded, fine- to medium-grained, gray limestone and 5-foot to 10-foot-thick layers of olive-green fissile shale and thin-bedded, fine-grained, yellowish-green argillaceous sandstone. Layers of shale at base, near center and near top of unit. Nodular

beds are partly or wholly composed of *Girvanella* ? algae, and all beds are flecked with limonitic shaly spots and partings. Unit weathers to low blocky ledges and poor exposures on steep slopes. Fossil locality 26 near center of unit.

Thickness ..... 95 feet

Limestone, massive, light-gray, compact, flecked with yellowish-tan limonite; weathers to low ledges on steep, block-covered slopes.

Thickness ..... 40 feet

Dolomitic limestone, thin- to medium-bedded, medium-crystalline, sandy; weathers to tannish-gray, low ledges on steep slopes; interbedded with 2-foot to 5-foot layers of fissile, olive-green shale.

Thickness ..... 25 feet

Total thickness of undifferentiated limestones .. 2210 feet

### Cambrian system

#### Tintic quartzite

Quartzite, medium-bedded, dark-green and brown, fine- to medium-grained, interbedded with 5-foot to 20-foot layers of olive-green fissile shale and very fine-grained sandstones. Thickness not measured.

This section is typical of the Paleozoic limestones in the area between Pioneer and Corn Creeks. In the fossiliferous layers near the bottom of the section fossils were collected at other localities, namely at locality 77a approximately 6 miles east of Kanosh on the pass between the head of Monk's Spring Wash and Leavitt Creek in the northwest  $\frac{1}{4}$  of sec. 3, T. 24 S., R. 4 $\frac{1}{2}$  W.; at locality 74, about 7 miles east of Kanosh on the saddle between the head of Cottonwood Creek and the head of the North Fork of Corn Creek; and locality 63, approximately 6 $\frac{1}{2}$  miles east of Fillmore on the west slope of Blue Ridge east of Reece's Canyon and north of the canyon of the North Fork of Chalk Creek.

Field identification of fossils demonstrates that the lower 325 feet of limestone were deposited during the early part of the Middle Cambrian epoch. This fact coupled with the absence of a stratigraphic break in the limestone section indicates the probable lower Paleozoic, if not Cambrian, age of the entire thickness of limestone. Limestones of later Paleozoic age occur in the area south of Kanosh and in the Canyon Range to the north.

## PERMIAN SYSTEM.

## KAIBAB LIMESTONE.

Limestone forms a considerable part of the small, low-lying foothills at the base of the Pavant Range southward from the mouth of Meadow Creek. These beds form the western, or overlying, and overturned limb of a prominent drag fold probably developed by west to east movement of the Pavant overthrust, (p. 328). No beds overlie the limestone in this area except scattered patches of Cambrian quartzite and limestone which are remnants of the overthrust sheet. Beds of younger formations underlie the limestone because it is part of an overturned fold. The limestone is light- to dark-gray, fine to medium-crystalline, generally medium- to thin-bedded, and most of the beds contain much chert. The highest beds are fossiliferous. The fossils have not yet been identified, but field examination suggests a probable Kaibab age.

The limestone was found to be over 300 feet thick. It weathers characteristically to low, blocky dark-gray and brown-streaked ledges. The brown streaks are desert varnish which forms on the surface of numerous chert layers. Generally the Kaibab limestone forms prominent hills and ledges which stand high topographically above the stratigraphically conformable shale and limestone beds of triassic age.

*Mesozoic Sequence.*

Rocks of Mesozoic age crop out in a broad belt along the lower western slopes of the Pavant Range and in a few small patches and strips in the foothills at the west base of the range. The outcrop area extends southward beyond Corn Creek from the mouth of Pioneer Creek. North of Corn Creek the Mesozoic rocks pass under the Pavant overthrust sheet, whereas south of Corn Creek they are partially overlain unconformably by the Wasatch formation. Most of the outcrop area of Mesozoic rocks is composed of the massive Navajo sandstone (Jurassic), and a small part of it is made up of Triassic rocks. No outcrops of Cretaceous rocks occur in the area.

## TRIASSIC SYSTEM.

Outcrops of Triassic beds occur only in small patches in the foothills at the west base of the Pavant Range, and in a

few poorly exposed areas in canyons where streams have cut downward through overlying Jurassic sandstones or, where the section is overturned, through the Kaibab limestone. All of the Triassic beds in the foothill area have been overturned and are generally faulted down against the Navajo sandstone. The beds are poorly exposed chiefly because they were deeply buried by Quaternary and Tertiary stream deposits. Also the soft, easily eroded Triassic rocks generally weather to slopes covered by alluvium rather than to well-exposed cliffs and ledges.

*Moenkopi Formation.*

The beds assigned to the Moenkopi formation consist of a basal member of light-gray, finely-crystalline, thin-bedded (rarely medium-bedded), compact, fossiliferous, somewhat argillaceous limestone interbedded with thin layers of gray shale and overlain by maroon, silty and sandy, laminated and thin-bedded shale. The gray limestone is apparently conformable with the upper beds of the Kaibab limestone. Field identification of fossils collected at the top of the cherty beds and from the first twenty feet of the gray limestone suggests that the Permian-Triassic contact lies between these two horizons. It is quite possible that a disconformity exists somewhere within the twenty feet of beds between the fossil horizons but the writer did not observe one in the area north of Corn Creek. The maroon shale is conformable with and overlain by the distinctive Shinarump conglomerate. It was not possible to determine the exact thickness of the formation because no complete section is exposed: however, a close estimate of its minimum thickness is 470 feet. The limestone member commonly is eroded to blocky and platy, poorly exposed slopes which are characteristically light-gray or white. In some places low ledges of the limestone occur. The shale member is eroded to dark-red or reddish-brown, gently-sloping saddles and valleys. A strike-valley is generally formed in the shale, with one side of the valley held up by the limestone and the other held up by the Shinarump conglomerate.

*Shinarump Conglomerate.*

Stratigraphically overlying the maroon shales of the Moenkopi and conformable with them is a light-gray and tan,

medium-grained, thin-bedded to massive sandstone that contains thin beds of granule- and pebble-conglomerate and much petrified wood. The outstanding feature of the conglomerate beds is that most of the pebbles are well-rounded and composed of bright-colored chert and quartzite. Many of the pebbles are bright orange-red, but a few are white and some are dark red or purple. Cross-bedding is common throughout the formation. The sandstone and conglomerate weathers to prominent, ridge-forming, brown-stained ledges and cliffs that generally form one side of the strike-valleys cut in the soft, relatively non-resistant maroon shales of the Moenkopi, and therefore, are well-exposed wherever outcrops occur. Because of its distinctive lithologic character and excellently exposed outcrops, the formation is one of the best stratigraphic markers in the area.

The stratigraphic position and lithology of the sandstone indicate that it is equivalent to the Shinarump conglomerate which crops out in many areas in southern Utah. The Shinarump averages approximately 80 feet in thickness in the Pavant area.

#### TRIASSIC AND JURASSIC SYSTEMS.

The Shinarump conglomerate is everywhere overlain conformably by light- to medium-red, fine- to medium-grained, generally massive (in part thin- to medium-bedded) sandstone with about 100 feet of basal purplish-red and lavender shaly sandstone, shale and variegated beds. Both the red and purple beds are cross-bedded and made up essentially of frosted quartz grains, features which indicate the probable eolian origin of the sand. The outcrop area of this red sandstone extends from the south side of Pioneer Creek to beyond the southern margin of Pavant Valley, a distance of more than 20 miles, and varies from 5 miles to  $\frac{1}{2}$  mile in width. The thickness of the sandstone as measured by aneroid from the top of the Shinarump conglomerate in the bed of Meadow Creek to the top of the divide between Meadow and Walker Creeks is over 2,000 feet.

In general the sandstone is jointed and broken and weathers to steep, usually vertical cliffs and to gentler slopes covered with blocks and ledges of the rock. The beds of the formation are nearly horizontal or have gentle dips. In most of



the area the sandstone is cut off and overlain by the overthrust block of the Pavant fault, the basal beds of which are either Tintic quartzite or early Paleozoic limestone. Elsewhere it is overlain unconformably by the Wasatch formation. Near the overthrust zone and along other fault zones, beds of sandstone have been shattered and altered to hard quartzitic sandstone and, less commonly, to quartzite.

Large, irregular, light-colored blotches occur throughout the thickness and particularly at the top of the formation. These patches vary from about one inch to several hundred feet in diameter. They show no definite relationship to either the bedding or the joint planes, which pass through them from the red sandstone in normal fashion. Because this condition is confined chiefly to the top of the formation adjacent to the thrust zone it is suggested that the blotches may be related in some way to the movement along the thrust zone. The possibility that the blotches may be related in some way to movement of ground water has been suggested.<sup>5</sup> Stratigraphic location, lithology, and the general character of the sandstone beds indicate that they are equivalent to the Chinle and Navajo formations which outcrop extensively in southern and southeastern Utah. It proved more practicable in the field to map the sandstone as a unit, than to attempt to map portions of it as separate units. In general, the sandstone forms a well-defined lithic unit and no fossils were found in any of the beds. However, there is little doubt that the lower part of the sandstone is the time equivalent of the Chinle formation. It is probable that the basal purple beds are equivalent to the Petrified Forest member<sup>6</sup> of the Chinle formation. Lithologic character and stratigraphic position also indicate that most of the red sandstone—certainly more than the upper half of it—is equivalent to the Navajo sandstone.

#### *Cenozoic Sequence.*

In general, the rocks of Cenozoic age in the area, fall into two classes, (1) older, well-consolidated and tilted formations, definitely deformed by earth movements subsequent to their deposition, and (2) relatively recent, poorly consolidated and undeformed beds of gravel, sand, silt, and clay. Most of the

<sup>5</sup> Gregory, H. E.: Personal communication.

<sup>6</sup> Gregory, H. E.: Personal communication.

rocks of the former class crop out in the higher hills surrounded by the alluvial apron and along the crest and east side of the Pavant Range, whereas those in the latter class form the valley fill and the alluvial apron.

#### TERTIARY SYSTEM.

Rocks of Oligocene and Miocene age are unknown in the area. Rocks of Eocene and Pliocene age belong to class (1) mentioned above.

#### EOCENE SERIES.

##### *Wasatch Formation.*

A thick, well-consolidated, well-exposed formation estimated to be over 4,000 feet thick and consisting of interbedded conglomerate, limestone, sandstone, and shale crops out along the crest of, and comprises the eastern slope of the Pavant Range. This formation is markedly unconformable with the underlying Paleozoic limestone and quartzite and the Mesozoic sandstone, and was deposited upon a surface of considerable relief. Only the western margin of the wide outcrop area of the formation is illustrated in Plate 1. The formation extends for many miles to the east and north, and several miles south of the margins of the map.

Observations made during a rapid reconnaissance indicate that the formation consists of two rather distinct parts; namely, a lower group of beds composed chiefly of a sequence of conglomerate, sandstone, and limestone, and an upper group of beds composed chiefly of shale and mudstone but with some interbedded limestone and conglomerate. The shale and clay layers are generally brightly colored. There is much less conglomerate in the upper group of beds than in the lower group. Essentially all of that part of the formation mapped on Plate 1 consists of the lower part of the formation.

The basal beds of the lower part of the formation are red, coarse, reasonably well-consolidated, poorly assorted conglomerate composed of well-rounded, chiefly purple, red, pink and white, predominantly quartzite pebbles, cobbles and boulders, which range in diameter from 1 inch to 10 feet, and which are cemented with a slightly calcareous red matrix of sand, silt, and clay. The conglomerate crops out in the bottoms of and well up on the slopes of the present main creek channels where it is as much as 300 feet thick but it is absent

or very thin on the higher slopes and peaks of the range. Thus the elevation of the base of the conglomerate in the canyons is as much as 2,000 feet lower than the corresponding base of the Wasatch formation on the ridges, indicating that the basal part of the Wasatch formation was deposited on a surface of high relief. That the difference in elevation is not a result of deformation is indicated by the uniform dip of the Wasatch strata at an angle of about  $15^{\circ}$  to the east. Overlying the Paleozoic and Mesozoic rocks and unconformably on the ridges and overlying the basal conglomerates conformably in the canyons, are beds of red and purplish-red, calcareous sandstone interbedded with thin layers of pebbly conglomerate, light-tan, white, and yellowish-white, medium-grained sandstones and sandy and algal limestones. Upward in the section this sequence is repeated several times. The various layers—conglomerate, red sandstone, algal limestone, and white sandstone and limestone—vary in thickness from an estimated 5 feet to 400 feet. The limestone is usually in thin layers and the conglomerate in thick layers. In general, the conglomerates and sandstones are medium-bedded to massive whereas the limestones are unevenly and thinly bedded. The lower part of the formation tends to weather to smooth, gentle to steep slopes with occasional ledges and cliffs of conglomerate and limestone. In some places, particularly on the slopes of the main stream channels where the basal conglomerate beds crop out, high, extremely rough ledges and steep slopes littered with rubble composed of fragments of the conglomerate are common. These rough slopes and ledges have prompted the residents of the area to call the formation "hardscrabble."

The upper part of the formation is composed of beds of sandstone, limestone, and some granule- to pebble-conglomerate interbedded and intercalated with much bright-red, pink, yellow, white, and tan, poorly consolidated shale and clay. The sandstone and limestone beds are similar to those included in the lower part of the formation, whereas the conglomerate is generally finer-grained, thinner-bedded, and usually not so highly colored as the lower conglomerates. Most of the beds of the upper part of the formation are poorly consolidated, non-resistant, and rapidly eroded, whereas certain beds are relatively very resistant and form cap rocks. Where streams undercut these cap rocks, high vertical cliffs and peaks are produced—colorful and picturesque topographic features

differing greatly from the slopes and the undulating surfaces produced by erosion on the lower part of the formation.

The formation dips  $15^{\circ}$  east and strikes about N.  $10^{\circ}$  E. Other than this gentle eastward tilt and minor jointing, the formation is undeformed.

The lithologic composition, position, and general character of the beds indicate that they belong to the Wasatch formation which caps the Gunnison Plateau to the north and east. Studies of the Wasatch formation in various areas on these plateaus and elsewhere in Utah indicate that it is of Eocene age. Basal beds previously referred to the Wasatch have been demonstrated to be Cretaceous by Spieker and others.<sup>7</sup> No fossils were found in the basal beds and the nature of the investigation precluded further study of the formation. Therefore, because the formation is a mappable lithologic unit, having distinctive lithology and general character, and because some of its beds are continuous with beds of the Wasatch formation where it has been studied in detail, the formation is assigned to the Wasatch and is considered to have been deposited during Eocene time with the exception of the basal beds which may possibly be of late Cretaceous age.

#### TERTIARY OR QUATERNARY SYSTEM.

##### PLIOCENE OR PLEISTOCENE SERIES.

##### *Sevier River Formation.*

Fanglomerate composed of poorly assorted pebbles, cobbles, and boulders, which range in diameter from  $\frac{1}{2}$  inch to 4 feet and which are cemented with pink and reddish-orange sand, silt, and clay, with some calcareous material, crop out near the front of the Pavant Range in the beds of the main creeks and in scattered hills which stand above the general level of the alluvial apron. Most of the material of which the fanglomerate is composed is angular, and is derived from formations which are Cambrian to Eocene in age. Particularly conspicuous and of great value in age identification are numerous conglomeratic boulders from the Wasatch that range up to several feet in diameter. There are also occasional fragments of middle (?) Tertiary volcanic rocks. Conformably overlying

<sup>7</sup> Spieker, E. M.: Late Mesozoic and Early Cenozoic History of Central Utah: U. S. Geol. Survey Prof. Paper (In Preparation).

Schoff, S. L.: 1938, Geology of Cedar Hills, Utah: Doctor's Dissertations, Ohio State University.

the fanglomerate is a light-gray to white volcanic ash layer which contains fragments of flow rock. Conformably underlying the fanglomerate are beds of poorly-consolidated, reddish-brown, red, and tan, coarse to fine-grained, thin to medium-bedded sandstone containing much argillaceous material. All of the beds have been broken and tilted and dip toward the east about  $35^\circ$  and strike N.  $45^\circ$  W. The beds are everywhere unconformable with the older Paleozoic and Mesozoic formations and also with the later undeformed Pleistocene gravels of which the alluvial apron is composed.

The fanglomerate weathers to smooth reddish-orange slopes, but steep rough slopes where it has been undercut by streams, providing well-exposed outcrops, are numerous. The underlying sandstone beds are poorly-exposed and crop out at only one place in the area, on the slopes of Chalk Creek Canyon about 2 miles east of Fillmore, Utah. They weather to smooth slopes which are generally red or orange, spotted with white. The overlying volcanic ash member is also not resistant and forms smooth slopes, generally light-gray or white.

Beds similar to this formation crop out along the west flank of the Canyon Range, from about one mile south of Oak City, Utah, to the south end of the range which is about 15 miles north of the northernmost outcrops of the formation in southern Pavant Valley. Similar deposits also occur south of the area in Clear Creek Canyon and east of the area in the Sevier River Valley where they occupy the lower basins and valleys. In all localities they have been tilted and faulted and are well-consolidated relative to the fan deposits which are deposited over and around them, yet generally not so well consolidated as the older Wasatch deposits. Studies have been made of the deposits in the Sevier River Valley and Clear Creek Canyon where they are called the Sevier River formation and, on the basis of fossils found in them, have been tentatively assigned to the late Pliocene or early Pleistocene.<sup>8</sup>

#### QUATERNARY SYSTEM.

Outcrops of rocks of Quaternary age in Pavant Valley are confined, with few exceptions, to the alluvial apron and the valley. They consist of gravel, sand, marl, and clay deposits

<sup>8</sup> Callaghan, Eugene: 1938, Preliminary Report on the Alunite Deposits of the Marysvale Region, Utah: U. S. Geol. Survey Bull. 886-D, 100-101.

which are occasionally cemented by caliche, generally near the land surface. The Quaternary beds are generally horizontal or dip gently to the west.

PLEISTOCENE SERIES.

*Alluvial Fan Deposits.*

The alluvial apron at the base of the Pavant Range is deposited around hills of the Sevier River formation. The rocks of the Sevier River formation dip approximately  $30^{\circ}$  to the east whereas gravels comprising the alluvial apron dip from  $5^{\circ}$  to  $10^{\circ}$  to the northwest and west. The apron is cut by the Bonneville Lake shoreline at an elevation of 5,130 feet above sea level.

The materials of which the alluvial apron are composed are poorly assorted boulders, cobbles, pebbles, and sand, silt, and clay. In general the finer materials form a poor cementing medium. In some localities one or more layers of caliche are present within 20 feet of the surface, and where this condition obtains the gravels are well-consolidated and hard. All of the constituents of the apron materials are poorly-rounded or sub-angular.

The alluvial apron is being dissected by present streams and the surface is cut by many washes, the depth of the cut depending on the size of the drainage area of the wash. The main creeks have cut canyons over 200 feet deep and together with their tributaries have stripped off later gravels exposing the Sevier River formation and older formations in many places along the mountain front. Temporary deposition of Recent alluvium is common along the beds of the washes and creeks, but large deposits of material deposited in the Recent epoch are not present on the alluvial apron. The age of the gravel is definitely fixed as pre-Bonneville because it is cut by the Lake Bonneville shorelines. It could not have been deposited earlier than late Pliocene or early Pleistocene because it lies unconformably upon deformed beds of the Sevier River formation. That the gravel beds extend westward into the valley, inter-finger with the finer well-assorted deposits of the Pleistocene lakes, and are overlain by the deposits of Lake Bonneville is demonstrated by logs of wells in Pavant Valley as well as by exposures of the gravel beds underlying the lake sediments in

natural and artificial excavations in the valley. This indicates that the gravels and the Pleistocene lake beds are, at least in part, synchronous deposits. On the west side of the valley, it seems quite possible that sand and fine gravel layers of the fan deposits may terminate at their contact with the Pavant flow rather than underlie it, and that they underlie the Ice Springs Craters and Tabernacle flows.

#### *Pre-Bonneville Lake Beds.*

Although there are no known outcrops of pre-Bonneville lake deposits in the area, sediments which have unquestionable lacustrine features and are older than Lake Bonneville sediments have been encountered in wells which have been drilled in Pavant Valley. These sediments interfingered with the early Pleistocene gravels and underlie sediments which have been identified as Bonneville. From actual outcrops and from well logs it was determined that the base of the Bonneville lake deposits is approximately 15 feet below the surface along a line which runs approximately north and south of Flowell Corner. Farther out in the valley one-half mile east of the east side of the lava flows the base of the Bonneville sediments is approximately 14 feet below the ground surface. The deepest well that has been drilled in the area, reported to be over 400 feet deep, encountered no change in sedimentation other than the usual interbedded lacustrine sediments and alluvial gravels which occur from the surface to unexplored depths. Thus, lacustrine and alluvial sediments of pre-Bonneville age have a known thickness of more than 400 feet.

The lacustrine sediments consist of interbedded, generally well-sorted fine sands and clay which are generally buff and light-gray colored. Some layers of the clay are black, very heavy and sticky when wet, and have a rotten-egg odor. In general the clay beds are thick in relation to the interbedded gravels, the later being from one-half foot to, infrequently, 20 feet thick, whereas the clay beds are five feet to over 200 feet thick. Because the lacustrine sediments are interbedded with the westernmost extremities of the Pleistocene gravels, and they are overlain by lacustrine beds of proven Bonneville age, the time of their deposition is reasonably well demonstrated.

## LAKE BONNEVILLE SEDIMENTS AND SHORE-FEATURES.

## GENERAL RELATIONS.

Shore features formed by the latest stages of the Pleistocene lakes in western Utah are a dominant factor in physiographic and topographic expression, and sediments formed synchronously are an important economic factor in many localities, particularly from the standpoint of ground-water occurrence. Undoubtedly, the later stages of the Pleistocene lakes were part of a continuing sequence, the initial stages of which are represented, in part, by the pre-Bonneville beds described in the above paragraphs. However, in contrast to the fragmental evidence of the earlier stages of the Pleistocene lakes, the preserved record of the later stages, which Gilbert called Lake Bonneville, is excellent and, in many localities, comparatively complete. Naturally, the excellence of preservation of the record and the dominance of the topographic forms produced by Lake Bonneville in the Great Basin attracted the attention of the early explorers and geologists and, consequently, the Lake Bonneville shore-features, sediments, and history were early studied and reported upon by Gilbert and others.<sup>9</sup> Gilbert's study has been freely drawn upon in the following discussion.

Lake Bonneville, during its highest or Bonneville<sup>10</sup> stage covered an area of approximately 20,000 square miles, had over 2,500 miles of shoreline, and its greatest depth was 1,050 feet. The shoreline cut at this time, because it is the mark delineating land eroded by streams and land sculptured by wave action of the lake, is the most continuously outstanding lake-formed feature. Accompanying the shoreline in localities favorable for their formation are numerous bay-bars, spits, and deltas, and infrequent along-shore bars. The outline of the lake was intricately sinuous due to variations in relief of the land over which it transgressed and there were many attendant bays, inlets, islands, and promontories.

The period preceding the highest level of the lake was one of oscillation when the lake built massive embankments rather than cut prominent features. The term "Intermediate," which has been given to the features formed at this time,<sup>11</sup> does not

<sup>9</sup> Gilbert, G. K.: op. cit.

<sup>10</sup> Gilbert, G. K.: op. cit., 93.

<sup>11</sup> Gilbert, G. K.: op. cit., 135, 170.

apply to the relative age of the deposits of the lake but to their vertical position in relation to features formed during the Bonneville stage and features formed during the later or Provo stage, the former occurring at higher levels and the latter at lower levels. Most of the features formed during this period of oscillation were built while the lake was attaining its maximum level, the Bonneville stage. However, Gilbert found evidence that there was an earlier high-water epoch lasting about five times the duration of the later epoch and ending with an epoch of desiccation longer than post-Bonneville time.<sup>12</sup>

Near the end of the Bonneville stage the water from the lake found an outlet over alluvial material at its northern end near the present northeastern Utah-Idaho boundary and drained northward into the Snake River.<sup>13</sup> The water cut rapidly downward through the alluvial material and formed an outlet now known as Red Rock Pass. Eventually the water in the channel cut down to resistant bedrock which held up the bed of the stream and consequently stabilized the level of the lake at more than 300 feet below the Bonneville stage. This lower and later level of the lake is known as the Provo stage,<sup>14</sup> the name being derived from the great delta of the Provo River which was built during that time. The shore-features and deposits of this stage are the best developed and the largest of any in the history of Lake Bonneville. The area of the lake during this stage was about 13,000 square miles.

Near the end of the Provo stage, owing to a change in climatic conditions, outflow from the lake ceased and the lake wasted away by desiccation to the present remnants—Great Salt Lake, whose level is approximately 650 feet below the Provo stage, and a few small playas in the basin floor, the largest of which is Sevier Lake in central Millard County.

#### BONNEVILLE SHORE-FEATURES AND SEDIMENTS IN PAVANT VALLEY.

Pavant Valley lies along the southeastern boundary of the area that was inundated by the higher levels of Lake Bonneville, and shore features and deposits formed during the

<sup>12</sup> Gilbert, G. K.: *op. cit.*, 316.

Fenneman, N. M.: 1931, *Physiography of Western United States*, 362.

<sup>13</sup> Gilbert, G. K.: *op. cit.*, 171-186.

<sup>14</sup> Gilbert, G. K.: *op. cit.*, 126-134.

various levels of the lake are significantly expressed in the topography of the valley. As in other parts of the old lake basin in Utah, the Bonneville level is a particularly well-marked feature, especially on isolated buttes and hills and other places where the waves had favorable access. The high elevation of the Pavant Valley limited the lake during the Provo stage to a shallow arm which had little cutting power and, therefore, Provo features in the valley are not as easily discerned as in other localities. Because of the high elevation of the valley floor there are no significant shoreline features below the Provo level, the valley having been drained soon after the Provo stage. Both the sediments and shore features of Lake Bonneville are undeformed and have been only locally eroded and covered since the disappearance of the lake. In general, the shorelines, bars, and embankments are cut through by the larger streams. Shallow minor washes have established themselves by headward erosion in the edges and on the sides of the features but have altered them beyond recognition only in isolated cases. Westward and northward from the Bonneville shoreline the surface of the valley floor is composed of Bonneville lake beds and these are covered in a few places by a thin veneer of recent alluvium, chiefly in the beds of washes and creeks. The lake beds are also covered by the lava of the most recent basalt flow from the Ice Springs Craters.

Lacustrine gravel, sand, silt, marl, and clay overlie the Pleistocene alluvial gravel below the highest shoreline cut on the alluvial apron. In general, the gravel consists of well-assorted, well-rounded pebbles and cobbles and forms large embankments and bars, whereas the sand and silt is relatively evenly spread over the area near the shorelines and grades laterally into the marl and clay farther out in the valley. Marl and clay are the usual lacustrine deposits in the valley west of a line drawn approximately around the west base of West Mountain, thence south paralleling and about  $\frac{1}{2}$  mile east of the Provo shoreline (Plate 1). The clay is generally buff to red and plastic and the marl is usually white or light-gray and is very argillaceous. In some localities the marl is quite sandy and when this is the case it usually bears fossil snails. A bed of medium-grained, black volcanic lapilli occurs throughout the area interbedded with the white marl and generally in the upper part of it. Near the base, the white marl

is sometimes stained and flecked with limonite. Two and one-half miles west of Fillmore, on Utah State Highway No. 100 about one-half mile west of the southeast corner of sec. 14, T. 21 S., R. 5 W., where the Old Field-Flowell-Chalk Creek irrigation ditch crosses the road, an outcrop of the white marl is exposed in the ditch bed where water in the ditch has cut down into the Pleistocene fan deposits. At this exposure the white clayey marl rests on coarse, poorly assorted gravel and is about five feet thick. Westward from this exposure to the Provo shoreline the white marl outcrops at the surface. Similar exposed sections were observed in irrigation ditches at numerous other localities in the valley. Farther west, test boreholes and wells showed a similar sequence of materials. Numerous outcrops of this white marl occur on surfaces of the volcanic flows on the west side of the valley. Fossils collected from various outcrops of the white marl compare with fossils which have been described in other studies of the invertebrate fauna of beds deposited during the Bonneville stage of the lake.<sup>15</sup> Also, the white marl lies above the Provo shoreline of the lake and is eroded by it. Gilbert divided the sediments of Lake Bonneville into two main groups, the underlying Yellow Clay separated from the topmost Bonneville deposit, the White Marl,<sup>16</sup> by a thickness of alluvial gravels. The writer did not observe a formation similar to Gilbert's Yellow Clay in Pavant Valley, although some of the clay beds underlying the uppermost gravel bed may be equivalent to his Yellow Clay. However, the white argillaceous, sandy marl which is so widespread there is undoubtedly correlative to Gilbert's White Marl which he described as a widespread deposit over much of the lake basin and which he said was particularly well-developed and well-exposed in the Leamington, Utah and Old River Bed areas<sup>17</sup> which are approximately 50 and 100 miles north of Pavant Valley, respectively. .

#### INTERMEDIATE SHORE FEATURES.

Embankments built up during the intermediate levels of Lake Bonneville are well-developed on West Mountain, at the north end of the area about 3 miles northwest of Fillmore;

<sup>15</sup> Gilbert, G. K.: op. cit., 298.

<sup>16</sup> Gilbert, G. K.: op. cit., 195.

<sup>17</sup> Gilbert, G. K.: op. cit., 192-194.

and on Black Rock Volcano, at the south end of the valley about  $2\frac{1}{2}$  miles west of Kanosh. Also one spit, probably built at an intermediate level of the lake but later re-sculptured during the Provo stage occurs on the east side of White Mountain about seven miles west of Meadow. Two miles north of West Mountain on Bald Mountain in northern Pavant Valley intermediate embankments are also well developed and prominent.

Although Gilbert described in detail the "Intermediate embankments" and their origin in other parts of the Bonneville lake basin<sup>18</sup> he does not mention intermediate embankments in Pavant Valley. These, however, resemble the embankments described in his monograph, particularly in regard to their position, probable mode of formation, and structure. One relatively constant feature of the embankments in Pavant Valley seems to be significant. One group of embankments occurring at all localities where intermediate features are present are aligned with their long axes pointing northwest-southeast, whereas all other Bonneville features in the area are aligned in a northeast-southwest position. In general, the former group of embankments are more dissected than the latter group, and, where field evidence is obtainable, seem to be overlain by northeast-southwest trending embankments which were also deposited when the lake was at intermediate levels. These embankments are also cut or overlain by the shore features of the Provo and Bonneville stages of the lake. Thus, there is present in Pavant Valley a group of older intermediate embankments, probably deposited at the earliest Intermediate levels of the lake, whose position and alignment are radically different from later deposits indicating a change in the direction of the shore currents subsequent to their deposition. Three postulates which might explain the change in direction of the shore currents are, (1) that the features of the land at the time the earliest embankments were being formed were different from those present at the time when the later embankments were deposited, (2) that the embankments as they were being built, affected and changed the direction of current and oscillation, or (3) that there was a change in wind-direction following the deposition of the older embankments; that is, that the wind direction during the formation

<sup>18</sup> Gilbert, G. G.: *op. cit.*, 135-137.

of the older deposits was predominantly northwest, whereas subsequent to their deposition the prevailing winds blew from the southwest, a change of approximately  $65^{\circ}$ .

A detailed study of the geologic and physiographic conditions in Pavant Valley has yielded evidence indicating that there has been no structural deformation of the valley since early Pleistocene time. Also pre-Bonneville vulcanism in the area probably occurred previous to the deposition of the oldest intermediate embankments and again subsequent to the cutting of the Provo shoreline, and there is no evidence indicating that there was a significant change of the land features during that time important enough to change the direction of the shore currents of Lake Bonneville in Pavant Valley. Therefore, the first postulate is not tenable as an explanation of the change in the direction of the currents. The second postulate also seems unreasonable because, if wind direction were the same during both periods of deposition and all other factors were very nearly the same as it appears reasonable to believe, deposition should have continued in nearly the same fashion. Available evidence, therefore, indicates that there was probably a change of prevailing wind direction during the early part of the deposition of the intermediate embankments.

Two closed depressions approximately 30 feet deep and 400 feet across occur in the top of the embankments forming the south end of West Mountain. At the northeastern side of West Mountain a combination of the two groups of intermediate embankments partially enclose a basin, the mouth of which is nearly closed by an older northwest-aligned embankment and the sides of which are composed of the younger southwest-aligned embankments. The position and structure of this partially enclosed basin indicate that had lake deposition continued it would have been completely enclosed, that is, it would have been a closed depression similar to the ones on top of the south end of West Mountain. The evidence furnished by the partially enclosed basin probably indicates that the south depressions evolved in a similar manner. The closed depressions are thus apparently products of overlapping intermediate embankments resulting from a change in the direction of the prevailing winds. The depressions have been slightly altered by subsequent lake and alluvial erosion.

**BONNEVILLE SHORE FEATURES.**

Although the highest level of Lake Bonneville cut a distinct shoreline on the alluvial apron and the mountains in Pavant Valley, the shoreline here is not as conspicuous as it is in other parts of the Bonneville basin. This is probably because the lake was shallower and the shore was protected from exceptionally strong currents and large waves by surrounding elevations. On the gently-sloping alluvial apron along the east side of the valley large waves would drag the bottom of the lake and break before cutting very deeply into the shore. However, evidence of the shoreline is abundant in the form of narrow wave-cut terraces along the alluvial apron, as wide terraces on the steeper shores of the lake, and as bay bars and spits built out across reentrants that were bays during the Bonneville stage. Deep cut terraces are present along the west side of Cedar Mountain, along the mountain sides southwest of Kanosh, and on the sides of Black Rock Volcano west of Kanosh. Well-developed bay bars are present approximately 1 mile north of Fillmore, about three miles south of Fillmore, and about 1 mile south of Kanosh. The shoreline along the alluvial fan between Cedar Mountain and the mountains southwest of Kanosh consists of a terrace from 10 to 20 feet wide and with a steep wave-cut cliff never more than 8 feet high, whereas the deeper cut terraces along Cedar Mountain and other steep slopes are over 100 feet wide with wave-cut cliffs 25 feet high. The bay bars are relatively small structures never more than 30 feet high and generally about 200 feet across. The elevation of the Bonneville shoreline in Pavant Valley is approximately 5,130 feet above sea level.

**PROVO SHORE FEATURES.**

Remnants of the shoreline of Lake Bonneville during the Provo stage are scarce and relatively indistinct in Pavant Valley and some difficulty was experienced in mapping the shoreline; however, it was possible to determine the elevation of remnants which were well-preserved and by means of instrumental leveling and aneroid barometer to establish an approximate line in the valley. One particularly well-preserved remnant of the Provo shoreline is located along the west slope of West Mountain. The elevation of the shoreline in this locality was determined by a Selsi aneroid to be 4,825 feet above sea

level. Another well-marked remnant of the Provo shoreline on White Mountain was determined by the same method to be 4,840 feet above sea level, and a third well-marked remnant located approximately 3 miles west of Fillmore, Utah, was found to be 4,845 feet above sea level. Other elevations determined along remnants of the shoreline range well within the limits set by these figures, generally closer to the lower limit than to the upper one and on the basis of this evidence it was decided to use a general figure of 4,830 feet above sea level for the elevation of the Provo shoreline. On West Mountain the terrace of the Provo shoreline varies from 30 feet to 60 feet in width and the wave-cut terrace of the shoreline is about 100 feet high. The dimensions of the back slope and terrace of the shoreline on the gently sloping fan surface are much smaller and at many places the shoreline is indistinguishable.

The lake at the Provo stage in Pavant Valley built a long spit eastward from the north end of the calcareous tufa ridge south of White Mountain. This spit curved to the north in the area west of Meadow and extended a short distance north to a point one mile west of Meadow, where it passes into a cut terrace which in turn swings northward across the alluvial fan of Pine Creek and Chalk Creek and around the west side of West Mountain. Approximately  $\frac{1}{2}$  mile west of and parallel to this cut terrace a large off-shore bar was built. This bar extends southward from West Mountain to the south line of sec. 34, T. 21 S., R. 5 W., and is locally known as "the Gravel Ridge." It is composed chiefly of well-rounded pebble and cobble gravel. At one place on the south side and at numerous places along the east side of the Tabernacle flow thin deposits of calcareous tufa occur at the approximate level of the Provo shoreline, and in numerous places on the sides of the flow there are notches of the Provo shoreline.

#### GEOLOGIC STRUCTURE.

The Pavant Range lies in a transitional zone between two provinces which exhibit strikingly different structural patterns. The Basin and Range Province to the west is characterized by block-faulted mountain ranges composed generally of Paleozoic and older rocks which, prior to the time of block-faulting, had been closely folded and thrust-faulted. These

ranges are separated by wide, open basins usually containing vast amounts of unconsolidated valley fill made up of lacustrine and alluvial sediments. The High Plateaus Province to the east is characterized by broad, open folds and domes generally in Mesozoic and younger rocks cut by normal faults of large throw and great linear extent.

The Pavant Range reflects features of both provinces. Its steep scarp slope on the west is in sharp contrast to its gentle dip slope on the east. The scarp slope, notched by steep V-shaped canyons, meets abruptly the thick alluvial deposits of the valley floor. Early thrust faulting and overturned folds involve Paleozoic and Mesozoic rocks. In contrast to these typical Basin and Range structures the Mesozoic rocks underlying the thrust sheet exhibit gentle dips except where locally disturbed near the thrust plane, and early Tertiary beds forming the broad summit and the entire east side of the range are tilted gently eastward. These latter features give to the Pavant Range the general aspect of the High Plateaus to the east.

#### *Folds.*

The Paleozoic rocks constitute a large homocline throughout the length of the Pavant Range except in the bed of the South Fork of Chalk Creek between the mouths of Shingle Mill and Chokecherry Creek Canyons, where it passes into an asymmetric anticline, the east limb of which is overturned. The Tintic quartzite and Paleozoic limestones of the homocline have an eastward dip of about  $40^{\circ}$ .

Mesozoic beds at the west base of the Pavant Range are overturned and dip westward at angles from  $20^{\circ}$  to  $45^{\circ}$ . North of the mouth of Meadow Creek Canyon an outcrop area of these overturned beds includes parts of the Shinarump, Moenkopi, and Kaibab formations. Approximately 2 miles southeast of this area, in the bottom of Meadow Creek Canyon, beds of the Shinarump conglomerate crop out. These beds are in normal position and dip gently to the northwest. This circumstance indicates that the fold at the west base of the range in which the overturned beds of the Shinarump are involved is a small asymmetric syncline, the west limb of which is overturned (see Structure section) and it seems entirely probable that all the overturned beds exposed at the west base of the range are parts of the west limb of this syncline.

All of these folds lie immediately above or below a large thrust plane (see below) and probably were formed during the period of thrusting. The overflow folds both above and below the fault plane appear to be drag structures. If this is the case, they indicate eastward movement of the overriding block.

*The Pavant Thrust Fault.*

The trace of a low angle, eastward-dipping fault, crops out along the Pavant Range from Pioneer Creek where it emerges from beneath the valley alluvium, southward to Corn Creek where it passes under beds of the Wasatch formation. In re-entrants on the west face of the range the fault trace swings eastward and upstream and on the salients it extends westward and downstream. Measurements of the dip of the fault plane approximate  $20^{\circ}$  to the east. The rocks above the fault trace are exclusively early Paleozoic, whereas the rocks below the fault trace consist of beds of Permian to Jurassic age. Beds belonging to the Wasatch formation are not involved in the fault. They were deposited over the eroded surface of Paleozoic and Mesozoic beds and over the fault trace. Thus, it is the trace of a thrust fault which occurred prior to Eocene time and subsequent to Jurassic time and, therefore, during the Laramide revolution.<sup>19</sup>

In general, the trace of the thrust is "clean" and beds above and below are surprisingly undeformed. Even small faults are not common. The Monk's Spring fault in Monk's Spring Canyon north of Corn Creek is probably the result of the difference in competency between the quartzite and limestone beds, the quartzite beds being eliminated from the thrust sheet south of Monk's Spring Canyon, leaving limestone beds as the lowest part of the upper thrust sheet. It seems quite probable that the asymmetric syncline in the Mesozoic beds at the base of the Pavant Range is a drag fold caused by the overthrust, and it is possible that the folding in the Paleozoic beds of the upper sheet of the thrust was also produced by the overthrust movement.

Reconnaissance in the north part of the Pavant Range beyond the area mapped and in the Canyon Range indicated that the overthrusting extends into these areas.

<sup>19</sup> Spieker, E. M.: 1939, (Paper at meetings of G.S.A. in Berkeley).

*Basin and Range Faulting.*

The abrupt west face of the Pavant Range with its steep V-shaped canyons is characteristic of the Basin-Range Province and suggests the probability of block faulting along the mountain front. It was probably this feature which prompted mapping of the northward extension of the Hurricane fault on the geologic map of Utah.<sup>20</sup> Post-Eocene tilting may be indicated by the attitude of Wasatch strata, because the present dip of  $15^{\circ}$  exceeds any reasonable estimate of initial dip of those strata. Also, Wasatch strata now form the top of the Pavant Range more than 3,000 feet above the valley and since it is improbable that this thickness of Wasatch could have been removed from the valley by stream erosion during Cenozoic times it is likely that the formation attained its present high elevation by uplift, probably by block-faulting. That the relative uplift of the Wasatch occurred prior to the deposition of the Sevier River formation is indicated by absence of Sevier River strata at high elevations and by the discordance between the attitudes of the beds of the Sevier River and Wasatch formations.

However, in many areas in the Great Basin there are present on the alluvial fans at the foot of the abrupt mountain front small fault scarps which attest to recent, and probably continuing, movement along normal faults located near the base of the ranges.<sup>21</sup> In Pavant Valley there are no such scarps breaking the alluvium. Indeed, lack of recent fault scarps and undeformed Pleistocene alluvial and volcanic rocks indicates that appreciable movement along normal faults at the base of the Pavant Range has not occurred since early Pleistocene time.

The steep eastward dip ( $40^{\circ}$ ) of the Sevier River deposits at the very foot of the mountains and against older beds much more gently inclined suggests renewed normal faulting after the deposition of the Sevier River formation and indicates at least two periods of normal faulting, the major movement

<sup>20</sup> Butler, B. S.: 1920, The ore deposits of Utah: Prof. Paper III, Pl. 4.

<sup>21</sup> Thomas, H. E.: 1942, Geology and Water Resources of Tooele County, Utah, 127. (Manuscript available at U.S.G.S. in Salt Lake City.)

Eardley, A. H.: 1933, Structure and Physiography of the southern Wasatch Mountains, Utah: Mich. Academy of Sciences, Arts, and Letters. 19, 389.

occurring during post-Wasatch, pre-Sevier River time, and the later movement following Sevier River and probably preceding Pleistocene time.

Traces of faults which crop out along the west base of the Pavant Range are shown on Plate 1. Several of these are believed to be thrust or reverse faults. However, the fault which occurs at the mouth of Meadow Creek where overturned beds of Moenkopi and Shinarump formations are dropped down against the Navajo sandstone and a similar fault at the mouths of the North and South Forks of Chalk Creek involving the same formations are believed to be normal faults of the Basin and Range type.

#### GEOLOGIC HISTORY.

Preceding paragraphs in this report have presented evidence that:

(1) During Lower and Middle Cambrian and Permian time, at least, the Pavant area was part of the Cordilleran Geosyncline.

(2) Rocks formed during the rest of Paleozoic time are not present in the area although a part at least of the missing section is present in Dry Wash Canyon south of Kanosh; in the mapped area these rocks are probably covered by younger beds or thrust sheets, or were removed by subsequent erosion or both.

(3) During early Triassic time marine deposition took place followed by terrestrial and brackish water deposition which continued through the Triassic and Jurassic periods until late Jurassic time when the area was again transgressed by the sea which deposited the Carmel formation, not found in the Pavant area but identified by Callaghan<sup>22</sup> in the Tushar Range and observed by the writer near Minersville, Utah, areas not far removed from Pavant Valley.

(4) Thrust faulting occurred following the deposition of the Carmel formation and previous to deposition of the Wasatch formation. At least one great block of early Paleozoic rocks was thrust eastward and over-rode the Mesozoic rocks. The period of overthrusting was probably accompanied and followed by extensive erosion which developed a topography having over 2,000 feet of relief.

<sup>22</sup> Callaghan, Eugene: Personal communication.

(5) Very late in the Cretaceous period or early in the Tertiary period, continental deposition took place and the great thickness of conglomerate, sandstone, shale, and fresh-water limestone of the Wasatch formation were deposited.

(6) Uplift and eastward tilting of the Pavant Range, probably accounting for most of its present elevation above the valley floor, accompanied by extensive erosion of the range and deposition in the valley of large amounts of alluvium in fans, and later beds containing much volcanic material (Sevier River formation) took place during Tertiary time.

(7) Renewed faulting occurred along the range front in Pliocene or early Pleistocene time, elevating the mountain block possibly several hundred feet and tilting the Sevier River deposits against the older rocks.

(8) Throughout Pleistocene time there was rejuvenated mountain erosion and deposition of alluvial materials, chiefly gravels, as great fans in the basin, alternating with several periods of lacustrine deposition in the lower parts of the basin.

(9) Rejuvenated stream erosion caused, in part at least, by a lowering of the base level of the streams due to disappearance of the Pleistocene lakes completed the development of the present landscape.

U. S. GEOLOGICAL SURVEY,  
LAS VEGAS, NEVADA.