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SURFICIAL DEPOSITS, GEOMORPHOLOGY, AND CENOZOIC HISTORY OF THE EUREKA QUADRANGLE, UTAH

by

Harry D. Goode

U. S. Geological Survey
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SURFICIAL DEPOSITS,
GEOMORPHOLOGY, AND CENOZOIC HISTORY
OF THE EUREKA QUADRANGLE, UTAH

by

Harry D. Goode

ABSTRACT

The Eureka, Utah, $7\frac{1}{2}$ minute quadrangle is about 65 miles south-southwest from Salt Lake City. The main divide of the East Tintic Mountains, one of the easternmost Basin Ranges, crosses the quadrangle from its northwest corner to the center of its southern border.

Rocks of the quadrangle range in age from Early Cambrian to Recent, but Pennsylvanian to Cretaceous rocks are absent, owing to nondeposition or to subsequent erosion. Nearly 10,000 feet of Paleozoic rocks were folded into a north-trending asymmetric syncline whose western limb is nearly vertical. Except where they have been stripped off the older rocks, Middle Eocene tuffs, flows, and intrusive rocks that are as much as 2000 feet thick cover the Paleozoic rocks.

Surficial deposits of the area consist of loess; alluvial and colluvial silt, sand, and gravel; and lacustrine deposits of Wisconsin Lake Bonneville. The age of the surficial deposits has been related to Lake Bonneville: the loess and certain alluvial-colluvial deposits are of pre-Lake Bonneville age; the lake deposits are of Lake Bonneville age; and other alluvial-colluvial deposits are of Lake Bonneville or post-Lake Bonneville (Recent) age.

The loess of pre-Lake Bonneville age is probably the oldest surficial deposit. The loess blanketed the area, perhaps in Yarmouth

time, and its silt-size grains of quartz were later eroded from the original deposits and were redeposited in most younger deposits. This silt probably was a source for the fine-grained deposits laid down by Lake Bonneville.

Extensive alluvial and colluvial gravels of pre-Lake Bonneville age occur in many canyons and along the mountain fronts. These gravels are overlapped along the quadrangle's eastern edge by lacustrine deposits of the Alpine and Bonneville formations of the Lake Bonneville group. The Provo formation, youngest member of the Lake Bonneville group, was not deposited in the quadrangle because the lowest point in the quadrangle is about 100 feet above the Provo shoreline. Alluvial silt and gravel have been correlated with formations of the Lake Bonneville group.

Recent alluvium and colluvium of silt, sand, and gravel partly fill most valleys and overlap Lake Bonneville deposits along the eastern edge of the quadrangle.

The landscape of the quadrangle has been controlled by the complex geology of the area. Differential erosion on rocks of many lithologies, volcanic activity, and uplifts by block faulting produced a dynamic mountainous landscape, whose major divide is even now moving from east to west. This movement of the divide, activated by an 850 foot difference in altitude between eastern and western base levels, is manifest on the eastern slope in stream piracies, landslides, and steep canyons, whereas on the western slope the topography is submature.

Features of the present landscape include 1) exhumed pre-volcanism rugged topography of the Paleozoic rocks near the axis of the syncline, 2) several uplifted erosion surfaces, 3) the large, wedge-shaped, uplifted Diamond Divide Block, 4) several areas whose accelerated erosion is due to structural or lithologic weakness of the bedrock, and 5) periglacial features such as inactive talus slopes and buried frost-action deposits.

Study of the rocks and physiography indicates that after Middle Eocene time volcanic rocks covered the folded and faulted Paleozoic rocks. The area then underwent extensive erosion that increased after periods of block faulting. Late Tertiary rocks were probably deposited in the adjacent basins but these rocks were covered by fanglomerate, alluvium, and lacustrine deposits of Pleistocene age. A cycle of 1) erosion in the mountains, 2) erosion and deposition in the foothills, and 3) deposition in the basins continues today.

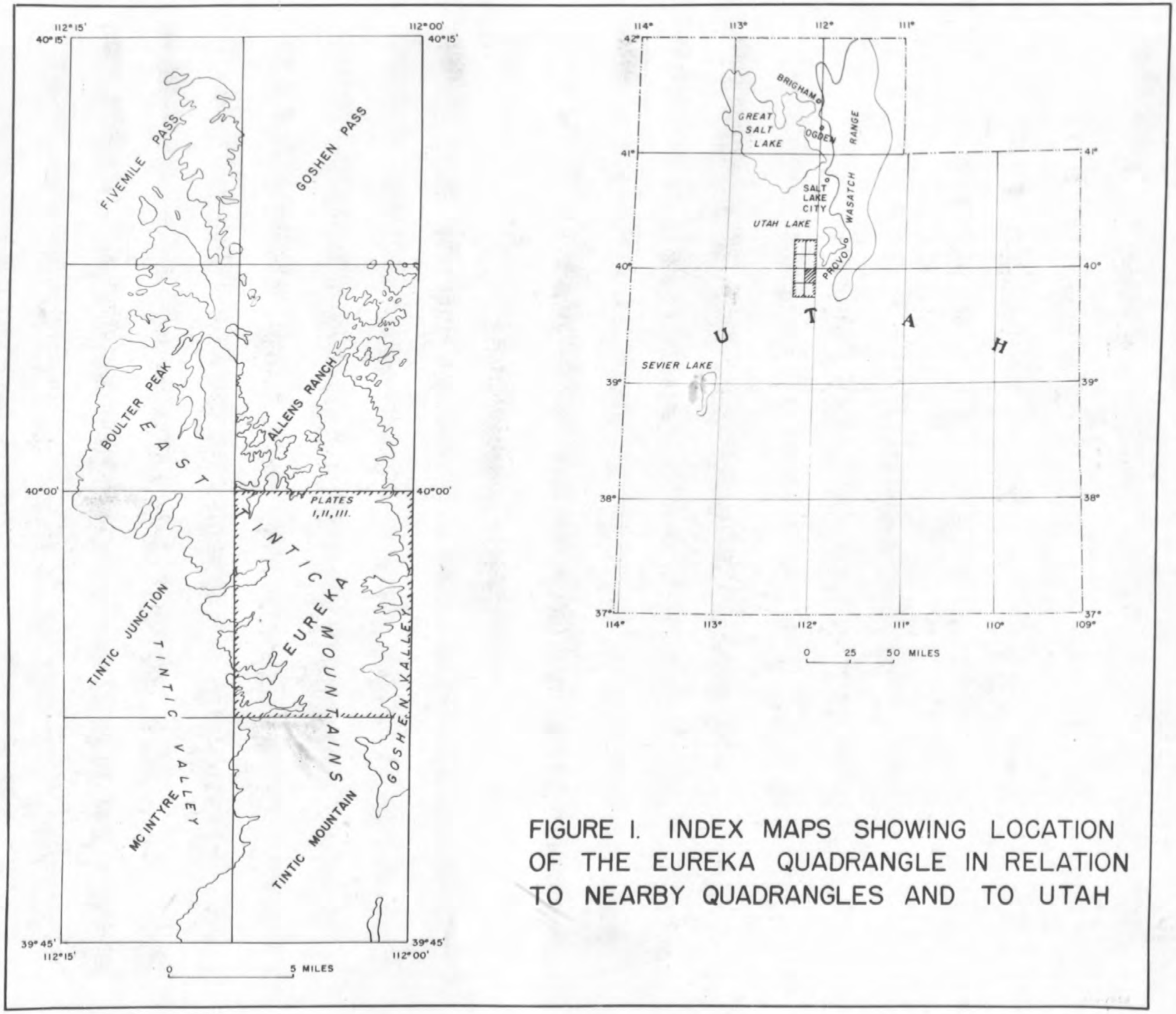


FIGURE I. INDEX MAPS SHOWING LOCATION OF THE EUREKA QUADRANGLE IN RELATION TO NEARBY QUADRANGLES AND TO UTAH

INTRODUCTION

Location and accessibility

The $7\frac{1}{2}$ minute Eureka quadrangle, in central Utah (fig. 1), is bounded on the east by the 112th meridian and on the north by the 40th parallel. Eureka, the principal town, is about 65 miles by air or 95 miles by road south-southwesterly from Salt Lake City. U. S. Highway 6 and 50 is the only paved highway in the quadrangle; it crosses the northern half of the quadrangle from west to east. In addition to the highway, about 25 miles of graded dirt roads and almost 70 miles of unimproved roads provide good access to most points within the quadrangle.

Physiographic setting

The Eureka quadrangle is about 15 miles west of the Wasatch Mountains, which in this part of Utah mark the eastern boundary of the Basin and Range Physiographic Province. The quadrangle is near the middle of the East Tintic Mountains, a range that is about 40 miles long from north to south and is about 15 miles wide at its widest part a few miles north of Eureka. The main ridge of the range enters the area about two miles south of the northwest corner of the quadrangle and follows a sinuous course to the south central edge of the quadrangle. In the southern part of the quadrangle and in most of the northwest corner, the main ridge of the mountains consists of Middle Eocene volcanic rocks, principally flow rocks of the Packard and Laguna Spring series. At one time these volcanic rocks probably covered the whole area, but subsequent erosion has removed them from parts of the range. In the northwestern part of of this quadrangle, Paleozoic rocks of the nearly vertical west side of the Tintic syncline have been exhumed and reveal a rugged topography that was carved into the Laramide syncline before the Middle Eocene volcanism (Pl. IV and Pl. VI).

The mountains of the Eureka quadrangle are bounded by two valleys, Tintic Valley to the west and Goshen Valley to the east. Goshen Valley (Pl. V) is about 850 feet lower than Tintic Valley (Pl. IV), and the stronger erosive power of the streams draining eastward toward Goshen Valley has produced sharp, V-shaped canyons whose profiles steepen sharply near the crest of the range, whereas the valleys draining westward over similar volcanic rocks are much flatter, generally contain more alluvium, and are not so steep near the main divide.

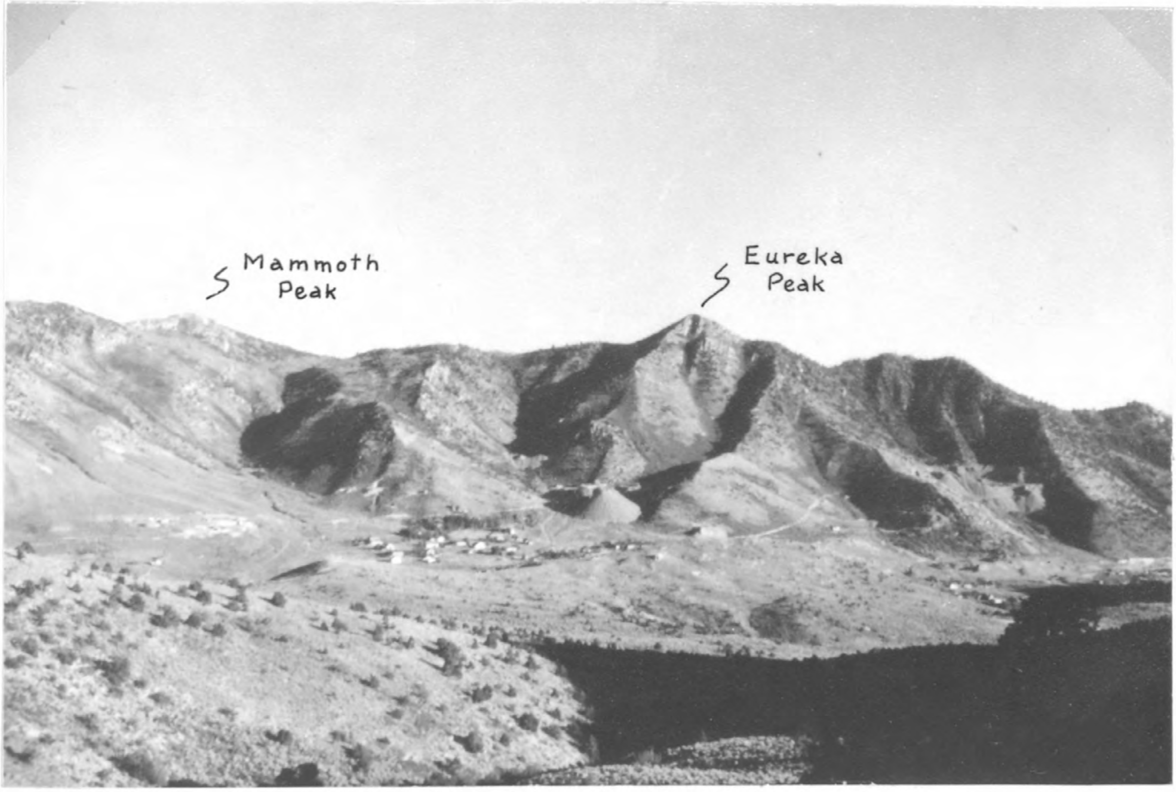
Climate and vegetation

The average annual rainfall and mean temperature of any locality in the quadrangle depend largely on the altitude of the locality. Records of precipitation collected at Weather Bureau observation stations, in Eureka at an altitude of 6530 feet and in Elberta about three miles east of the quadrangle at an altitude of 4650 feet (U. S. Weather Bureau, Climatological Summary for Utah, 1956), suggest that the average precipitation in the quadrangle ranges from about 11 inches a year at the lower elevations of about 4900 feet to 18 or 20 inches a year near the tops of the 8000 foot peaks. In Eureka, the greatest precipitation falls during the cold winter months, although about 26 percent of the annual precipitation falls during the driest third of the year in June, July, August, and September.

Plate IV.- East Tintic Mountains from the north and from Tintic Valley

Top.- Paleozoic-rock ridge south of Eureka. The nearly vertical attitude of the beds near Eureka Peak is clear.

Bottom.- West side of East Tintic Mountains looking southeast from northern end of Tintic Valley. Paleozoic sedimentary rocks form mountain masses topped by Eureka Peak and Mammoth Peak. Volcanic rocks make up low hills to the right of Mammoth Peak.


Mammoth
Peak
Eureka
Peak

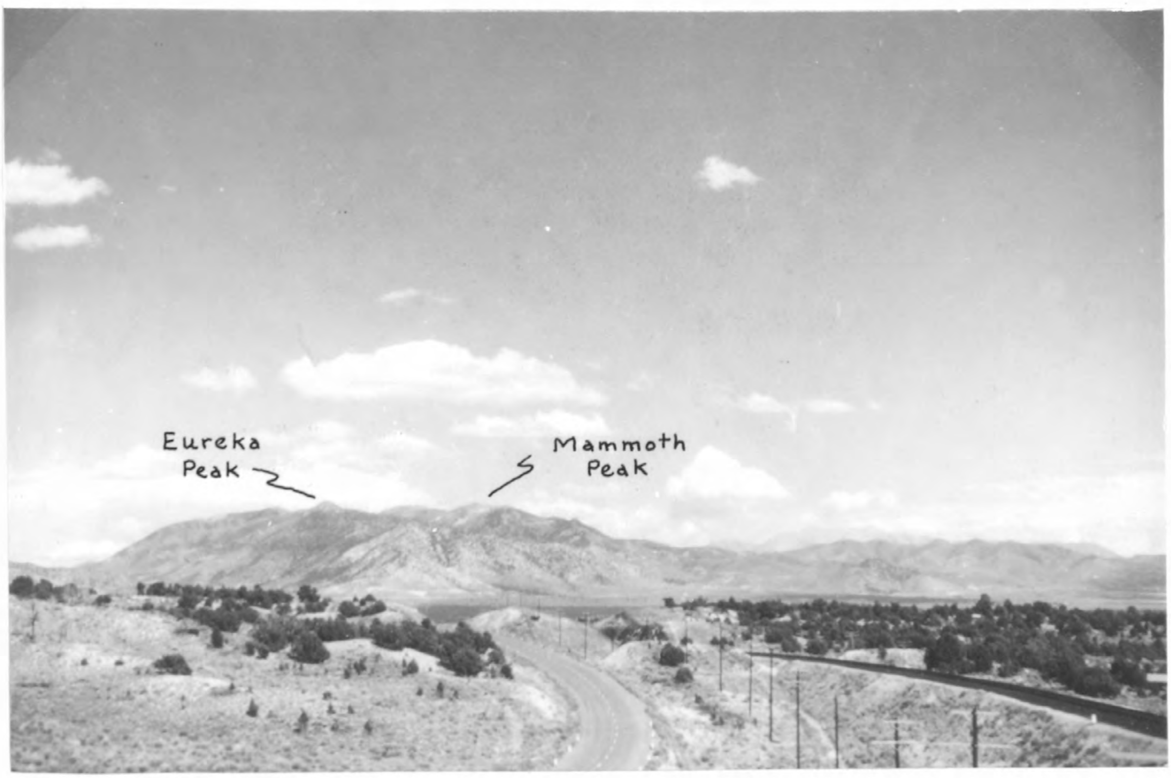
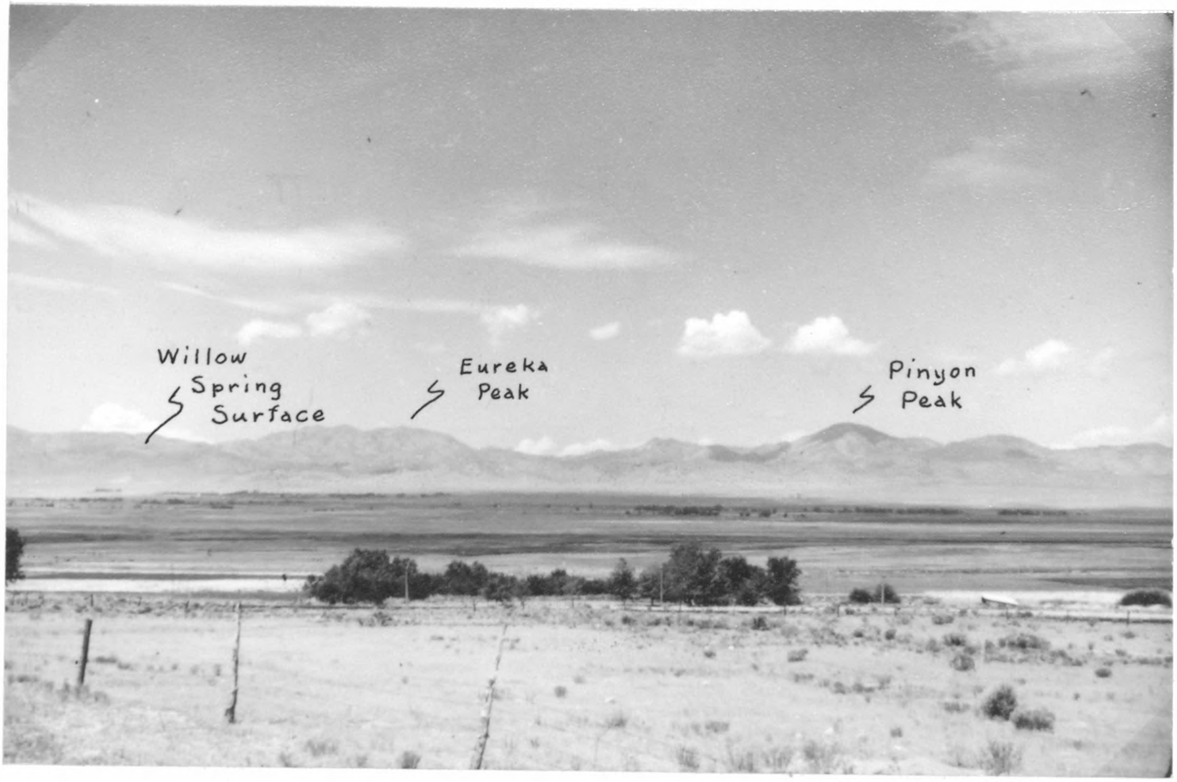
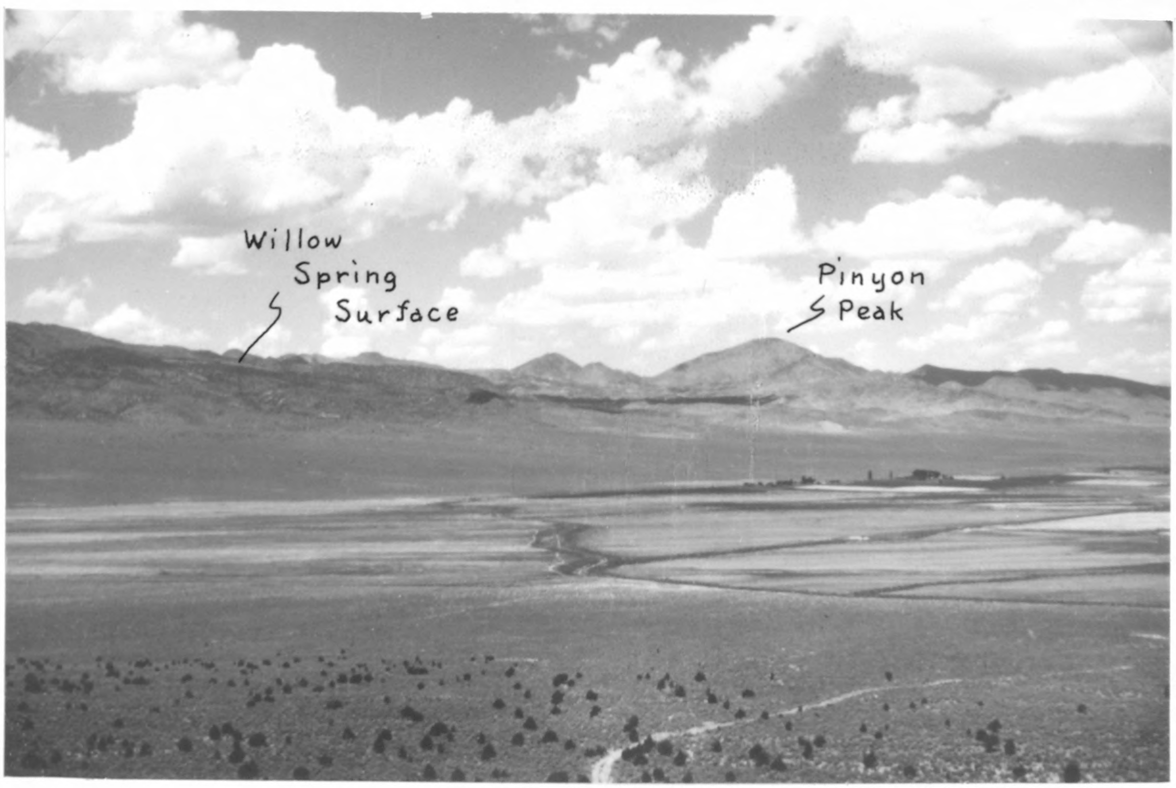

Eureka
Peak
Mammoth
Peak

Plate V.- Goshen Valley and east side of East Tintic Mountains

Top.- Goshen Valley and east side of East Tintic Mountains from east side of Goshen Valley near Genola.

Bottom.- East side of the East Tintic Mountains from Long Ridge near south end of Goshen Valley.


Willow
Spring
Surface
Eureka
Peak
Pinyon
Peak


Willow
Spring
Surface
Pinyon
Peak

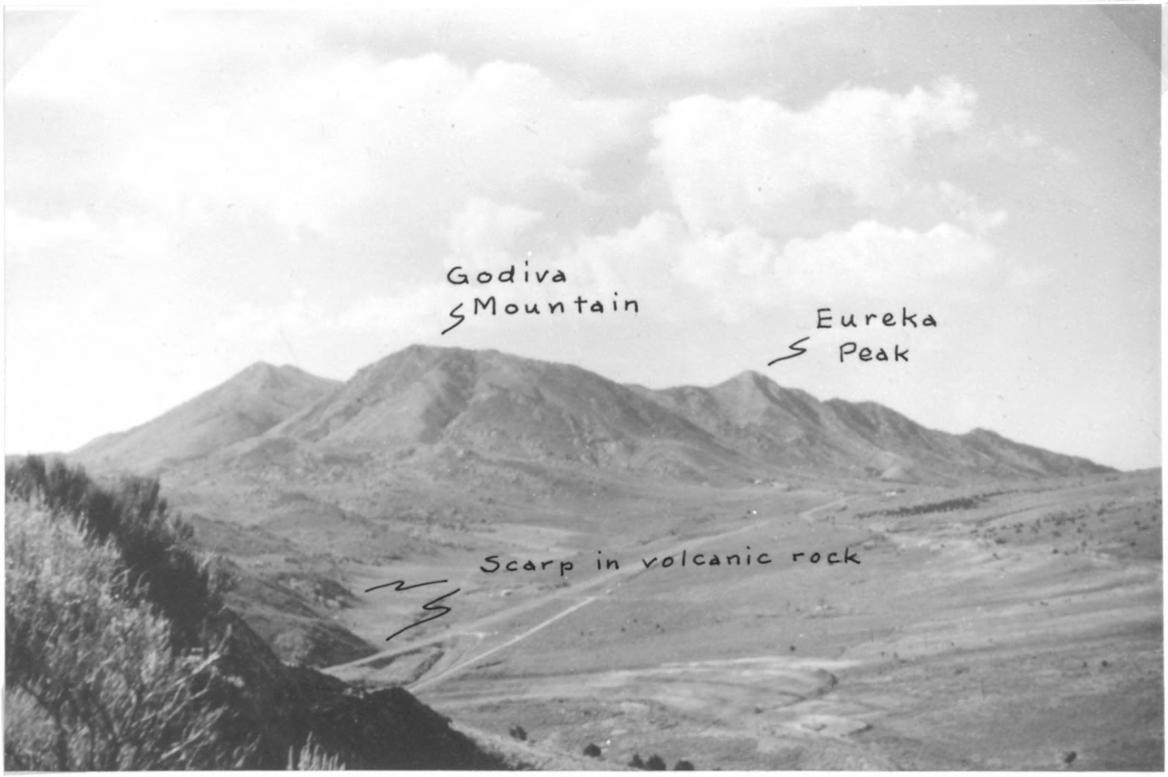


Plate VI.

Paleozoic-rock peaks of the East Tintic Mountains and Homansville area from west side of Lime Peak.

The highway is U. S. 6 and 50. Eureka is across the divide on the right.

Water for Eureka comes from wells dug into the surficial deposits in Homansville area in the foreground.

Temperatures measured by members of the U. S. Geological Survey from 1949 to 1951 at about 5900 feet altitude, near Dividend, ranged from a high of 103°F on August 6, 1949 to a low of -17°F on February 1, 1951. At the highest elevations in the quadrangle it is unlikely that the highest summer temperatures rise above 90°F, and it is doubtful that winter temperatures go below -20°F anywhere in the quadrangle.

The flora supported by the moderate rainfall in the quadrangle is typical of semiarid areas at 5000 to 8000 feet altitude along the 40th parallel. The common sagebrush grows at altitudes up to about 7500 feet, but is most prominent in the broad valleys and on the lower slopes. A similar plant, the rabbitbrush, lines the edges of many dry washes. Elongate stands of western sugar maple grow in steep gullies and high ravines, especially on north-facing slopes. The quaking aspen is found almost exclusively on north-facing slopes above 7500 feet. The juniper tree is common below 7000 feet and has achieved its best growth on the dissected pre-Lake Bonneville fans that flank the western front of the mountains. Above 7000 feet, many slopes, especially north-facing slopes, support moderate stands of pinyon pine and mountain mahogany.

Sparse though the vegetation is in this semiarid area, the meager grass, edible shrubs, and succulent cacti provide at least scanty grazing for the native wildlife, for a few horses and cattle, and for sheep that are driven through the area twice each year on their way to and from the summer pastures in the high valleys of the Wasatch Mountains.

Previous and contemporary work

Two major geologic reports on the Tintic quadrangle, a 15 minute quadrangle that includes the Eureka quadrangle, emphasized the economic geology of the Tintic mining district, the eastern part of which lies within the Eureka quadrangle west of 112° 05' 30" west longitude, and had only small sections about the physiography and geography of the area. The Tower and Smith report (1899, p. 664-669) discussed weathering, Tintic Valley alluvium, the Lake Bonneville beds, and talus deposits. Loughlin (Lindgren and Loughlin, 1919, p. 15-21) described geographic position, topography, water supply, and vegetation. The geologic maps of both reports showed only two Quaternary formations, alluvium and Bonneville lake beds.

In 1941, T. S. Lovering, of the U. S. Geological Survey, began detailed mapping of the East Tintic district, east of 112° 05' 30", at a scale of 1:9,600; the project was later expanded to include geologic mapping of the whole Eureka quadrangle for publication at a scale of 1:24,000. In 1954, H. T. Morris assumed direction of mapping the East Tintic district.

Purpose of the investigation

The present study of geomorphology and surficial deposits is intended to supplement studies that Lovering and Morris made of the bedrock geology. Lovering divided the surficial deposits of the East Tintic district into three units: older gravels, younger alluvium, and the Lake Bonneville beds, which were subdivided into sand, silt, and gravel. The present report subdivides the deposits that Lovering mapped as older gravels and younger alluvium into lithologic units that are older than, contemporary with, and younger than Lake Bonneville. This subdivision recognizes loess and alluvium-colluvium of pre-Lake Bonneville age, two alluvial deposits of Lake Bonneville age, and alluvium and colluvium of post-Lake Bonneville age. The lacustrine deposits in this quadrangle are similar to and are here correlated with the Alpine and Bonneville formations of northern Utah Valley as described by Hunt (Hunt, Varnes, and Thomas, 1953, p. 17).

The work of Lovering and Morris concentrated on the hydrothermal alteration of the Paleozoic and Tertiary rocks and on the relation of the alteration to ore deposits. The present study of the area has used geomorphology to recognize major movement on post-volcanism faults, and has used the Tertiary rocks, the surficial deposits, and geomorphology to interpret the Cenozoic history.

Method of work

At the beginning of the field work the surficial deposits of some areas were mapped directly onto a 1:9,600 topographic base map; the deposits of other areas were mapped on aerial photographs at 1:20,000 and 1:24,000 scale. Critical features were located in the field by three-point resection using a Brunton compass or in the office by careful transfer from aerial photographs.

After the general stratigraphic relations of the deposits had been determined by detailed work on the Pinyon Creek drainage, in Burriston Canyon, along Silver Pass Creek, in Ruby Hollow, in Diamond Gulch, and in several localities outside the quadrangle,

Lake formation, described in the section on stratigraphy. Although the Salt Lake formation is not known to crop out in the quadrangle, its presence so close to the quadrangle and its record of part of the Cenozoic tectonic history of the region make it seem worthy of mention in this report.

Acknowledgments

The writer is indebted to many colleagues of the U. S. Geological Survey whose endeavors on similar or allied projects provided examples and yardsticks for the work here reported. He is especially grateful to T. S. Lovering who first suggested the project and who supplied information on the Middle Eocene tuffs, and to C. B. Hunt and R. B. Morrison who visited the writer in the field and helped with some of the problems that are peculiar to Pleistocene stratigraphy. Several colleagues have read early drafts of sections of this report, and the writer has taken advantage of their useful suggestions.

The writer is also indebted to the geologists who worked in the area and wrote reports on it long before he saw it: Tower and Smith (1899); Lindgren and Loughlin (1919); Lovering and others (1949); and Morris (1947).

The mining people of the area were generous in supplying information to the writer. He would like to express particular appreciation to the Chief Consolidated Mining Co. and its officers, especially to Mr. Cecil Fitch, Jr., Mr. Harry Pitts, and Mr. Robert Steele.

Some residents of Eureka and Dividend aided in providing

information about the history, water problems, and weather of the area. Among these people are Mrs. Belle Coffey, Mr. Tim Sullivan, Mr. Roscoe Harper, Mr. John Boss, Mr. Dee Clement, and Mr. Ira Miller.

SUMMARY OF THE GEOLOGY OF THE BEDROCK

Paleozoic stratigraphy

Paleozoic rocks of the Eureka quadrangle range in age from Early Cambrian to Late Mississippian. Although earlier workers in the area did not recognize Silurian rocks, Morris (1957, p. 12) indicates that part of the Bluebell dolomite is of Silurian age. The complete Paleozoic section consists of about 6500 feet of dominantly carbonate rocks lying on about 3000 feet of Lower Cambrian Tintic quartzite.

The table that follows is adapted from Loughlin (Lindgren and Loughlin, 1919) and from Morris (1957). In this table, the age, name, thickness, and description of lithology of the formations are adapted from Loughlin. Where the description by Morris differs appreciably from Loughlin's, Morris's description is given in parentheses. These differences of opinion about the formations range from minor differences in descriptions of lithology and measurements of thickness to the major difference in stratigraphic position of the Victoria formation. Loughlin believed that the Victoria quartzite is younger than the Pinyon Peak limestone, and Morris reports that the Pinyon Peak limestone overlies the Victoria formation.

Table 1. Generalized section of Paleozoic rocks in the Eureka quadrangle.

(Sources: Loughlin, in Lindgren and Loughlin, 1919, and Morris, 1957.)

SYSTEM and SERIES	NAME OF UNIT	THICKNESS IN FEET	DESCRIPTION
Mississippian System			
Upper Mississippian	Humbug formation	250 (650)	Brown and red sandstone beds 1 to 90 feet thick (8 inches to 15 feet or more) alternating with gray, blue, and black fossiliferous limestone beds 3 to 25 feet (1 to 10 feet or so) thick. Light-brown sandy shale about 30 feet thick forms the basal bed, and brown quartzitic sandstone about 12 feet thick caps the formation.
Upper and Lower Mississippian	Pine Canyon limestone (Deseret limestone)	1000 (900-1200)	Black, dense, cherty limestone in the lower part; medium to light gray, medium to coarse grained, cross-bedded, fossiliferous limestone in the upper part. (3 members: 1) basal phosphatic shale, 10 to 150 feet thick; 2) lower sandy or silty cherty limestone about 450 feet thick; and 3) an upper coquinoidal limestone with large nodules of black chert.)

SYSTEM and SERIES	NAME OF UNIT	THICKNESS IN FEET	DESCRIPTION
Lower Mississippian	Gardner dolomite (Madison limestone)	750 (700-900)	Mostly fine-grained, gray to dark bluish-gray dolomite with silicified fossils. At or near the top is 100 feet of black, highly carbonaceous, pyritic, shaly limestone. (Lower member averages 280 feet thick and contains 8 lithologic units of sandstone, limestone, and dolomite; upper member of two fossiliferous limestone units, the lower 375 and the upper 125 feet thick.)
Lower Mississippian (Upper Devonian)	Victoria quartzite (Victoria formation)	100 (250-300)	Alternating beds of limy quartzite and siliceous limestone, some conglomeratic. Pebbles of conglomerate are dolomitic, bluish-gray where fresh, but yellowish, pinkish, or reddish where weathered. (Includes 70 to 80 feet of coarse-grained dolomite of Devonian age included by Loughlin in lower part of Gardner dolomite. The lower 200 feet of the Victoria is actually gray dolomite interlayered with thin and thick beds of brown-weathering dolomitic sandstone.)
	Unconformity		

SYSTEM and SERIES	NAME OF UNIT	THICKNESS IN FEET	DESCRIPTION
Devonian System			
Upper? Devonian (Upper Devonian and Mississippian?)	Pinyon Peak limestone	150 (70-300)	Shaly limestone with mud cracks and possibly worm trails. Abundant fossil fragments, mostly unrecognizable.
Ordovician System			
Lower to Upper Ordovician (Ordovician, Silurian, and Devonian.)	Bluebell dolomite	700 to 1000 (350-600)	Mostly fine-grained dolomite but in part medium- to coarse-grained. Beds weather light to dark bluish-gray. Cherty beds about 100 to 200 feet above base. (Transfer lower third to Fish Haven.)
(Upper Ordovician)	(Fish Haven dolomite)	(275-350)	(Lower third of Loughlin's Bluebell. Thin- to massive-bedded, medium- to coarse-grained, dark- to light-gray dolomite.)
Lower Ordovician	Opohonga limestone	700-1000 (400-1000)	Mottled shaly limestone. Bands of medium- to light-gray limestone alternate with bands of yellow to red argillaceous material. Contains thin beds of intraformational conglomerate, and other beds containing pebbles of underlying formations. (Base is limy sandstone or sandy limestone.)
Lower Ordovician (Upper Cambrian)	Ajax limestone	770 (500-730)	Dark bluish-gray, cherty, magnesian limestone with a creamy-white dolomite bed, the Emerald dolomite member, 90 feet above the base. Above the Emerald member, the Ajax limestone is fine-grained and cherty. (The upper member is chiefly dolomite.)

Unconformity
(No unconformity)

SYSTEM and SERIES	NAME OF UNIT	THICKNESS IN FEET	DESCRIPTION
Cambrian System			
Upper Cambrian	Opex dolomite	390 (150-350)	Dark to light gray dolomite with green and red shale near middle of formation and with shaly limestone in top 85 feet and in a bed about 15 feet thick about 170 feet above the base. (Lower dolomite now in Cole Canyon dolomite.)
Middle Cambrian	Cole Canyon dolomite	510 (830-900)	Alternating dolomite beds 10 to 25 feet thick that weather white to dark gray. Dense, finely banded beds are argillaceous, other crystalline beds are pure dolomite. (Includes lower dolomite of Opex formation as originally defined.)
Middle Cambrian	Bluebird dolomite	175-200 (150-220)	Dark bluish-gray, fine-grained dolomite having short (10 mm) white rods of coarser grained calcareous dolomite.
Middle Cambrian	Herkimer limestone	225-235 (350-430)	Bluish-black, mottled, shaly, carbonaceous limestone. Has yellowish-brown to reddish blotches rich in iron and clay. (Divided into lower limestone, middle shale, and upper limestone members.)
Middle Cambrian	Dagmar limestone	75-100	Medium- to dark-gray argillaceous limestone that weathers yellowish to grayish-white.
Middle Cambrian	Teutonic limestone	565 (375-425)	Dark-gray to dark bluish-gray limestone, argillaceous and shaly in part. Has yellowish-brown bands or blotches in lowermost 100 feet.

SYSTEM and SERIES	NAME OF UNIT	THICKNESS IN FEET	DESCRIPTION
Middle Cambrian	Ophir formation	160-475 (275-430)	Green to dark brown, fine-grained, impure sandstone at base. Thick beds of shale and limestone alternate with limestone at top of formation. (Basal and top beds are shale.)
Lower Cambrian	Tintic quartzite	6000 (2300-3200)	Fine, even-grained, white to pale pink, nearly pure quartzite. Broken by three or more systems of vertical joints. Contains a few conglomerate beds. (Conglomerate beds are common near base and a basalt flow sheet 2 to 30 feet thick occurs about 980 feet above base.)

Structure of the Paleozoic rocks

The major structure in the Paleozoic rocks is the asymmetric, north-trending syncline whose axis is about half a mile east of Eureka. The syncline is broken by many high-angle faults, most of which strike between northwest and northeast. Formations on the eastern limb, as exposed on Pinyon Peak (Pl. VII) commonly dip 20° to 30° to the west, but formations on the western limb of the syncline are nearly vertical (Lovering and others, 1949, p. 13). The vertical beds of the western limb of the syncline are well exposed along Eureka Gulch, east of Eureka, and in the main east-west trending ridge south of Eureka (Pl. IV).

Complexities of the structure in the Paleozoic rocks have been discussed in all three major publications on this area (Tower and Smith, 1899; Lindgren and Loughlin, 1919; and Lovering and others, 1949), and in the latter two publications faulting in the area has been summarized as follows:

> "(1) during folding, (2) after folding but before volcanic activity, (3) during volcanic activity, (4) soon after volcanic activity but before mineralization, and (5) distinctly later than mineralization." (Lindgren and Loughlin, 1919, p. 90.)

> "Steep-angle faults are more prominent in the Tintic Mountains than are thrust faults but in the East Tintic district, low-angle movement at approximately the contact between the Ophir formation and the Tintic quartzite was widespread at an early stage in the Laramide revolution. Folding, steep-angle faulting, and minor thrusting were repeated during at least three intervals after the first low-angle movement and before ore was deposited." (Lovering and others, 1949, p. 13.)

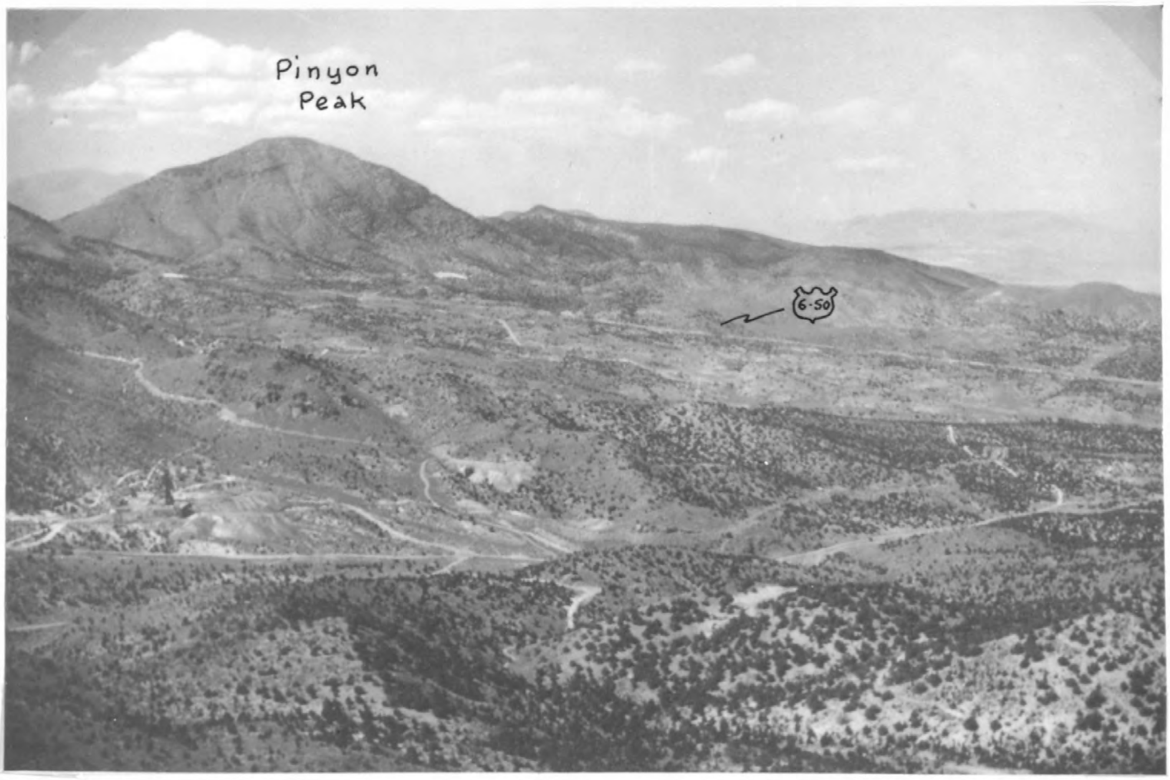


Plate VII.
Pinyon Peak and Goshen Slope area looking north-northeast from west end of Latite Ridge.

Tertiary igneous rocks

Igneous rocks of the Eureka quadrangle include both intrusive and extrusive series, and all series probably belong to the same epoch of volcanism. Morris (1947, pl. 8) indicated that the diverse sequences of igneous rocks that he mapped in the East Tintic district, which is included in the Eureka quadrangle from 112° 00' to 112° 05' W. and from 39° 55' to 40° 00' N., are different in different areas because the rocks range from plugs and dikes, through flows, to tuffs and volcanic breccia. Although Morris showed no standard sequence of extrusive and intrusive rocks, it is possible to construct such a generalized sequence from the work of Morris (1947, pl. 8) and from the work of Lovering (Lovering and others, 1949, p. 10-12; written communication, 1950). This composite sequence of the igneous and pyroclastic rocks of the East Tintic district includes:

Hornblende-biotite latite (youngest)
Augite latite
Tuffaceous conglomerate
Trachy-andesite
Biotite latite
Vitrophyre
Tuffs and agglomerate
Monzonite and latite dikes, pebble dikes, monzonite plug
Vitrophyre
Weathered surface; unconformity?
Quartz latite
Vitrophyre
Tuffs
Latite (oldest)

The total thickness of the extrusive rocks may be as much as 3000 feet. The complete sequence of rocks probably cannot be found at any one place in the area, but the common sequence of quartz latite, tuffs, and hornblende and biotite latites probably aggregated more than 2000 feet in most places, for the quartz latite is more than 1200 feet thick (Lovering and others, 1949, p. 10), and the latites are probably more than 500 feet thick.

CENOZOIC STRATIGRAPHY

TERTIARY SYSTEM

The Tertiary sedimentary rocks of the East Tintic Mountains include lower Tertiary(?) conglomerate, Middle Eocene tuffs, and the Pliocene(?) Salt Lake formation--a lacustrine deposit.

In the Eureka quadrangle, the lower Tertiary(?) conglomerate has been reported only from underground occurrences. The Pliocene(?) Salt Lake formation is not known to be exposed within the quadrangle, but is described here because it gives evidence that helps to fill a large gap in the geologic history of the quadrangle. In contrast to these two units, the Middle Eocene tuffs are abundant, especially along the eastern flank of the mountains.

Lower Tertiary(?) conglomerate

In the East Tintic Mountains, conglomerate of probable early Tertiary age has been reported as overlying the Paleozoic rocks and underlying the Middle Eocene volcanic rocks. In the Eureka quadrangle, along the northern and eastern slopes of Godiva Mountain, a pre-volcanism talus deposit of angular limestone blocks, somewhat cemented by rhyolite, was reported (Tower and Smith, 1899, p. 652). This conglomerate nowhere contains fragments of volcanic rocks; evidently it is a pre-volcanism talus or colluvial deposit. It may have been deposited early in the Tertiary period as a result of erosion following the Laramide orogeny.

The conglomerate may be exposed at the surface in places outside the quadrangle but has been found here only in tunnels and shafts between Paleozoic sedimentary rocks and Tertiary lava. In the Apex Standard No. 2 shaft, the conglomerate is several hundred feet thick (Lovering, personal communication).

Middle Eocene tuffs

The tuffs (Pl. VIII) of the Eureka quadrangle intertongue with flows. Both flows and tuffs are included in the Packard volcanic series and in the Laguna Spring volcanic series of Middle Eocene age (Lovering, written communication, 1956). The Packard tuff is the older and, where fresh, "is composed of distinct grains of feldspar, quartz, and biotite and fragments of glassy rhyolitic and latitic groundmass" (Lindgren and Loughlin, 1919, p. 45). The overlying Laguna Spring tuffs include 1) agglomerates and breccias containing fragments from the intertonguing flows or fragments of the Paleozoic rocks, and 2) "soft, gravel-like beds that intertongue with the Laguna Spring latite flows" (Lovering, written communication, 1956). These gravel-like beds are prominently exposed along the eastern front of the range in the northeast portion of the quadrangle (Pl. VIII). Because these deposits are not lithified, they are similar in appearance to Pleistocene deposits of volcanic gravel, but their Middle Eocene age is established by their intertonguing with flows of the Laguna Spring series that have been dated by plant fossils in the nearby Long Ridge area (Muessig, 1951, p. 96, 97).

Plate VIII. Outcrops of tuff

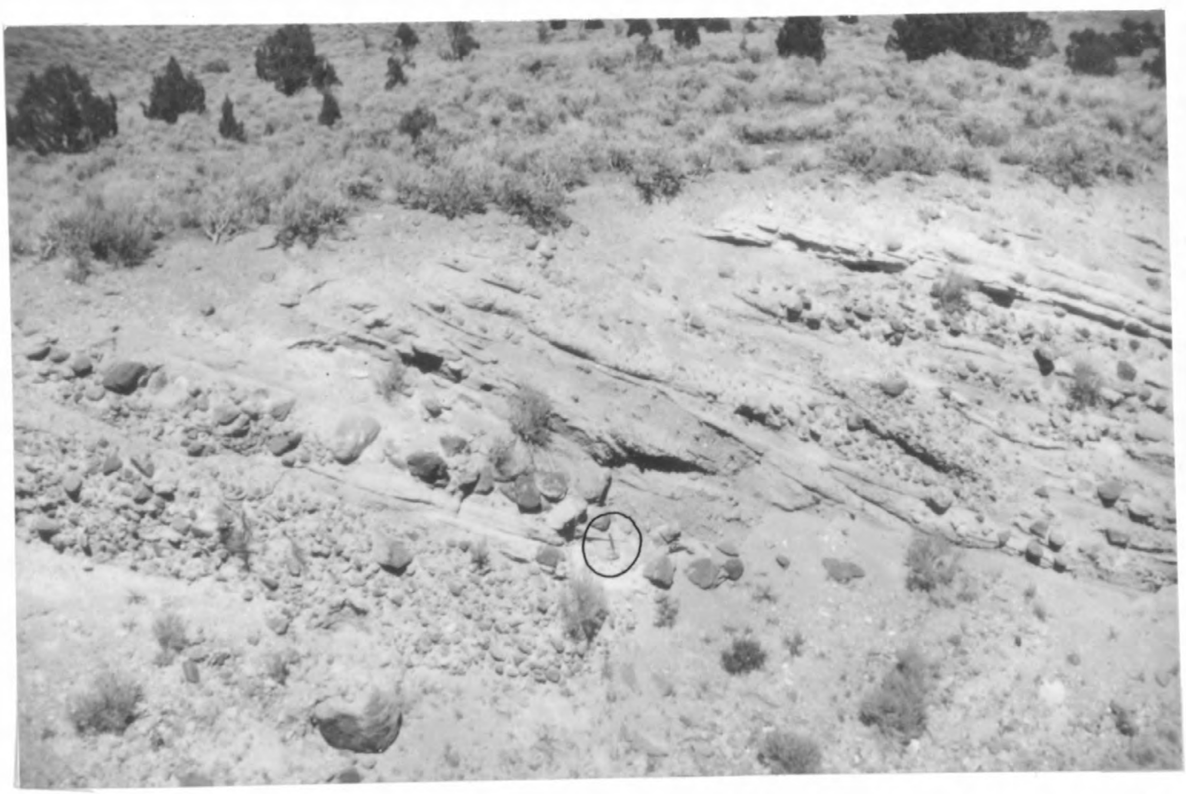
Top.- Outcrop of tuff at mouth of Dry Herd Canyon.

Flows overlie the cliff-forming tuff beds in the center of the picture.

Bottom.- Gravel-like tuff (tuffaceous conglomerate) of the Laguna Spring series in railroad cut in sec. 26, T. 9 S., R. 2 W.

The circled hammer shows scale.

Plate VIII.



Salt Lake formation

Occurrence and lithology.- The Salt Lake formation of Pliocene(?) age does not crop out in the Eureka quadrangle but it occurs about six miles west of Packard Peak, which is in the northwest corner of the quadrangle. The presence of the Salt Lake formation nearby helps to fill a gap in the rather meager late Tertiary history of the area.

Beds that I have assigned to the Salt Lake formation ([illegible], in prep.) crop out about 100 yards east of State Highway 36, about two miles north of the Juab-Tooele county line. The lowest beds are soft bentonitic clay. The clay is overlain (disconformably?) by thick-bedded white marl or soft limestone that contains abundant fresh-water gastropod and ostracode shells. Overlying the soft limestone is a buff tuffaceous sandstone containing clear volcanic glass shards that have an index of refraction of 1.496 $\pm$.004 (determined by E. J. Young of the U. S. Geological Survey). The sequence of beds is about 200 feet thick and dips about 15° eastward toward the mountains. Disconformably overlying these strata is a large Pleistocene fan that extends westward from the mountains.

The fossils and lithology show that the Salt Lake beds here belong to a fresh-water lake series, and the bentonite and glass shards show that the strata are in part of volcanic origin.

Significance of the Salt Lake formation.- The full story to be deciphered from the Salt Lake formation will not be known until more work is done, but the position of Salt Lake beds about 1000 feet above the highest shoreline of Pleistocene Lake Bonneville indicates that the Pliocene fresh-water lakes were more extensive than the Pleistocene lakes or that subsequent diastrophism changed the Pliocene basin much more than the 150 feet that post-Lake Bonneville undulations disturbed the Lake Bonneville basin (Gilbert, 1886, p. 298, and Pl. VIII). Fifteen degree dips of the Salt Lake beds indicate that post-Salt Lake diastrophism better explains the present position of these Pliocene(?) strata; more work on the formation elsewhere will undoubtedly reveal what other parts of the basin were deformed after Salt Lake time.

QUATERNARY SYSTEM

The Quaternary rocks of the East Tintic Mountains consist of four types: 1) eolian silt and sand; 2) alluvium and fan gravel; 3) colluvium, talus, and landslide debris; and 4) lacustrine clay, silt, sand, and gravel. Remnants of once-thick loess indicate widespread eolian activity in pre-Lake Bonneville time. The lake sediments were deposited in Pleistocene Lake Bonneville; the alluvial and colluvial deposits of the mountains are subdivided as to age on the basis that they are older than, contemporary with, or younger than the Lake Bonneville lacustrine deposits.

Some stratigraphic relations described here are compromises that best fit the known conditions. The difference in base level on the two sides of the range is by far the most important factor that determined erosional and depositional conditions in the quadrangle. The difference in base level resulted in fine-grained deposits and smooth slopes on the west side of the range and coarse-grained deposits and steep canyons on the east side of the mountains. Local weaknesses in the bedrock also caused more rapid erosion in some places than in others. Another factor complicating the stratigraphic interpretation is the abundant silt, apparently derived from an early Pleistocene loess, that in any given exposure may have been reworked once or many times since it was first deposited in the area. Many outcrops that are mostly silt look alike, and where the local stratigraphic relations are not clear, the silts have no infallible identifying characters that permit one to distinguish between silt that has been reworked once and silt that has been reworked many times. These complicating factors make correlation between deposits on different sides of the range tenuous, and make correlations between isolated deposits largely a matter of guesswork.

Pleistocene Deposits

Deposits of pre-Lake Bonneville age

LOESS

Occurrence and lithology.- One of the oldest Quaternary deposits in the area, perhaps the oldest, is a loess. Many remnants of this once-extensive deposit have been mapped, and it has been identified at several exposures where it lies buried beneath younger deposits. The loess consists principally of quartz grains, but also contains veinlets of lime carbonate, broken shards of clear volcanic glass, and a few rock fragments near the base. Fewer than one percent of

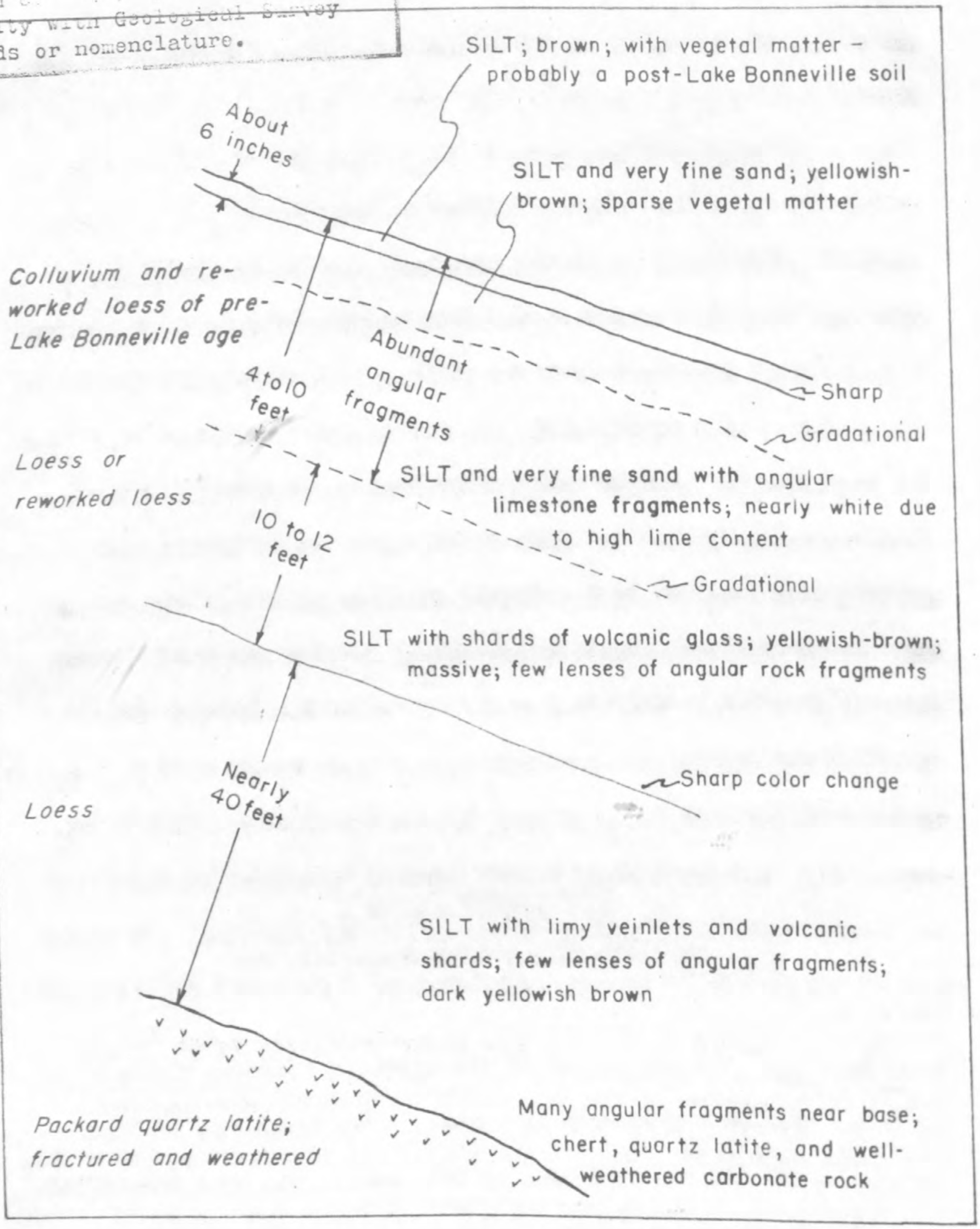


Figure 2.- Generalized section at portal of Tetro Tunnel, SE 1/4 sec. 18, T. 10 S., R. 2 W. Loess of pre-Lake Bonneville age overlain by colluvium of pre-Lake Bonneville age.

the grains are as large as 0.5 mm and most grains pass a 300-mesh screen.

At the caved portal of the Tetro Tunnel, on the north slope of Godiva Mountain (fig. 2), a 40-foot-thick stratum of medium brown loess overlies about one foot of colluvium of lava bedrock and underlies silt that grades upward into angular limestone colluvium, on which a pre-Wisconsin soil (p. 35) has been developed. In the Original Iron King shaft, about 200 feet above the bottom of Burriston Canyon, similar loess underlies a stream gravel that has a pre-Wisconsin soil. The base of the loess is covered in the shaft, and only about 8 feet of the deposit is exposed, but its position high on the side of a steep narrow canyon suggests that the canyon was filled to that height by loess or by other deposits on which the loess was deposited. It seems likely that the carving of the canyon in bedrock was accomplished before the loess was deposited because such a deposit could hardly survive throughout an erosion cycle capable of lowering the bottom of the bedrock canyon 200 feet. A thickness of 200 feet is probably excessive for the loess, but a blanket of loess only 20 feet thick could have supplied the tremendous amounts of fine-grained sediment laid down by Lake Bonneville during Wisconsin time.

The loess in its original state, or in one of its earliest reworked stages, underlies the old colluvium at the head of Ruby Hollow where in the shaft at an altitude of about 6640 feet in the NE$\frac{1}{4}$ sec. 5, T. 11 S., R. 2 W., it has been recognized about 6 feet below the surface.

Many exposures of remnants of silt deposits have been mapped on the eastern slope. These deposits have been identified as loess by their lithology and have been correlated with the buried loess because of the silt's medium brown color and the abundance of lime carbonate veinlets. Similar silt is buried under colluvium of pre-Lake Bonneville age in the railroad cut northeast of the Central Standard shaft (Pl. IX).

In most mapped exposures, the identity of loess as an eolian rather than an alluvial deposit is not readily recognized because it occurs on low-lying, gently dipping surfaces that admit either interpretation. However, these low-lying deposits have been interpreted as loess because their lithology not only is the same as deposits in the Tetro Tunnel but is the same as deposits high on steep slopes such as on the northern edge of sec. 10, T. 10 S., R. 2 W., and in the southwestern corner of sec. 2, T. 10 S., R. 2 W., where the topographic position of these steep deposits definitely indicates eolian origin.

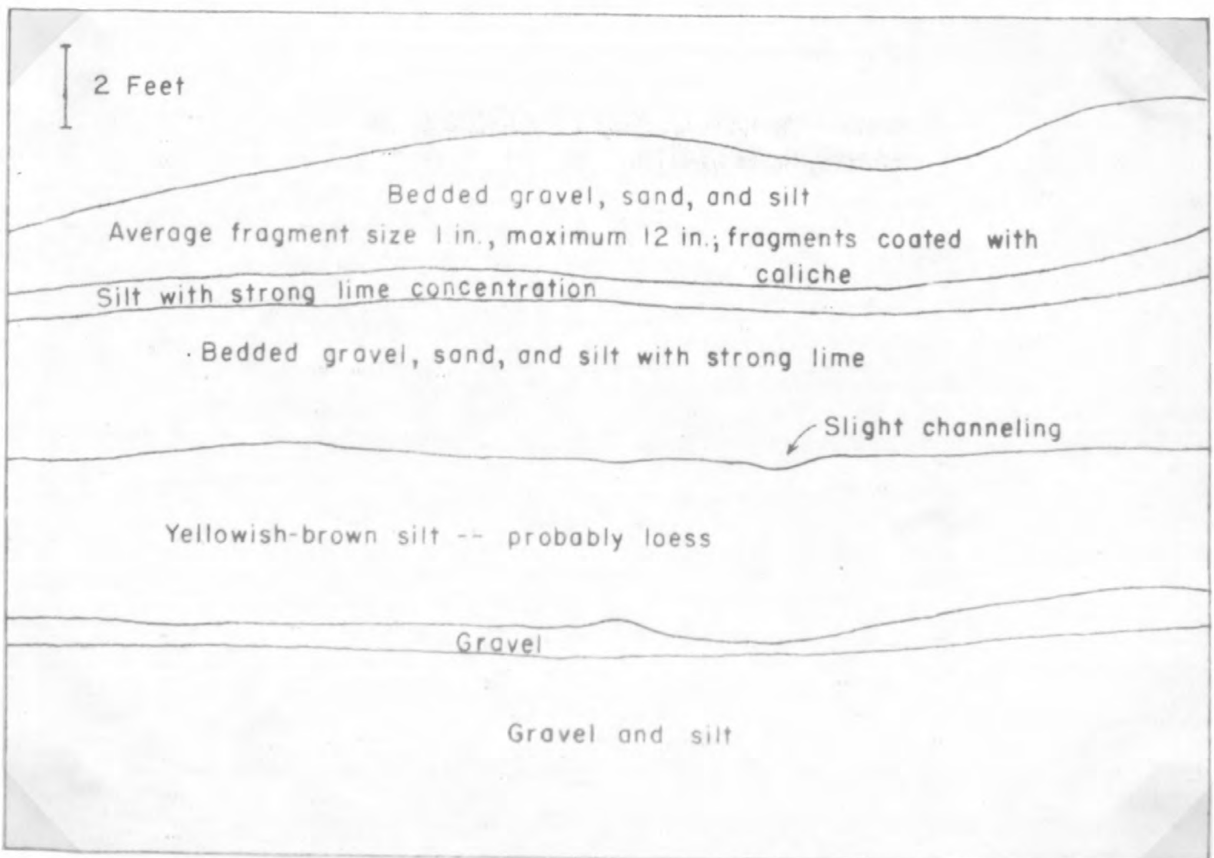
Geologic age.- The age of the loess can be fixed only within rather indefinite boundaries.

A bone fragment collected from loess underlying pre-Lake Bonneville fanglomerate in a stream channel in NE¼ sec. 3, T. 10 S., R. 2 W., was identified by Jean Hough of the U. S. Geological Survey as possibly belonging to a mule deer of the species *Odocoileus* (*Eucervus*) *hemionus*, whose range may be Yarmouth to Recent. Although this fossil has such a wide range, the closer dating of

Plate IX.- Section and sketch of pre-Lake Bonneville fan.

Top.- Section of a pre-Lake Bonneville alluvial-colluvial fan in railroad cut northeast of Central Standard shaft.

Bottom.- Sketch showing lithology in photograph above.


2 Feet
Bedded gravel, sand, and silt
Average fragment size 1 in., maximum 12 in.; fragments coated with caliche
Silt with strong lime concentration
Bedded gravel, sand, and silt with strong lime
Slight channeling
Yellowish-brown silt -- probably loess
Gravel
Gravel and silt

of the loess as early pre-Lake Bonneville age is suggested by lithology and by stratigraphic position.

The loess is probably younger than the Salt Lake formation for it is not indurated and is not tilted or faulted like the Salt Lake formation. Furthermore, the loess contains shards of volcanic glass that are similar to shards in the Salt Lake formation. The shards in the Salt Lake formation have an index of refraction of 1.496 $\pm$.004 (determined by E. J. Young of the U. S. Geological Survey), and have a fan-like habit that appears to be their original structure. The shards in the loess are not so abundant as the shards in the Salt Lake formation, but have an index of refraction of 1.496 $\pm$.001 (also determined by E. J. Young), and although most shards are broken, many fragments have the same fan-like habit. It seems likely that the shards in the loess were derived from the Salt Lake formation, and it is possible that the fine grains of lime carbonate and the silt-size and smaller quartz grains in the loess may also have been derived from the tuffaceous sandstone of the Salt Lake formation.

The loess is certainly older than the deposits of pre-Lake Bonneville age that overlie it in the Tetro Tunnel and in the Original Iron King shaft, but such an upper age limit is indefinite, for pre-Lake Bonneville Pleistocene time was at least ten and perhaps fifty times as long as Lake Bonneville and post-Lake Bonneville time combined (Flint, 1957, p. 300-1). Much more work is needed to subdivide pre-Lake Bonneville Pleistocene deposits and to make their age more precise.

Significance of the loess.- The loess has played three important roles that are not evident in the few deposits that remain in the area. If, as seems likely, the loess once blanketed the whole region, 1) it probably supplied a homogeneous base on which the pre-Wisconsin paleosol was developed; 2) soil and alluvial deposits derived from the loess probably supplied most fine-grained material now contained in deposits of the Alpine formation in the Bonneville basin; and 3) the loess supplied material for a transported arable soil in an area where climatic conditions since Lake Bonneville time have not been capable of developing an arable soil on bedrock, sand, or gravel.

1.) The 40-foot thick deposit of loess in the Tetro Tunnel and many eroded loess remnants throughout the quadrangle strongly suggest that a blanket of loess once covered the whole quadrangle, and probably the whole region. Such a blanket of loess could have been the base on which the strangely uniform pre-Wisconsin paleosol of the Rocky Mountain region was developed. Many remnants of the pre-Wisconsin paleosol in the Rocky Mountain region have been reported (Hunt and Sokoloff, 1950; Malde, 1955; Richmond, 1955; and others). Regardless of the composition of the underlying material, all workers attest the remarkable uniformity of the clay layer. Hunt (1954, p. 103) has said, "The similarity of the clay through the Rocky Mountain region, regardless of the great variations in the composition of the underlying parent materials, suggests a loessial origin." I believe that the loess of this quadrangle indicates that in early Pleistocene time loess may have been deposited widespread in the Rocky Mountain region and it provided a fairly homogeneous material on which the pre-Wisconsin soil was developed.

2.) If the loess supplied the base on which the pre-Wisconsin paleosol was developed, it is probable that the loess indirectly supplied the fine-grained material for the Alpine formation. This quadrangle does not cover a sufficiently representative part of the Bonneville basin to provide data for reaching such a conclusion, but Hunt (Hunt, Varnes, and Thomas, 1953) published figures to show that the 2.6 cubic miles of the Alpine formation in northern Utah Valley "represents an average lowering of the bedrock surface (in the Wasatch Range) of about 14 feet" (p. 37). He attributed the fine material derived from the lowering of that bedrock surface to a thick pre-Wisconsin soil whose upper portion was principally red-brown clay (p. 47).

If Hunt's assumptions are correct, a deposit of loess 20 feet thick would have been more than enough to supply all material for the Alpine formation and would have left plenty for the fine-grained material in the Provo formation. The 40-foot thick deposit of loess in the Tetro Tunnel indicates that a 20-foot average thickness for the loess is possible.

3.) Farming is not an occupation of the people of the Eureka quadrangle, but the loess of the quadrangle suggests that similar wind-blown material may have been the source for an arable transported soil in nearby agricultural areas of Utah.

The most intensively farmed areas of the state are along the Wasatch front (fig. 1) where ample water from the mountains supports truck farming, fruit orchards, and dairy farming. The most productive areas along the Wasatch front from south to north are Utah Valley (vicinity of Provo), Jordan Valley (Salt Lake City area), and the East Shore area between Salt Lake City and Brigham. In these areas, the greatest cultivation is on the lacustrine deposits of the Alpine and Provo formations or on alluvium and lacustrine deposits of post-Lake Bonneville age. Few pre-Lake Bonneville fans are cultivated because most are too gravelly. Hunt (1953, p. 47), in writing about northern Utah Valley, about 35 miles northeast of the Eureka quadrangle, said, "The only strongly developed and deep soils in Utah Valley are those ancient clayey ones that were formed prior to the period of Lake Bonneville. Soils that are post-Provo in age are only feebly developed and are shallow as compared to older soils." Thus farming of the Alpine, Provo, and younger formations is on soils whose arable characteristics are due to the fineness of the material that was transported to where the soils are now tilled. The arable soils are not due to pedologic processes but to the nature of the material when it was deposited.

Thus the loess, as the probable source of most of the fine material of the Alpine, Provo, and younger formations, has provided an ample supply of fine-grained, transported soil that, along with abundant water, has made the area along the Wasatch front one of the richest agricultural areas in the Rocky Mountain region.

ALLUVIUM AND COLLUVIUM

Occurrence and lithology.- In the Eureka area, alluvium and colluvium of pre-Lake Bonneville age are widely distributed as alluvial terraces in canyons and as slopewash and alluvial-colluvial fans in wide valleys and along the mountain fronts. The deposits are heterogeneous in size, shape, bedding, sorting, cement, and lithology of rock fragments.

Although flat-lying streamlaid alluvium is generally readily distinguished from the much steeper creep and slopewash colluvium, alluvium and colluvium commonly intertongue in many deposits and therefore such deposits of pre-Lake Bonneville age are described together here.

The alluvial deposits range in size from a sparse scattering of lithologically anomalous lag gravels on bedrock spurs, as on the spur 500 feet south of Apex Standard shaft, through well-developed terraces, as in the southern part of Goshen Slope, to large thick fans covering hundreds of acres, as at the mouths of Dry Herd and Rock Canyons and in Diamond Gulch (Pl. X). The colluvial deposits range from tiny remnants seemingly plastered high against bedrock cliffs, as the deposits on the south face of Pinyon Peak, to large bodies

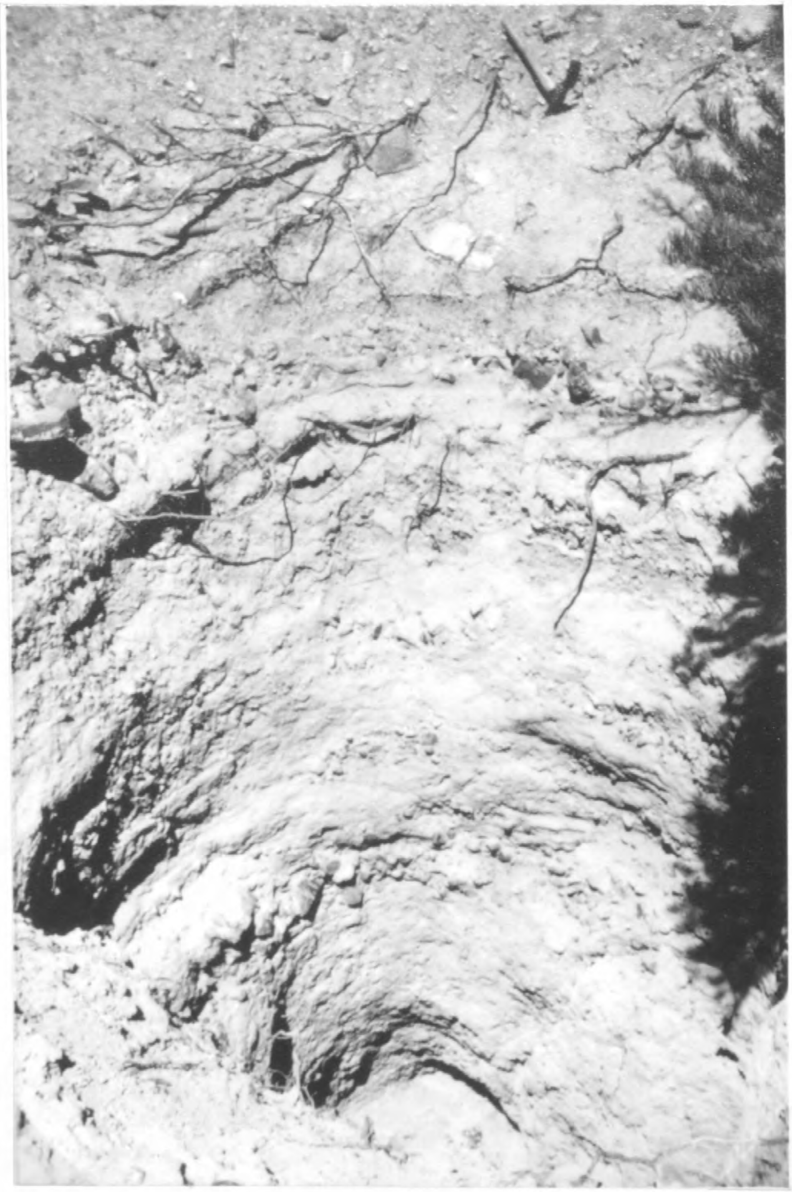


Plate X.
Pit dug 19 feet into pre-Lake Bonneville fan north of Diamond Gulch in sec. 12, T. 11 S., R. 3 W.
(The lithology in this pit is given in Appendix, section 3.)

such as the fans lower on the same slope on Pinyon Peak (Pl. XI).

Locally the alluvial-colluvial deposits are cemented with caliche. Caliche near the surface is hard and forms irregular plates, a few inches to several inches square and commonly up to an inch thick. It also coats pebbles and larger rock fragments. Commonly the plates and coated pebbles are embedded in an unconsolidated soft lime carbonate and silt.

Other caliche-cemented lenses or beds occur well below the surface or near the base of the gravels; some caliche-cemented lenses are 10 to 30 feet below the surface. Other lenses that are at the base of gravels deposited on volcanic bedrock are cemented by iron- and manganese-oxides. A typical exposure of a gravel cemented by iron- and manganese-oxide occurs 500 feet southwest of the Water Lily shaft, southeast of Pinyon Peak (Pl. XII). The base of this gravel is a dark-gray, grayish-black, or brown, porous conglomerate 2 to 4 feet thick; it contains volcanic and carbonate rock fragments, and its cement has oxides of iron and manganese but little or no lime; its porosity is due to voids left after solution of many carbonate pebbles. The few carbonate fragments that remain are badly decomposed from acidic ground water moving over the underlying, more impermeable, volcanic rock.

Geologic age and correlation.- Gastropod shells are locally abundant in the pre-Lake Bonneville alluvium-colluvium but have provided no precise information about age. Specimens of the gastropod *Oreohelix strigosa depressa* Cockerell collected from the upper part of a deposit

Plate XI. Colluvial fan on south slope of Pinyon Peak.

Top.- Colluvial fan on south slope of Pinyon Peak. The fan surface dips 9°.

Bottom.- Closeup of center part of photograph above.

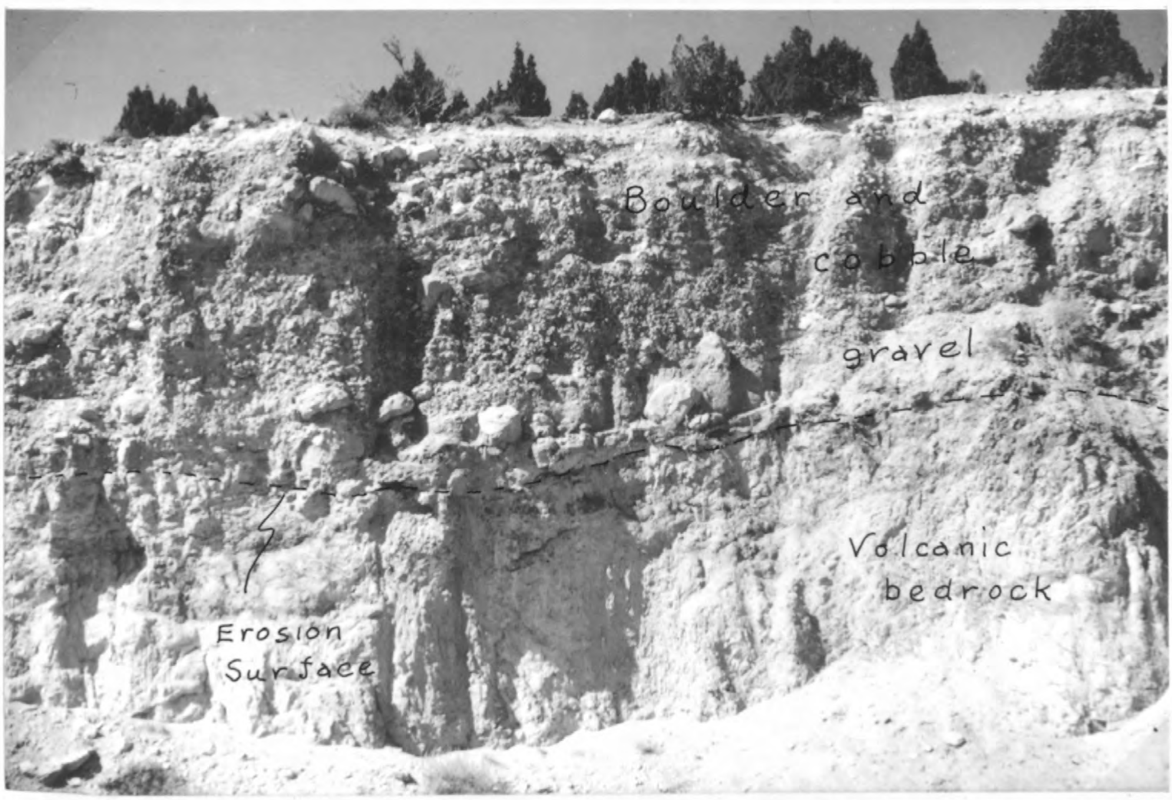

Boulder and
cobble
gravel
Volcanic
bedrock
Erosion
Surface

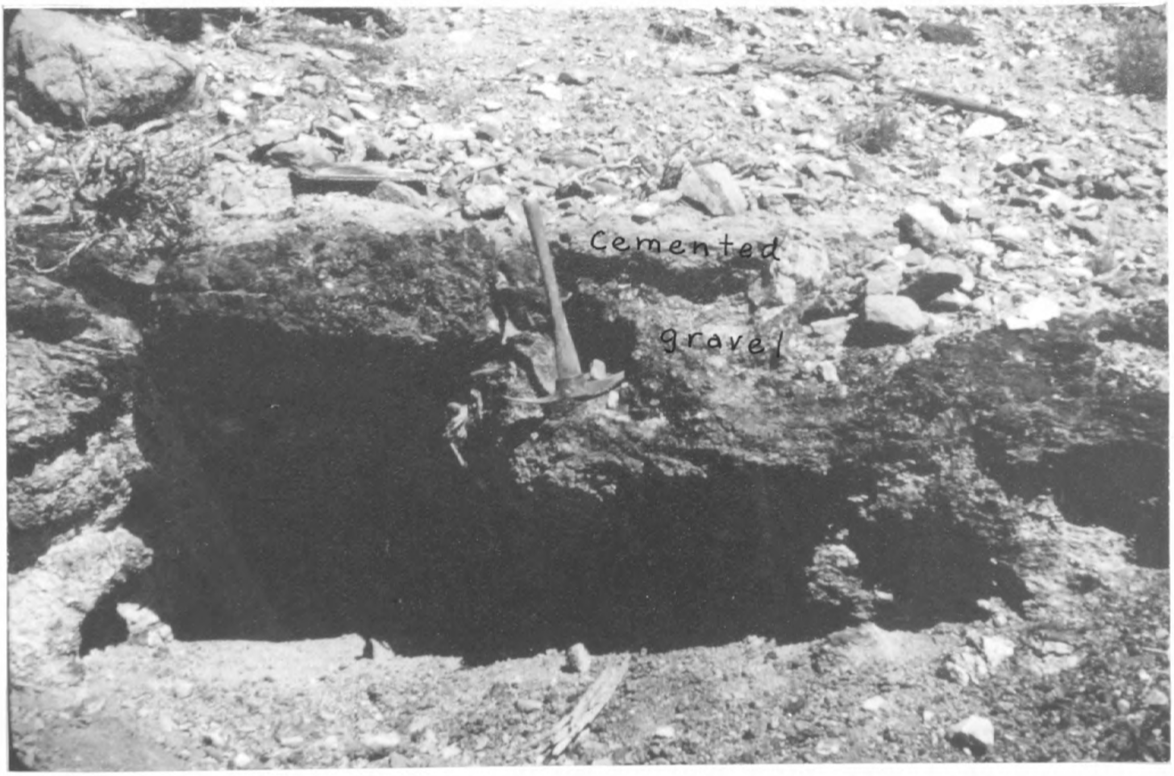
Plate XII - Gravel of pre-Lake Bonneville age.

Top.- Gravel cemented by iron- and manganese-oxide at contact with underlying volcanic rock.

Outcrop is on west slope of hill 500 feet southwest of Water Lily shaft in sec. 3, T. 10 S., R. 2 W.

Bottom.- Pre-Lake Bonneville alluvium in Burriston Canyon.

The pick points to a fossiliferous horizon containing _Oreohelix_ shells.


Cemented
gravel


Pleistocene-
Recent colluvium
Boulder
alluvium
Alluvial
silt with
gravel lenses

of pre-Lake Bonneville alluvium in Burriston Canyon (Pl. XII) in NE¼ sec. 20, T. 10 S., R. 2 W., were identified by J. P. E. Morrison of the U. S. National Museum. He said they could be Pleistocene or Recent.

The fossils are probably not older than Pleistocene, and therefore I believe that the unconsolidated deposits of this quadrangle that are equivalent to deposits lying above the Salt Lake formation west of the quadrangle are Pleistocene in age. This interpretation conflicts with the interpretation of Slentz (1955, p. 23) who, on geomorphic evidence in lower Jordan Valley, placed the 300-foot-thick Harkers fanglomerate in the Pliocene section of the Salt Lake "group." The Harkers fanglomerate is an unconsolidated deposit that, like the fans bordering the eastern flank of the East Tintic Mountains, has been "truncated and buried beneath the sediments of Lake Bonneville and more recent stream gravels" (Slentz, 1955, p. 28). The Harkers fanglomerate disconformably overlies tilted older members of Slentz's Salt Lake "group" in the same manner that the Pleistocene gravel mentioned in p. 23 disconformably overlies the Salt Lake formation west of the Eureka quadrangle. Inasmuch as the Harkers fanglomerate and the Pleistocene gravel west of the Eureka quadrangle occupy essentially the same stratigraphic position, contain similar beds of limy silt, and are evidently the result of similar regimens of deposition, I believe the two are equivalent. The age of neither deposit has been fixed with certainty, but the Pleistocene or Recent fossils at one locality in the Eureka quadrangle suggest that the deposits are not older than Pleistocene.

CYCLIC DEPOSITION OF ALLUVIUM OF PRE-LAKE BONNEVILLE AGE

In most places the only evidence that the depositional regime during pre-Lake Bonneville time was interrupted from time to time is the cut and fill structure of some exposures and the lithologically different beds, such as alternating gravels and silts, of other exposures. Along lower Silver Pass Creek, near the Apex Standard No. 1 shaft, however, three pre-Lake Bonneville alluvial gravels can be separated by geomorphic position as well as by lithology. The oldest (oal_1) is a gravel of quartzite, volcanic porphyry, limestone, and dolomite boulders lying on a hilltop about 170 feet above the present channel. About a quarter of a mile downstream from this gravel are two alluvial terrace gravels, one (oal_2) about 80 feet above the present channel, and the other (oal_3) about 35 feet above the present channel. Both younger gravels contain mostly volcanic rock fragments; the higher one has 2 to 10 percent carbonate rock fragments and the lower one has 10 to 25 percent carbonate rock fragments. The lowest of these gravels (oal_3) can be traced in almost continuous exposures to the Bonneville shoreline where the Bonneville gravel overlies it. Most other gravel mapped simply as oac is believed to be equivalent to this youngest gravel of pre-Lake Bonneville age.

PRE-WISCONSIN SOIL

Pre-Wisconsin soil--called paleosol (Hunt and Sokoloff, 1950, p. 109)--is less strongly developed in the East Tintic Mountains than in many places in the Rocky Mountain region. In its typical development in other parts of the Rocky Mountain region, the paleosol consists of about 5 to 20 feet of lime-enriched weathered parent material overlain by as much as 10 feet of lime-free reddish-brown clay whose lower part may contain tiny veinlets of $CaCO_3$ (Hunt and Sokoloff, 1950, p. 110). In nearby Utah Valley, this soil has been developed about equally well on a wide variety of parent materials, although the lime-enriched zone has little calcium carbonate where the soil is formed on non-limy parent materials (Hunt, Varnes, and Thomas, 1953, p. 44). In the East Tintic Mountains area the typical reddish-brown clay of the pre-Wisconsin paleosol occurs in few localities and is generally not more than 18 inches thick; more commonly, residual remnants a few inches thick remain. The clay has not been found on any of the large fans that are cut by lake-shore erosion and are overlain by lake deposits; if the paleosol was once well developed in the East Tintic Mountains, the clay zone has been almost entirely removed. However, all deposits described here as of pre-Lake Bonneville age are lime rich, generally throughout their full thickness. Powdery lime carbonate is mixed with fine silt, caliche coats gravel fragments, and in many places hardpan caliche occurs near the surface. Most pre-Lake Bonneville gravel deposits contain 20 to 90 percent silt and clay, either mixed with coarse fragments or as distinct beds or lenses several feet thick. The lime carbonate is disseminated through this fine material to depths of 15 to 20 feet, and the amount of lime is surprisingly uniform whether the contained gravel is limestone or volcanic rock. The small amount of gravel in many deposits and the freshness of the pebbles in that gravel strongly suggest that the lime carbonate may be more closely related to the silt than to the gravel contained in the silt.

As a working hypothesis in the field, this lime-richness of some deposits has been correlated with the lime-enriched zone of the pre-Wisconsin paleosol, and deposits containing it are described as of pre-Lake Bonneville age. This hypothesis does not imply that only the deposits of pre-Lake Bonneville age are lime rich, but rather that deposits of pre-Lake Bonneville age have more lime than younger deposits, which are otherwise lithologically similar. Deposits of pre-Lake Bonneville age contain sufficient lime to lighten the color of the silt and locally make it white or cream colored, whereas the deposits of Lake Bonneville age do not contain enough lime to affect appreciably the color of the fine-grained portions. Also, the strong lime zone of the older deposits is 3 to 5 times as thick as in the younger deposits and has been found in all deposits that are cut by lake-shore erosion or are overlain by lake sediments, but has not been found in deposits younger than the lake.

The evidence presented above suggests some tentative conclusions about the development of the pre-Wisconsin paleosol in the East Tintic Mountains. The sparse thin remnants of the characteristic reddish-brown clay of the pre-Wisconsin paleosol indicate that the old soil was not so strongly developed in the East Tintic Mountains as in the Wasatch Mountains and elsewhere, or that subsequent erosion has removed all but a few remnants of the clay. The vast quantities of lime carbonate in the deposits of pre-Lake Bonneville age could be the result of the same pedologic processes as the sparse reddish-brown clay, but the absence of a clay zone on the thick lime-rich alluvial fans of undoubted pre-Lake Bonneville age may be due to the fact that the lime was concentrated without the development of a strong clay; perhaps the lime was deposited with the silt as fine detrital calcium carbonate, as Brown suggested that lime was deposited in the Llano Estacado (Brown, 1956, p. 1-15).

Deposits of Lake Bonneville age

Wisconsin Lake Bonneville filled Goshen Valley and inundated the eastern border of this quadrangle. The lake cut shorelines at many different levels; the highest shoreline, named Bonneville (Gilbert, 1890, p. 93-94), is most prominent. Both bedrock and alluvial fans were cut by the shorelines; and lake clay, silt, sand, and gravel were deposited on bedrock and fans. After the lake receded, the shorelines and lake deposits were in turn cut by stream channels and were partly covered by younger alluvial and colluvial deposits.

In the vicinity of the Eureka quadrangle, Lake Bonneville had three main stages. The deposits of the same three stages in Utah Valley were called by Hunt the Lake Bonneville group, and were divided by him into three formations: the Alpine, Bonneville, and Provo formations (Hunt, Varnes, and Thomas, 1953, p. 17). The classification of the lacustrine deposits of the Eureka quadrangle follows Hunt's pattern except that within this area there are no lacustrine deposits of the Provo formation because the highest level reached by Lake Provo is about 100 feet below the lowest point in the quadrangle. However, many alluvial deposits of the uplands are of Provo age so the term is used extensively in the following text.

Landslides are believed to be of Lake Bonneville age because of the age of soil developed on them. Landslide deposits are differentiated on the geologic map but are discussed in this paper as physiographic features rather than as sedimentary deposits.

LAKE BONNEVILLE GROUP

Alpine formation

At the type locality in northern Utah Valley, the lacustrine Alpine formation consists of a gravel member, a sand member, and a silt and clay member and has a maximum thickness of about 150 feet. (Hunt, Varnes, and Thomas, 1953, p. 17-18.)

In the Eureka quadrangle, the Alpine formation is principally gray silt and fine sand. It is well sorted, moderately well-bedded, and contains abundant gastropod and ostracode shells. Half a mile south of U. S. Highway 6 and 50 near the eastern edge of the quadrangle, extensive Alpine deposits occur. During the lake stages, streams draining eastward from the Goshen Slope area carried fine detritus into the lake. Lake currents then carried the material southward and westward and deposited it as an L-shaped embankment around the bedrock headland. These deposits of the Alpine formation are probably thicker than other deposits along the eastern edge of the mountains, but the base is concealed and the estimated thickness, 25 feet, is little better than a guess.

Other exposures of the Alpine formation occur sparsely along the mountain front, and many deposits are probably concealed by younger alluvium.

Bonneville formation

The Bonneville formation includes gravel and sand deposited at or just below the Bonneville shoreline, which is at an altitude of about 5135 feet. Along the eastern edge of the quadrangle, lacustrine gravel and sand extend for about nine miles, and occur here and there as beaches, benches, bars, and spits.

The gravel consists of rounded fresh pebbles and small cobbles, many of them flattened or discoidal--additional evidence that the deposits of gravel are littoral in origin. Fine slopewash or windborne material of later age is commonly mixed into the upper few inches, but below this cover the deposits are mostly gravel. In many places the gravel may be identified by "displaced lithologies" (Jones and Marsell, 1955, p. 89), so named because the gravel fragments are different from the nearby source rocks. For example, the beach deposits in sec. 27, T. 10 S., R. 2 W., contain limestone moved southward by shore drift across the mouths of local streams that drain only volcanic rocks.

Although gravel deposits occur at or immediately below the Bonneville shoreline, about half a mile south of U. S. Highway 6 and 50 in sec. 6 and eastward, several parallel benches of gravel overlie the embankment deposit of Alpine silt, and collectively the benches have a vertical range of at least 200 feet. The gravel benches are L-shaped, convex toward the lake, and evidently are beach deposits, showing that the lake stood at many levels below 5135 feet.

In other places the gravel occurs as bars, as in the SW$\frac{1}{4}$ sec. 1, T. 10 S., R. 2 W.; and as spits, as in sec. 1, T. 11 S., R. 2 W. The base of the gravel is not exposed, but nowhere is the gravel more than 15 or 20 feet thick.

Sand deposits are exposed in sec. 12, T. 10 S., R. 2 W., north of U. S. Highway 6 and 50. The sand averages 1 to 2 mm in diameter, but contains some pebbles as much as 15 mm. It occurs in two exposures that are dissected portions of a once-continuous bar. The sand and pebbles are finer southeastward; the decrease in grain size southeastward indicates shore drift in that direction. The bar rests on bouldery fanglomerate or tuff.

The deposits of the Bonneville formation are as sparse in this area as in other parts of the Lake Bonneville basin (Hunt, Varnes, and Thomas, 1953, p. 20). Along the whole nine-miles-long shoreline in this quadrangle the Bonneville formation covers about 300 of the nearly 1500 acres inundated during the Bonneville stage. The sparse distribution of these deposits is due principally to their having been deposited only at or near the shoreline of Lake Bonneville, but is also due to post-Lake Bonneville erosion that has extensively dissected them.

ALLUVIUM OF LAKE BONNEVILLE AGE

The great difference in the stream regimens produced by the different gradients of the two sides of the mountains has made it necessary to group the deposits differently on the two sides of the range. On the east side, where gradients are steeper, no alluvial deposits of Alpine or Bonneville age have been recognized, and all alluvial deposits that are correlated with the Lake Bonneville group are believed to be of Provo age; on the west side of the range, the deposits are appreciably finer grained and some deposits may be as old as Alpine.

Silt of Alpine, Bonneville, or Provo age

Occurrence and lithology.- A light yellowish-brown to reddish-brown silt overlaps gravel of pre-Lake Bonneville age in Diamond Gulch, Ruby Hollow, and other smaller canyons that drain westward. This silt forms blanket deposits that probably are less than five feet thick, and partly fills channels cut into deposits of pre-Lake Bonneville age.

Many samples of the silt were sieved by hand, and the various fractions were examined under the binocular microscope. These analyses show that the silt consists mostly of silt and clay; less than 5 percent of any sample contains fragments larger than 0.5 mm.

The most abundant recognizable fragments are angular to rounded quartz grains, but the samples also contain small fractions of feldspar, volcanic glass, and dark minerals, of which only magnetite was identified. Most samples strongly effervesce in dilute hydrochloric acid owing to the presence of powdery lime carbonate.

The sparse coarse sand and gravel in the silt commonly occur as lenses and, where present, distinctly show the bedding of the deposit.

Geologic age.- It is difficult to distinguish this yellowish-brown silt from the loess of pre-Lake Bonneville age and from the silt beds in other pre-Lake Bonneville deposits. In this area, the age of the yellowish-brown silt has been determined as Lake Bonneville because the silt fills channels cut into the alluvium-colluvium of pre-Lake Bonneville age and has been overlapped by Recent deposits. In Diamond Gulch, for example, the flood plain of the Gulch is 10 to 20 feet below the terraces of pre-Lake Bonneville gravel and is filled with the silt. The silt in turn has been cut by gullies that are filled with Recent deposits.

The precise correlation of this silt with the lacustrine deposits of Lake Bonneville age is not known because it has not been possible to trace the silt with any certainty to the nearest Bonneville shoreline, some 10 miles away in Tintic Valley. This silt could be as old as an alluvial silt of Alpine age that in the Fivemile Pass quadrangle, about 20 miles to the north, was traced to an Alpine lacustrine deposit. Or it could be the same age as the gravelly-silt of Provo(?) age in the Boulter Peak quadrangle, which adjoins the Eureka quadrangle to the northwest. ([illegible]). Until its age can be more definitely established, it is here correlated with one or more of the units within the Lake Bonneville group.

<u>Gravel of Provo(?) age</u>

Gravel of sub-rounded pebbles, sand, silt, and sparse cobbles forms terraces 5 to 15 feet below terraces of pre-Lake Bonneville age. These terraces have been partly or completely removed from many canyons, but in the broader valleys, such as the upper part of Pinyon Creek, tributary terraces are graded to the main stream terraces. The deposits are distinctly bedded and in general have only fair sorting except in lenses, where the gravel is well sorted.

Fans formed by this gravel along the mountain front have smooth rather than rubbly surfaces. The soil developed on the gravel is weak; it consists of a leached zone 6 to 12 inches thick at the surface and a zone of weak calcium-carbonate concentration for 2 to 3 feet below the leached zone.

The gravel has been mapped on the east side of the mountains as Provo(?) age because it cuts the Bonneville shoreline and is in turn overlapped by two younger gravels. East of the quadrangle the gravel may intertongue with lacustrine deposits of the Provo formation, but this possibility has not been proved.

This gravel has been distinguished from the silt of Alpine, Bonneville, or Provo age because the relationship between the two is not clear. The great difference in the lithology probably is due principally to the great difference in the stream regimens on the two sides of the range, but the difference in lithology could be due in part to a wider age range for the silt. It is likely that the upper part of the silt of Alpine, Bonneville, or Provo age is the equivalent of the gravel of Provo(?) age, but correlation between the two cannot be made until more is learned about both.

Pleistocene-Recent Deposits

COLLUVIUM OF LAKE BONNEVILLE-RECENT AGE

Distribution and lithology.- Colluvium of Lake Bonneville-Recent age includes the almost ubiquitous slopewash of both steep and gentle slopes and sparse talus and other deposits due to frost-action.

The more common slopewash deposits of Lake Bonneville-Recent age contain gray or brown silt, angular to subrounded pebbles and cobbles, and are moderately well-bedded subparallel to their slopes. Most deposits which are only a few feet thick overlap and partly or completely conceal older alluvial and colluvial deposits.

As is common in western United States, the colluvial cover in the quadrangle is generally better developed on north-facing slopes than on south-facing slopes. This development is especially evident in Ruby Hollow where the north-facing slopes are covered with apparently thick deposits of both older and younger colluvium, whereas the south-facing slopes are virtually bare. Presumably the greater retention of winter snow on north-facing slopes promotes deeper weathering of bedrock and better development of vegetation, and the heavier vegetal cover then holds the colluvium in place.

Talus and rock streams occur on steep slopes on both Paleozoic and Tertiary rock formations but are more widespread and thicker on the latter (Pl. XIII). Talus is composed principally of fresh angular rock fragments from pebble- to large block-size and little or no fine material. Both large and small fragments have apparently been broken from bedrock by the action of frost. On slopes of Paleozoic bedrock, rock streams of pebble-size fragments commonly surround remnants of pre-Lake Bonneville colluvium. An extensive talus deposit fills the scarp of the landslide on the east face of Lime Peak. Some talus deposits, such as the one on a north-facing slope of latite in sec. 29, T. 10 S., R. 2 W., consist largely of blocks 2 to 4 feet long.

Other deposits due to frost-action occur in nearly flat, shallow depressions at high elevations. These deposits are commonly only a few feet thick and consist of angular cobbles mixed with smaller fragments and sand and silt, and covered by 10 to 12 inches of silty material that has a weakly developed soil profile. The rather sharp contact between the dominantly fine top layer and the coarse fragments below suggests that the frost-action which stirred the lower material became less active at some time in the past, and fine slopewash later covered the deposit.

Age and correlation.- The Lake Bonneville-Recent colluvium unconformably overlies the pre-Lake Bonneville alluvium-colluvium. In most places the older deposit is topographically higher than, but surrounded by, the younger colluvium; in a few places the younger deposit completely covers the older deposit, and some seemingly-thick deposits of Lake Bonneville-Recent age owe most of their bulk

Plate XIII.
Talus-covered volcanic-rock slope in Rock Canyon shows that the volcanic rock weathers readily.

to buried pre-Lake Bonneville deposits.

The age of the deep dissection of the pre-Lake Bonneville alluvium-colluvium is not certain, but the dissection is presumed to have occurred in an arid cycle that preceded the filling of Lake Bonneville. The topographic unconformity therefore has been used to separate some Lake Bonneville-Recent deposits from deposits of pre-Lake Bonneville age.

No fossils have been found in the deposits of Lake Bonneville-Recent age, but these deposits can be separated from older deposits by lithologic differences that are due principally to stronger soil development on the older deposits. The younger colluvial deposits have little or no caliche and less lime carbonate than the pre-Lake Bonneville deposits, and are generally characterized by gray or brown rather than tan silt.

Most slopewash deposits of Lake Bonneville-Recent age probably span a long period of time--which began after the deep dissection of the pre-Lake Bonneville colluvium and continued almost to the present. This deposition was not necessarily continuous but it is likely that there was no marked slope erosion between deposition of the Lake Bonneville colluvium and of most Recent colluvium.

The flat-lying frost-action deposits and the talus deposits that consist principally of boulder-size material probably were formed when the climate was more severe than it is at present. This observation is difficult to confirm in the talus deposits, for weathering of the surfaces of the blocks is about the same as weathering of bedrock exposures, but the unmixed relatively fine-grained upper layer covering the frost-action deposits indicates that the frost activity is less now than it was at the time when the underlying coarse and fine material was thoroughly churned.

Recent Deposits

ALLUVIUM

The earliest Recent alluvium is a gravel that fills or partly fills the present floodplains of most major streams and many tributaries and, in areas draining volcanic rock, forms extensive rubbly fan deposits, such as along the eastern front of the mountains. In the major streams, the gravel consists of small cobbles, pebbles, sand, and silt, up to a thickness of 15 feet. It is well bedded, but individual beds are not as distinctively sorted as are beds in some alluvium of pre-Lake Bonneville age. At the mouths of canyons along the eastern mountain front, gravel of coarse pebbles and small boulders forms fans that are lithologically like the gravel of Provo(?) age but are readily distinguished from the older fans by their rougher surfaces. The Recent fans are rubbly and have cobbles and small boulders scattered over their surfaces.

The early Recent alluvium is difficult to distinguish from the gravel of Provo(?) age in any area where only one of the deposits is present. Where both deposits are present, the Recent alluvium is two to five feet below the gravel of Provo(?) age and is separated from the older deposit by a steep but smooth slope. Where only one deposit is present topographically below a deposit of pre-Lake

Bonneville age, the slight difference in terrace level is not sufficient to identify the single deposit, and the following criterion has been used: tributary terraces in the gravel of Provo(?) age are graded to the main stream deposits; tributary terraces of Recent alluvium are slightly higher than main stream terraces where the two join. The difference in height may be as much as a foot or more but commonly is only a few inches. It is sufficient, however, to be readily recognized.

Other and younger alluvial deposits form narrow, vegetation-covered terraces, 2 to 3 feet above present channel bottom along parts of some major streams. They are discontinuous and difficult to correlate. They may be proto-historic or historic deposits (Bryan, 1925; Hunt, 1954, p. 117), but no artifacts or fossils have been collected from them.

An unusual cementation in Recent alluvium occurs in the channel of Silver Pass Creek near the Apex Standard No. 1 shaft in sec. 22, T. 10 S., R. 2 W. Some gravel in the channel bottom is cemented by iron oxide, probably Goethite, part of which was deposited in the summer of 1952 (Pl. XIV). Upstream from this area are many mine dumps containing limestone and pyrite. During times of heavy run-off such as followed the winter of 1951-52, the waters of the stream carry iron and carbonate leached from the mine dumps. At places in the stream bed the heavily mineralized water deposits iron oxide as a colloform coating of Goethite on pebbles and boulders. As the amount of water decreases, more and more evaporates in the stream

Plate XIV.
Deposit of Goethite in channel of Silver Pass Creek in NE$\frac{1}{4}$ sec. 22, T. 10 S., R. 2 W.

channel; the resulting precipitant leaves a hard brown crust that cements the pebbles into a compact conglomerate.

A striking, though sparse and not extensive, alluvium consists of angular to subrounded boulders and cobbles deposited in bottoms of steep canyons or near their mouths. This alluvium contains little or no fine material; some deposits contain only fragments six inches or more in diameter. The deposits apparently are lag gravels that remain from mudflows whose fine constituents later were moved downstream.

COLLUVIUM

Two Recent slump deposits can be dated by aerial photographs, although they are not shown separately on the geologic map. The two dated slumps, which involve only a few thousand square feet of surface, appear on photographs taken in 1952 but not on photographs taken in 1943. One slump in sec. 33 near Silver Pass (Pl. XXII and p. 83) evidently resulted from the headward erosion of a stream which effected a capture in Recent, probably Historic, time (Goode, 1954, p. 1376). Another slump occurred on the north face of the hill south of Dividend. This slump appeared fresh in the summer of 1952, and may have occurred during the spring thaw after the heavy snows of the winter of 1951-1952.

The lack of extensive slump and creep deposits indicates that the colluvial slopes of the East Tintic Mountains are stable now and have probably been stable since Lake Bonneville time. This present stability could suggest that the slopes will remain in equilibrium for a long time in the future, but it is likely that the present equilibrium has resulted from stable climatic conditions that may even now be changing. If arroyo cutting were to increase significantly, headward erosion by streams could oversteepen many slopes and result in widespread colluvial activity.

GEOMORPHOLOGY

The Landscape and Its Control

The diverse landscape of the Eureka quadrangle was formed by weathering and erosion in an area of complex structure and of varied lithology. The effects produced by running water, frost, mass-wastage, and wind have been different from place to place because of differences in resistance of the rocks; erosion is stronger on the east side of the range because of steeper stream gradients; and the intensity of weathering and erosion has changed from time to time as a result of diastrophism and of changes in climate.

The Eureka quadrangle is near the center of the East Tintic Mountains, one of the fault-block Basin Ranges. Most of the quadrangle is underlain by volcanic flows, pyroclastic rocks, and surficial deposits, but near the crest of the range, the volcanic cover has been stripped away to expose an ancient mountain mass carved into a faulted Laramide syncline of Paleozoic rocks. The Paleozoic rocks retain much of their pre-volcanism topography, which suggests that the stripping is relatively recent. The topography in the volcanic rocks is youthful on the east side of the range but is submature on the west side because of the difference in gradients on the two sides of the mountains (Pl. XV). The surficial deposits range from remnants of early Pleistocene loess to Recent boulder fanglomerate. The deposits cover many slopes and fill or partly fill canyons; excess material from the mountains has spilled out from the canyons to form fans along the mountain fronts. Flanking

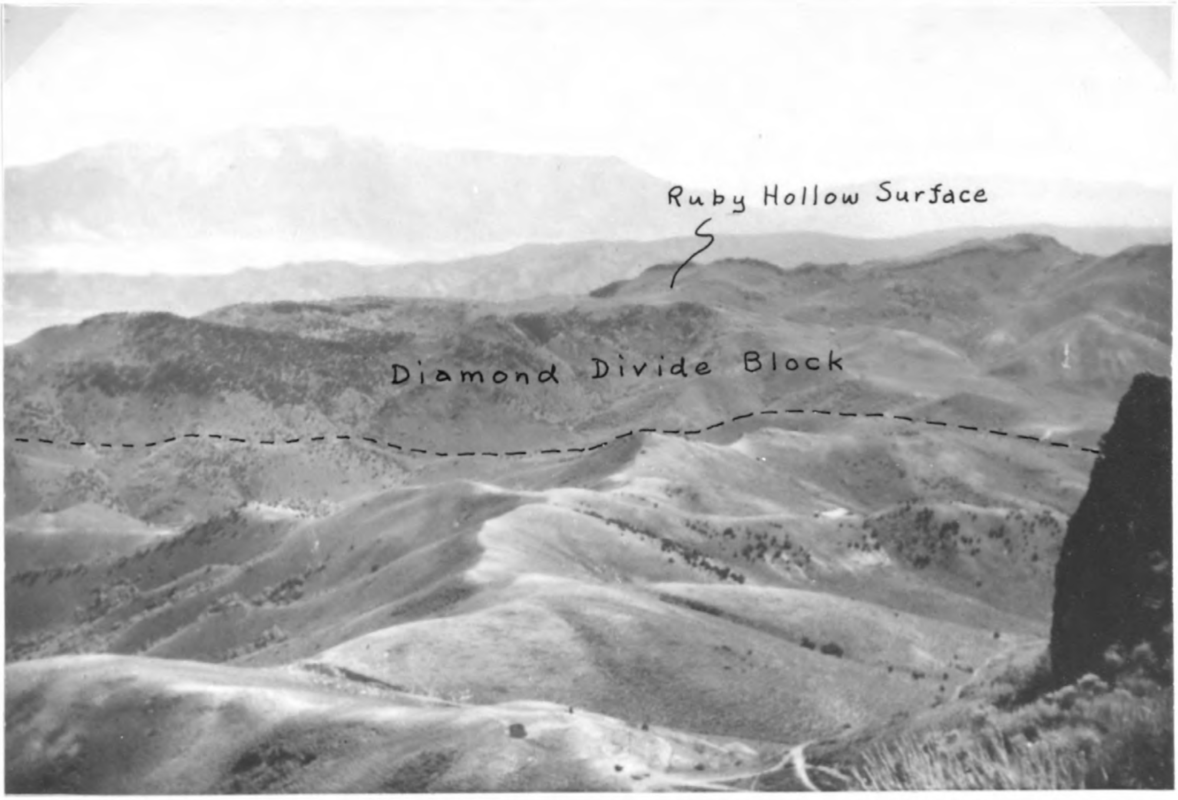


Plate XV.

Looking southeast along the county-line divide from east face of Mammoth Peak.

The difference in steepness of eastward-draining (to the left) and westward-draining (to the right) slopes is apparent.

The Ruby Hollow Surface on the uplifted Diamond Divide Block is flat surface in center of picture. Only the central part of the Diamond Divide Block is visible.

the eastern edge of the mountains are sparse deposits of Lake Bonneville.

Resistance of the rocks

The combinations of factors that determine the kind and shape of landforms in an area as complex as the Eureka quadrangle are almost limitless. Important among the features that control the shape of landforms are differences in resistance of fresh rocks and the changes in resistance wrought by alteration or weathering on certain rocks. The fresh rocks of the quadrangle include quartzite, limestone, dolomite, shale, latite, quartz latite, tuff, and the surficial deposits. The Paleozoic rocks and the volcanic rocks have been altered in places by hydrothermal solutions, and all rocks have been weathered. In general, rocks that are hydrothermally altered weather more readily than fresh rocks.

The effects of alteration, weathering, and erosion on the rocks of the quadrangle must be considered together because all three factors have contributed in forming today's landscape. Weathered rocks erode more readily than fresh rocks; and altered rocks weather more readily, and hence are eroded more easily, than fresh rocks. The changes in certain rocks effected by alteration and weathering and the susceptibility of the rocks to erosion will be described here; the landforms that have resulted from the effects of erosion on the various rocks will be described later as <u>Physiographic Features</u>.

Effects of alteration

Prominent among the types of hydrothermal alteration described by Lovering (Lovering and others, 1949, p. 16-21, p. 25) are "sanding" of dolomite, pyritic alteration, argillic alteration, and "accelerated weathering."

Sanded dolomite has been leached until only individual grains of dolomite "sand" remain; sanded dolomite is exposed in the road cut at the end of the Paleozoic-rock ridge in NE$\frac{1}{4}$ sec. 9, T. 10 S., R. 2 W.

Pyritic alteration of volcanic rock is so called because pyrite has been disseminated through the rock. The rock remains resistant until weathering changes the pyrite to limonite, after which the rock breaks down readily.

A rather dramatic example of the results of the difference in the speed of weathering between pyritized quartz latite and nearby carbonate rocks is to be found in a deposit laid down since mining was begun at the Iron King No. 2 mine in sec. 2~~7~~1, T. 10 S., R. 2 W. The dump from that mine dammed a small valley and caused the detritus from upstream to be deposited in the basin formed by the dam. About 95 percent of the gravel deposited in this basin since the damming is of volcanic rock, although only Paleozoic carbonate rocks are exposed for about a quarter of a mile upstream. The volcanic rocks are above the Paleozoic-rock area, and cover about twice as much of the drainage area as the Paleozoic rocks. Most detritus in this stream channel comes from the southeastern ridge of Big Hill where the volcanic rocks are pyritized.

Argillic alteration includes the changing of feldspar phenocrysts to clay and the replacement of minerals by clay. A striking example of the latter type of alteration occurs in Dragon Canyon, in sec. 31, T. 10 S., R. 2 W., where halloysite that replaced limestone is being mined for use in oil refining.

Accelerated weathering may be the result of leaching by supergene as well as hypogene solutions; the rock so altered is easily removed by mass-wastage. In a road cut at the west end of Homansville Canyon, in NW¼ sec. 9, T. 10 S., R. 2 W., the altered volcanic rock is about as resistant to mass-wastage as loess.

Effects of weathering

The term weathering as used in this section includes all effects produced on rock by exposure to the elements that are active now: mechanical disintegration due to frost action or to alternate heating and cooling by diurnal changes in temperature, solution by rainwater, and chemical addition or subtraction of elements by water or air.

The spectacular effects of weathering occur in rocks that are hydrothermally altered, but some unaltered volcanic rocks readily disintegrate mechanically, and carbonate rocks are susceptible to solution.

Fresh latite near the mouth of Rock Canyon in sec. 2, T. 11 S., R. 2 W., has broken down readily under weathering conditions of this area (Pl. XIII).

Etched carbonate rock is common in the quadrangle, and is especially noticeable where the rocks contain chert. About 200 feet north of the road in the east half of sec. 2, T. 10 S., R. 2 W., a large dolomite boulder rests on top of gravel of pre-Lake Bonneville age. This boulder has many small chert nodules that stand above the general surface of the rock; the nodules are similar to nodules shown in Plate XVI. One of the smallest pieces of chert stands atop a pedestal of dolomite about one-eighth inch in diameter and five-eighths inch high. Obviously such a slender pedestal could not have survived transportation, and thus the weathering that removed the dolomite from around the pedestal must have been accomplished since the boulder reached its present resting place.

Bedrock exposures of chert-bearing limestone and dolomite show similar etching. Approximately the same amount of material has been removed from boulders as from bedrock, and on bedrock and boulders about the same amount of surface is etched from both horizontal and vertical faces (Pl. XVI).

If studies were made to determine the speed of etching it might be possible to determine when the last period of strong frost activity occurred in the Eureka area. Probably the boulders were removed from bedrock by severe frost activity such as would exist in a periglacial climate. The large blocks moved downslope, and when the climate became warmer the surfaces of both boulders and bedrock were subjected to etching. Presumably the periglacial climate existed during one of the Pleistocene glacial epochs; the

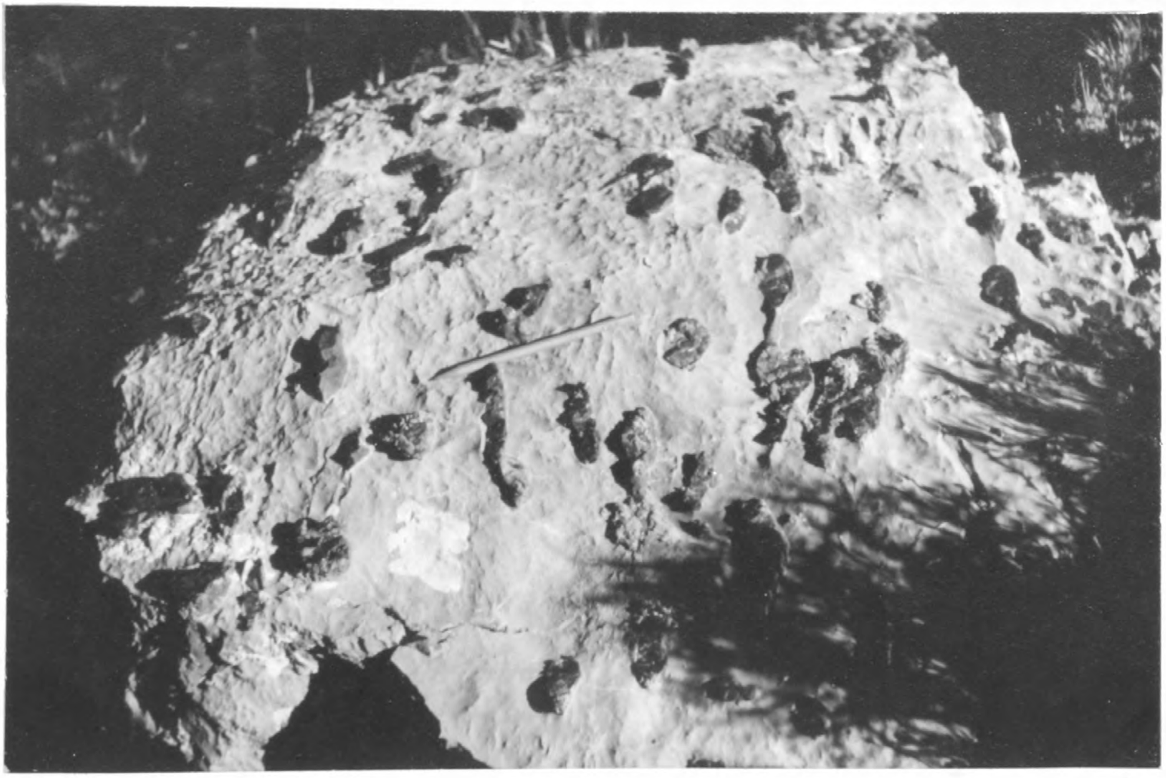


Plate XVI.

Boulder of carbonate rock showing relief of chert fragments after removal of surrounding carbonate by weathering.

About the same amount of etching has occurred on the nearly vertical face in the foreground as on the horizontal face in the upper part of the picture.

position of the boulders at the top of pre-Lake Bonneville deposits suggests that the boulders came to rest during late pre-Lake Bonneville or early Lake Bonneville time. Thus a determination of the rate of etching might help to determine the age of Lake Bonneville.

Resistance to erosion

The brief sketches of the effects of alteration and weathering on certain rocks of the quadrangle indicate the magnitude of the problem of predicting the effects of erosion on the rocks. Nevertheless, I have prepared a table to show the relative resistance to erosion of some common rocks of the Eureka quadrangle. Table 2 shows four Paleozoic rocks, four volcanic and pyroclastic rocks, and four surficial deposits listed in order of decreasing relative resistance to some erosive forces. The first column lists fresh rocks in order of resistance to running water; quartzite is undoubtedly most resistant and sand perhaps least resistant. The second column attempts to show the change that occurs in resistance if the rocks are weathered before running water attacks them. Of the consolidated rocks, latite and quartz latite weather more readily than limestone or dolomite, and quartzite is affected by frost action; after weathering, then, latite, quartz latite, and quartzite are less resistant but limestone, dolomite, shale, and perhaps tuff are changed very little. The third column attempts to show how the relative resistances might be further changed if the exposed

Table 2. Hypothetical relative resistance to erosive forces of some common rocks in the Eureka quadrangle. In all columns the most resistant rock is at the top.

Relative resistance of fresh rock to running water.	Relative resistance of weathered rock to running water.	Relative resistance of rocks to mass-wastage. All rocks are weathered; the volcanic rocks are also hydrothermally altered.
Quartzite	Dolomite	Dolomite
Latite	Limestone	Limestone
Quartz latite	Quartzite	Shale
Dolomite	Shale	Quartzite
Limestone	Tuff	Tuffaceous conglomerate
Shale	Latite	Fanglomerate
Tuff	Quartz latite	Stream gravel
Tuffaceous conglomerate	Tuffaceous conglomerate	Loess
Fanglomerate	Fanglomerate	Latite
Stream gravel	Stream gravel	Quartz latite
Loess	Loess	Tuff
Sand	Sand	Sand

volcanic rocks were previously hydrothermally altered, then weathered, and subjected to mass-wastage instead of to stream erosion.

The work of erosion in developing the landscape after volcanism

Post-volcanism development of the landscape of the Eureka quadrangle probably began with erosion that started before the end of Middle Eocene volcanism. For simplicity, the starting point of landscape development can be a fresh volcanic pile large enough and high enough to cover the Paleozoic rocks.

Evidence is not positive that the Paleozoic-rock peaks south of Eureka were once covered by volcanic flows, but Parkard Peak is composed entirely of volcanic rocks and its top, at an altitude of 7828 feet, is only slightly below the 7900- to 8100-foot peaks in Paleozoic rock. Remnants of volcanic rock have also been mapped on Pinyon Peak at about 7100 feet altitude.

It thus seems likely that after the volcanic episode only volcanic rocks were exposed in the quadrangle, and stream courses were controlled by the initial surface of the volcanic rocks and by differences in the lithology of those rocks. For example, some gravel-like tuffs must have been removed more readily than the latite and quartz latite flows. This wasting of the volcanic pile, however, was controlled even more by climate and by the relative relief. If the volcanic pile had little local relief, it is probable that a long time elapsed before the Paleozoic-rock core was exposed. If the local relief was considerable, as the 15° to 20°

dips in the gravel-like tuffs on the east side of the range indicate (Pl. VIII), it is likely that the volcanic rocks were worn down rapidly. It is unlikely, however, that the volcanic rocks above the Paleozoic-rock core were removed completely until late Tertiary time, for it is evident that the Paleozoic rocks have undergone relatively little erosion since they were exhumed. After the Paleozoic-rock core was exposed, greater resistance of the sedimentary rocks to stream erosion forced the streams to follow the contact between the Paleozoic and volcanic rocks; thus began the stripping of the volcanics from the core.

The present form of the peaks in the Paleozoic rocks is due to structure and to slight differences in the resistance of the sedimentary rocks. The dominant peaks along the crest of the range are Godiva Mountain, Sioux Peak, and Mammoth Peak, all formed of Mississippian limestone in nearly vertical beds that are west of the north-trending axis of the syncline (Pl. IV). Eureka Peak, about 3300 feet nearly due west of Godiva Mountain, is formed of Opohonga limestone, also in nearly vertical beds which are slightly more resistant than the adjacent dolomite beds.

These peaks probably had much of their present form before they were covered by volcanic rocks. Removal of the volcanic rocks has revealed that the pre-volcanism topography was perhaps steeper than the present rugged landscape. Below the contact with volcanic rocks the Paleozoic-rock slope steepens, and deposits of blocky limestone talus occur locally beneath the volcanic rocks (Tower and Smith, 1899, p. 652); but the present steepness of the Paleozoic-rock slopes above the contact with volcanic rocks indicates that little back-weathering has occurred since exhumation. This conclusion is supported by the relative lack of carbonate-rock detritus below the Paleozoic-rock slopes. Local rock streams partly fill gullies high on the steep slopes, but towards the base of the slopes carbonate-rock detritus forms only a thin cover over, or fills channels in, the thicker older surficial deposits, principally loess. For example, at the caved portal of the Tetro Tunnel near the base of Godiva Mountain, a 40- to 50-foot thick deposit consists principally of loess and contains few fragments from the higher slopes except in the top 10 to 20 feet (fig. 2, opposite p. 26). Even in this upper part the material is principally reworked loess. This deposit, which is almost completely of pre-Lake Bonneville age, lies essentially at the land surface, and indicates either that little deposition from the higher slopes has occurred since pre-Lake Bonneville time or that the younger deposits have been removed. The profile in the pre-Lake Bonneville colluvium, which overlies the loess (fig. 2), suggests that an appreciable part of the B horizon of the soil formed in pre-Lake Bonneville time remains, and that probably no more than a few feet have been removed. If the erosion had been strong enough to remove many feet of material from the surface, it is probable that such strong erosion would have dug deeper into the remaining unconsolidated material. The deposit that remains at the portal of the Tetro Tunnel is about 60 feet thick and lies on a 15° bed-rock slope.

Effects of block faulting

If the erosion of the area had continued uninterrupted for the 45-50 million years since Middle Eocene time, the landscape would by now be nearly a peneplain. Instead, much of the landscape is youthful, which suggests that strong erosion, probably due to an increase in relief, has occurred once or perhaps several times since the volcanism. The control exerted over erosion by the different resistances of rocks was probably dominant for long periods but this dominance was superseded from time to time and from place to place by block faulting that changed the positions of base levels. Although the extent and duration of fault-block movements are unknown, the recognized evidence indicates that such movements 1) uplifted the mountains, 2) lifted the mountains and Tintic Valley with respect to Goshen Valley and thus caused the divide to migrate from east to west, and 3) uplifted the large Diamond Divide Block within the range.

Uplift of the mountains

Evidence indicates block faulting between the mountains and valleys. On both sides of the central and southern parts of the range, the bedrock has faceted spurs, and the alluvium locally has small scarps; both features indicate uplift of the mountain block relative to the adjacent valleys. On the west side of the range the evidence is in the Tintic Junction quadrangle[1/] adjacent

[1/] The Tintic Junction quadrangle and the Tintic Mountain quadrangle also mentioned in this paragraph are $7\frac{1}{2}$ minute topographic maps published by the U. S. Geological Survey.

to the Eureka quadrangle on the west. Steep bedrock spurs occur north of Eureka Creek in secs. 14 and 15, T. 10 S., R. 3 W.; at the end of Quartzite Ridge; and at the ridges north and south of Silver City. The only known fault in the alluvium west of the Eureka area is north of the gravel pit in the center of sec. 12, T. 10 S., R. 3 W. On the east side of the range, more or less pronounced spurs occur all along the mountain front, but south of Goshen Slope the sharpest spurs are west of the easternmost bedrock outcrops and along a fault that is here called the East Goshen Valley fault. The East Goshen Valley fault can be traced southward from the spurs to the mouth of Rock Canyon in sec. 2, T. 11 S., R. 2 W. The Goshen Valley fault is nearly parellel to and about half a mile west of the East Goshen Valley fault. This fault has a 12-foot-high scarp with fresh slickensides on the ridge north of Rock Canyon in the center of sec. 2, T. 11 S., R. 2 W. (Pl. XVII), and has been traced southward into alluvium of pre-Lake Bonneville age in the tunnel in the north central part of sec. 14, T. 11 S., R. 2 W., in the Tintic Mountain quadrangle.

Uplift of the mountains and Tintic Valley

The faults and scarps on both sides of the range indicate that the range rose with respect to both flanking valleys. This is true, but Tintic Valley is some 850 feet higher than Goshen Valley, and strong evidence indicates that at least part of Tintic Valley's higher altitude is due to uplift of the valley itself.

Plate XVII. Fault scarps

Top.- Fault scarp formed by Goshen Valley fault on ridge north of Rock Canyon near center of sec. 2, T. 11 S., R. 2 W.

Bottom.- Head of Ruby Hollow near Silver Pass. The dashed line marks the approximate base of the eroded scarp of the Silver Pass fault. The hills behind the fault are part of the Diamond Divide Block.

The Pliocene(?) lacustrine Salt Lake formation now exposed near the head of Tintic Valley was probably laid down in a basin that was similar to the Bonneville basin. If the Pliocene basin had external drainage, the highest level of deposition was limited by the position of the lowest dam, which was probably no higher than the dam in Red Rock Pass (Gilbert, 1890, p. 260) that limited the high-water line of Lake Bonneville to about 5135 feet. If the Pliocene basin had no external drainage, the highest level of deposits was limited by the hydraulic regimen of the region and was lower than if the basin had external drainage.

Most known exposures of the Salt Lake formation occur below the level of the high Bonneville shoreline at 5135 feet. At the head of Tintic Valley, about six miles west of Packard Peak, however, tilted and faulted beds of the Salt Lake formation are at about 6100 feet, almost 1000 feet above the Bonneville shoreline. I believe that the maximum post-Salt Lake uplift of the valley and adjacent mountains occurred near the head of Tintic Valley and that, although the rest of Tintic Valley rose slightly less, the uplift was sufficient to account for most of the difference in base level between Tintic and Goshen Valleys.

In the Boulter Peak quadrangle, which adjoins the Eureka quadrangle to the northeast, this valley uplift was accompanied by an even greater uplift in the mountains in the southern part of the quadrangle.

Within the Eureka quadrangle and in the Tintic Junction quadrangle adjacent to the Eureka quadrangle on the west, the smoothness of the topography and the great expanse of alluvial fill in Diamond Gulch and Ruby Hollow suggest that the positions of Tintic Valley and the mountains to the east have been as they now are for most of the Pleistocene period. Therefore I believe that the northern part of Tintic Valley and the adjacent mountains were uplifted together in late Pliocene or early Pleistocene time, and that Goshen Valley was left essentially where it had been before the uplift.

The difference produced in gradients between the eastward and westward drainages of the mountains by simultaneous uplift of Tintic Valley and the East Tintic Mountains is perhaps the most significant factor in post-volcanic development of the landscape, for this difference results in dynamic geomorphology. The steep gradients of the streams flowing eastward into Goshen Valley are making the divide move westward, not only by headward erosion of streams, but also by stream piracy. Near Silver Pass a Recent beheading of a small stream has transferred some 200 acres from westward to eastward drainage. This Recent stream capture and the presence of landslides only on the eastern side of the range are striking evidence of the continuing movement of the divide. (See also Stream captures and landslides.)

Uplift of Diamond Divide Block

Almost as striking as the effects that were wrought by difference in base levels and that resulted from uplift of the range as a whole or in large segments, is evidence that uplifts involving small mountain blocks occurred within the range: 1) a mountain block, described here as the Diamond Divide Block, has sharper relief than other areas in the quadrangle, and 2) many flat erosion surfaces occur in the quadrangle at several different elevations. Erosion surfaces at different elevations are more reasonably accounted for by differential uplift of small mountain blocks than by many separate cycles of erosion, each of which resulted in base-leveling and each separated by small uplifts of the whole area. The Diamond Divide Block will be discussed here, the flat erosion surfaces will be discussed under High-level Erosion Surfaces.

In the southern part of the Eureka quadrangle, a northward-pointing, projectile-shaped block that is bounded on the northwest and west by the Silver Pass fault and on the east by the Goshen Valley fault moved upward relative to the mountain mass northwest of it (Pl. II). This block, called here the Diamond Divide Block (Pls. XV, XVII, and XVIII), is bounded by scarps on the west, northwest, and east, and continues southward into the Tintic Mountain quadrangle. Within the Eureka quadrangle, the Silver Pass fault on the west side of the Diamond Divide Block is marked from south to north by the steep western face of Sunrise Mountain, by a scarp north of Sunrise Mountain, by the steep face of the ridge northeast of Diamond, and then in succession by the scarp south of Silver Pass (Pl. XVII), the brecciated zone at the point of stream capture east of Silver Pass, and the steep face of the ridge

Plate XVIII. Diamond Divide Block, Keg Spring Pediment, and Willow Spring Surface.

Top.- The Diamond Divide Block looking southwest from ridge on east side of sec. 14, T. 10 S., R. 2 W.

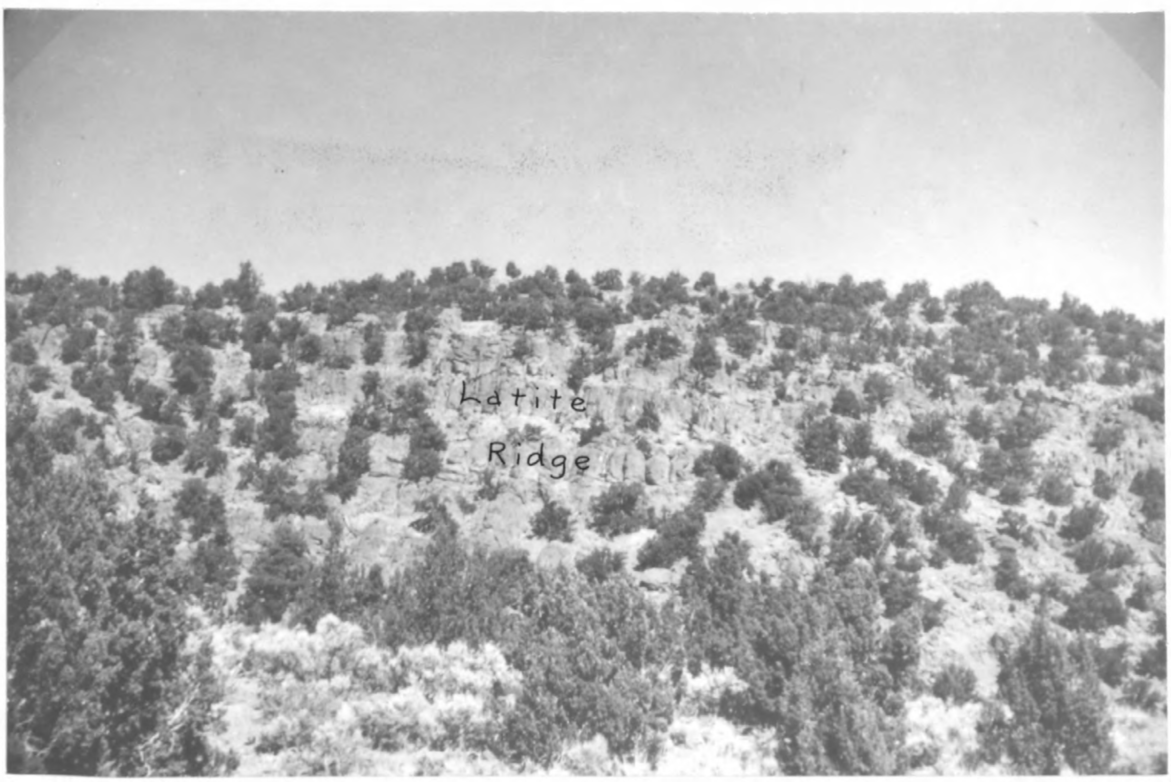
The flat valley in the foreground is part of the Keg Spring Pediment, and the bare surface near center of picture is the Willow Spring Surface.

Bottom.- Latite Ridge from the Willow Spring Surface.

The top of the Willow Spring Surface in the foreground is about parallel to the flows on the ridge.

Plate XVIII.


Diamond Divide Block
Willow Spring Surface
Latite Ridge
Keg Spring Pediment


Latite Ridge

northeast of Silver Pass. This fault is probably a southern extension of the Eureka Lily fault (Morris, 1957, Plate 1). The fault that probably marks the northwestern boundary of the block is evidently obscured by alluvium of the lower part of Silver Pass Creek, but topographic prominence of the block indicates that the northwestern boundary is marked by a strong fault. The eastern side of the Diamond Divide Block is not so well defined; its most important boundary is probably the Goshen Valley fault (Pl. XVII), but additional uplift evidently occurred along the East Goshen Valley fault, half a mile east of the Goshen Valley fault.

Mere topographic prominence of a block may be weak evidence of boundary faults, but in the absence of stratigraphic evidence in the volcanic rocks, the topographic evidence is here accepted. In the Boulter Peak quadrangle, adjoining this quadrangle to the northwest, stratigraphic displacement of recognizable Paleozoic formations indicates that topographic prominence of some areas of Paleozoic rocks is the result of structural uplift. ([illegible], in prep.).

The age of movement of the Diamond Divide Block may be Pliocene but is more likely Pleistocene because the following reasons indicate that the Diamond Divide Block rose later than the rest of the range: 1) topographic prominence does not endure long in the easily weathered volcanic rocks; 2) continuing thick alluviation shown by the relatively abundant Lake Bonneville and Recent deposits on the east side of the range south of U. S. Highway 6 and 50 is probably due to late uplift that has had a strong effect on the fast-weathering

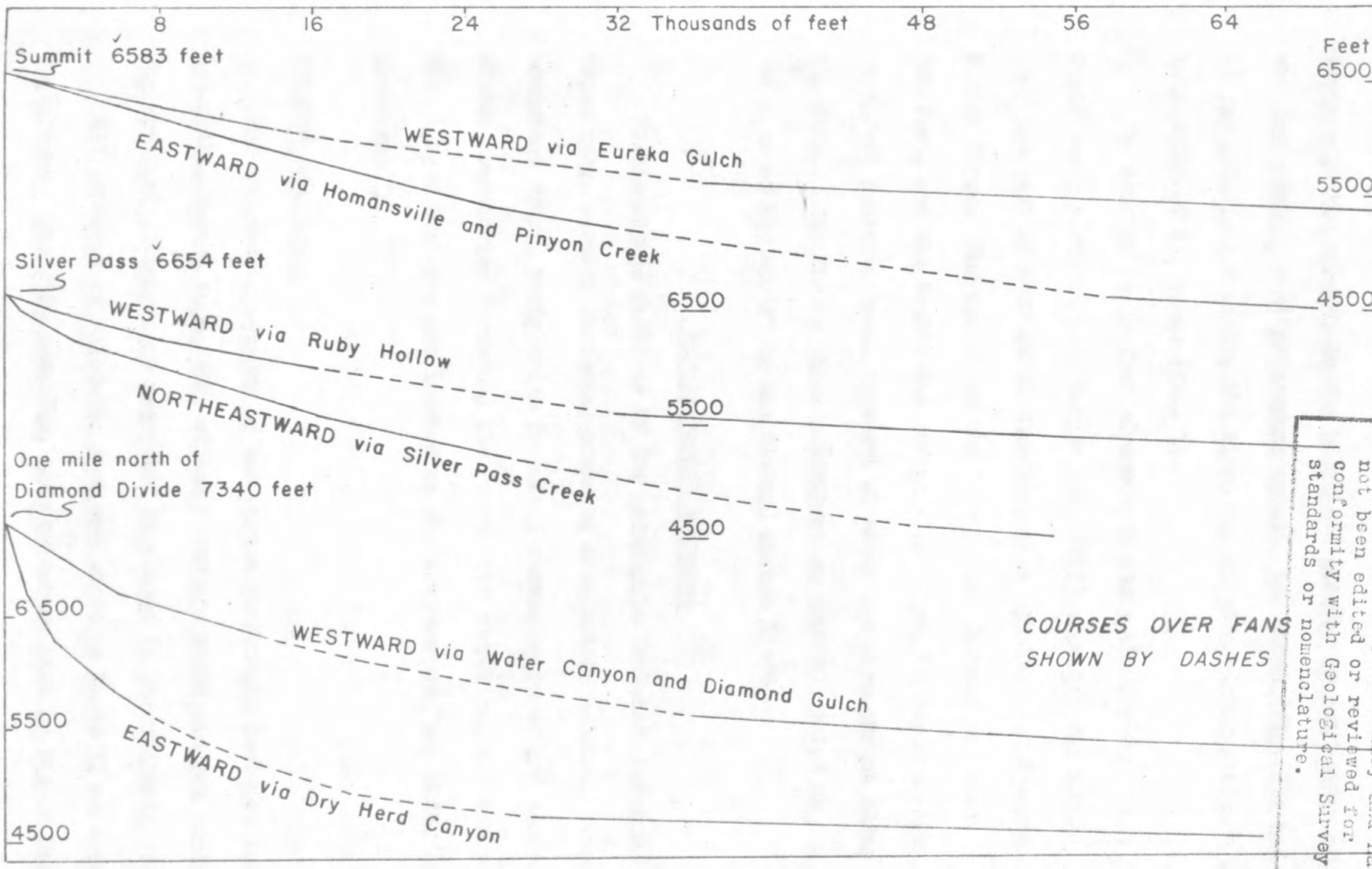


Figure 3.- Generalized stream profiles showing difference in gradients between streams flowing eastward and westward. The streams of the top two pairs of profiles head at passes, the streams of the bottom pair head on the Diamond Divide Block.

latite; 3) the canyons in the block are steeper on both sides of the range than are other canyons outside the block (fig. 3); and 4) fan alluviation within the block occurs at a higher altitude on both sides of the range (fig. 3).

The measurable 12 feet of movement along the Goshen Valley fault scarp north of Rock Canyon (Pl. XVII) probably represents only the last of many small movements that uplifted the Diamond Divide Block. The uplift of the Ruby Hollow Surface is about 300 feet, and the fault-line scarps that bound the Block on the northwest indicate total movement of about the same amount along the Silver Pass fault; these estimates are probably valid as measures of the uplift of the Diamond Divide Block.

Physiographic Features

Physiographic features of the quadrangle include: exhumed topography, erosion surfaces, areas of accelerated erosion, canyons, accordant spurs, periglacial features, stream captures and landslides, weathering features, the Bonneville shoreline, and arroyos. Most larger features are located on the accompanying map which shows landforms (Pl. II).

Exhumed topography

The exhumed topography of the Eureka quadrangle includes the pre-Middle Eocene topography of the Paleozoic rocks and the early Pleistocene(?) topography reexposed in places in the volcanic rock.

All outcrops of Paleozoic rock are shown on Plate II as exhumed topography. Strictly speaking, many outcrops, such as Pinyon Peak and Lime Peak, have probably been free of their volcanic-rock cover for so long that extensive erosion has made their present topography more modern, and it is now probably smoother than it was immediately after exposure. The ridge of Paleozoic rocks south of Eureka, however, has a rugged topography controlled by different resistances of the vertical beds. This topography probably has back-weathered little since the volcanic rocks were stripped away, and thus may be truly classed as exhumed and of pre-Middle Eocene age.

Two surfaces of the volcanic rocks may represent exhumed topography, but of a much younger age than the exhumed topography in the Paleozoic rocks. The first surface is in the Goshen Slope area, along both sides of U. S. Highway 6 and 50 (Pl. VII). Most of it is in sec. 10, but parts are in secs. 11 and 15, all in T. 10 S., R. 2 W. Steep sided gullies in bedrock, 2 to 10 feet deep on the average, but in places as much as 40 feet deep, characterize this surface. These gullies do not belong to the present cycle, for many have been covered by the loess of pre-Lake Bonneville age that is now nearly stripped from the area. (See also Areas of accelerated erosion.)

Another possibly exhumed surface on volcanic rock has been classed as a pediment. (See Keg Spring Pediment.) This bedrock surface is in the embayment where secs. 13, 14, 23, and 24, T. 10 S., R. 2 W., come together (Pl. XVIII). The embayment is extensively covered by thin deposits of alluvium of Recent or Provo(?) age, and remnants of deposits of pre-Lake Bonneville age occur on the slopes surrounding the embayment. If the pediment itself was once covered by deposits of pre-Lake Bonneville age that have since been removed, it must be considered to be an exhumed surface, probably of Pleistocene age.

High-level erosion surfaces

Erosion surfaces that were cut before the present erosion cycle occur in the quadrangle at altitudes of 5850 to 8000 feet. All these surfaces have smoother topography than surrounding areas, and where surfaces, such as the Water Canyon Surface, are at the heads of valleys, the streams leading from the surfaces have cut youthful canyons beyond the boundaries of the surfaces. All surfaces that truncate volcanic rock were probably cut by stream erosion, and the Godiva Mountain Surface, which truncates Paleozoic rock, may have been cut by streams or by frost action. Each of these surfaces has been given a separate name because uplift of the mountains in the quadrangle has been by separate segments rather than as a whole, and correlation of surfaces on blocks that have been uplifted different amounts is tenuous.

Godiva Mountain Surface on Paleozoic rock.- The highest erosion surface in the area is cut on Paleozoic rocks at altitudes between 7600 and 8000 feet near Godiva Mountain in sec. 19, T. 10 S., R. 2 W. (Pls. II and XIX). This surface, called here the Godiva Mountain Surface, covers an area of about 30 acres in three locations. It

Plate XIX.
Parts of the Godiva Mountain Surface as seen from a point east of Eureka Peak.

is gently rolling east of Eureka Peak, but is steeper on Mammoth and Sioux Peaks. This surface could have been developed by streams when the area had less relief than now, or it could have been developed at its present position by periglacial activity during one of the glacial stages. Both possibilities will be discussed, but the periglacial origin seems more tenable.

If the Godiva Mountain Surface was developed by streams when the mountains were much lower, it could be the oldest erosion surface in the area. It could have been developed long before volcanism and before carving of the steep canyons that antedate the volcanism, or it could have been cut soon after the Paleozoic rocks were first exposed after the volcanism.

In order to accept pre-volcanism development of the surface, it is necessary to postulate that a period of peneplanation or pedimentation preceded the pre-volcanism canyon cutting. Pre-volcanism planation would fit Gilbert's belief that peneplanation in the Wasatch Mountains occurred after the post-Jurassic diastrophism (Gilbert, 1928, p. 67), but would not agree with the Miocene age of the oldest planation, represented by the Herd Mountain Surface, which Eardley (1944, p. 876) found in the north-central Wasatch Mountains. Furthermore, if peneplanation preceded volcanism, remnants of the volcanic rocks should remain on the flat part of the surface east of Eureka Peak. No volcanic rocks have been found there although they may underlie the surficial deposits.

It thus seems more likely that if this surface was developed by stream erosion, the erosion occurred after the Paleozoic rocks were first exposed by slow removal of the volcanic cover. Such a surface could have been cut if the exposure of the Paleozoic rocks occurred at a time of low relief when the streams had low gradients and cut sideways rather than downward. This period of slow erosion and low relief probably lasted until the late Miocene or early Pliocene block faulting (Nolan, 1943, p. 183), and if so, the Paleozoic rocks were not exposed until near the end of the cycle. When block faulting occurred and the area was uplifted, the volcanic rocks were quickly stripped from the sides of the Paleozoic-rock peaks, and the East Tintic Range started on the long erosion cycle that resulted in the range as it is today.

If, on the other hand, the Godiva Mountain Surface was formed by periglacial activity, an entirely different history must be postulated for it.

These mountains were uplifted before Pleistocene time, and the volcanic cover probably was already removed from the Paleozoic rocks so that the sedimentary rocks were exposed during one or more glacial epochs. If the glacial activity had been severe it would have cut cirques in the mountains, but it was not and, instead, the excess snow and ice that accumulated on these northeast-facing areas cut only shallow depressions in which frost-action deposits accumulated.

Smoothing of the steep parts of this surface on Sioux and Mammoth Peaks seems to be the result of frost action, but the flatness of the area east of Eureka Peak could be due only in part to frost action. Most material at the surface in that area is silt, probably reworked loess, for an auger penetrated five feet of silt near the middle of the area. If frost action during early or middle Pleistocene time had excavated and smoothed a hollow in the bedrock east of Eureka Peak, the present flatness of the area can be attributed to later accumulation of loess.

High-level surfaces on volcanic rock.- Other surfaces that extend through a wide range of altitudes cut volcanic rocks at several localities in the quadrangle (Pl. II). These surfaces are at altitudes of 7200 to 5850 feet as follows: 1) Ruby Hollow Surface, at 7150 to 7075 feet, principally in W half sec. 34, T. 10 W., R. 2 W.; 2) the Water Canyon Surface, at 7200 to 6700 feet, in secs. 3, 4, 9, and 10, T. 11 S., R. 2 W.; 3) the Flattop Surface, at 6975 to 6900 feet, in SW$\frac{1}{4}$ sec. 5, and NE$\frac{1}{4}$ sec. 6, T. 10 S., R. 2 W.; 4) the Laguna Surface, about 6350 to 6250 feet, in S$\frac{1}{2}$ sec. 27 and NE$\frac{1}{4}$ sec. 34, T. 9 S., R. 2 W.; 5) the Willow Spring Surface, at 6500 to 5850 feet, south of Latite Ridge, in sec. 23 and westward to sec. 27, T. 10 S., R. 2 W.; and 6) the Independence Surface, at 6150 to 5875 feet, in secs. 2 and 11, T. 10 S., R. 2 W.

The Ruby Hollow Surface (1, above) is the name given to the subdued topography east of Silver Pass (Pl. XV). It is so named because, although it is now in the eastern-slope drainage, it undoubtedly was formed while it was part of the western slope. The gentle northeast to southwest gradient of the surface slopes toward Ruby Hollow, and the carving of this pirated Ruby Hollow Surface itself occurred during the erosion cycle that carved Ruby Hollow. This erosion cycle probably began with the Miocene-Pliocene block faulting before the Pliocene(?) Salt Lake formation was deposited. The cycle continued until uplift of the Diamond Divide Block along the Silver Pass fault lifted this area above the rest of Ruby Hollow. Later captures by streams isolated this high surface by transferring it into the drainage of the eastern slope.

The Water Canyon Surface (PL. II) is south of the Ruby Hollow Surface on the Diamond Divide Block. It is a rolling upland surface whose drainage gradient is much less than the gradient in the lower reaches of Water Canyon. Although this surface is not as mature as the Ruby Hollow Surface, it was likely carved before the Diamond Divide Block was uplifted.

The Flattop Surface (3, above) is probably the result of stripping of easily removed overlying beds from the more resistant rocks now forming the surface. Both remnants of the surface conform closely to layering in the volcanic rock.

The horseshoe-shaped Laguna Surface above Laguna may be a remnant of a more extensive surface that has been removed by backweathering of the slopes surrounding this mesa, whose surface is essentially as it was after the softer tuffs had been stripped from its top. Fresh latite bedrock is exposed over most of this surface, and only a few inches of surficial material occur in scattered depressions on the mesa top. Weathering on the surface probably proceeds slowly because there are no surficial deposits to hold water, and running water and wind cause little abrasion on this isolated surface.

It thus seems reasonable to believe that this surface has not been lowered greatly since it was isolated.

The Willow Spring Surface (Pl. XVIII), south of Latite Ridge, has a distinct break in slope at about 6325 feet and is steeper below that altitude and flatter above. This difference in the two parts of the slope suggests that the origin of the surface is composite: the flatter slope appears to conform closely to layering in the underlying latite, which apparently parallels the layering on Latite Ridge (Pl. XVIII), whereas the lower and steeper portion of the surface cuts across the layering in the latite in places but parallels it on narrow irregular benches. The upper, flatter portion of the surface may thus be the result of stripping off a softer, overlying rock, perhaps a tuff. The lower, steeper portion, on the other hand, is probably the result both of weathering and of erosion by streams from above, after the overlying softer beds were stripped.

The Independence Surface in secs. 2 and 11, T. 10 S., R. 2 W., readily shows that it is the result principally of stripping of the latite volcanic rock from the quartz latite. The larger and more southerly remnant of this surface has two small patches of the overlying latite that have not yet been stripped from the quartz latite.

Keg Spring Pediment

The Keg Spring Pediment consists of two parts: 1) the embayment in the corner of secs. 13, 14, 23, and 24, T. 10 S., R. 2 W., (Pl. XVIII) was cut by streams flowing from the vicinity of Latite Ridge; 2) the bedrock shelf in secs. 13 and 14, same township, was cut by the stream that drains the central part of the quadrangle. Both parts of the pediment are well graded, but whereas the streams that cut the embayment portion continued to erode many channels below the pediment surface (and later deposited alluvium in most of these younger channels), the stream that cut the shelf to the north carved a more definite channel and thereafter avoided the higher surface.

The age of the pediment has not been established but it is doubtful that the pediment is older than Pleistocene because the northern portion is so little higher than the alluvium of pre-Lake Bonneville age deposited in the adjacent channel.

Areas of accelerated erosion

Three areas of the quadrangle--the valley at Homansville and southwestward, Goshen Slope, and the upper part of Pinyon Creek Valley--are here called areas of accelerated erosion because they were subjected to greater erosion than other areas of comparable topographic position (Pl. II). These areas differ from the high-level erosion surfaces, which were described earlier, in that the drainage from or through them is essentially continuous, without pronounced nickpoints, but passes between steep canyon walls downstream from the areas of accelerated erosion. Erosion in these areas is thus more mature than in areas downstream from them, whereas in reasonably homogeneous rocks sub-aerial erosion normally produces a topography that is more mature in the downstream reaches of a stream. It is likely that faults bounding one or more sides of the areas were the principal factors in localizing them; but it is not certain whether the faults prepared the way for accelerated erosion by breaking the rocks or merely by acting as passages for hydrothermal solutions that altered the rocks.

The valley near Homansville.- The broad valley that trends southwestward from the head of Homansville Canyon to The Summit (Pl. II and Pl. VI), owes its existence principally to the Selma fault whose eastern side, rising relative to the western side (Morris, 1957, Pl. I), raised Lime Peak and Pinyon Peak and created a scarp in the volcanic rock to form the steep eastern and southeastern sides of the valley. Solution of Paleozoic carbonate rocks at the junction of the Selma and Homansville faults may have caused collapse of the brecciated overlying volcanic rocks, and localized the deepest part of the valley at that point.

The Goshen Slope area.- All eastward- and northeastward-flowing streams that drain some eight square miles in the central part of the quadrangle come together in the Goshen Slope area of accelerated erosion (Pl. II and Pl. VII) and pass through a single outlet to Goshen Valley. This area of erosion was evidently localized on the downthrown block east of the Goshen Valley vault.

Although the Goshen Valley fault cannot be traced with any certainty northwestward from its mapped end on Latite Ridge, it seems likely that faulting or folding on the west side of the Goshen Slope area localized the anomalous deeper erosion of that area. Furthermore, two springs, the Hidden Treasure in sec. 10 and the Jameson in sec. 15, T. 10 S., R. 2 W., suggest that the Goshen Valley fault continues northward.

Other factors that could have contributed to the localization of erosion in the area are: 1) the Silver Pass fault probably continues across the southern part of the area; 2) the latite cap may have been thinner over the Goshen Slope area because of a piling up of the tuffs in that area during the volcanism; 3) the pyritic alteration that is now apparent in the quartz latite may have weakened the overlying rocks and permitted their swift erosion; 4) the volcanic rocks of the area may have been weakened by renewed movement on the Eureka Standard or Apex Standard faults in the underlying Paleozoic rocks, as shown by Lovering (Lovering and others, 1949, Pl. 1).

Upper Pinyon Creek Canyon.- The broad upper part of the canyon formed by Pinyon Creek trends generally northeasterly and lies almost wholly in secs. 3 and 4, T. 10 S., R. 2 W., (Pl. XX). This wide eroded area is surrounded completely by steep walls of rock: on the south by volcanic rocks along Pinyon Creek, on the west by Lime Peak, on the north by Pinyon Peak, and on the east by the steep scarp through which Pinyon Creek has cut its lower canyon. The rocks within the eroded area are more highly altered than in most

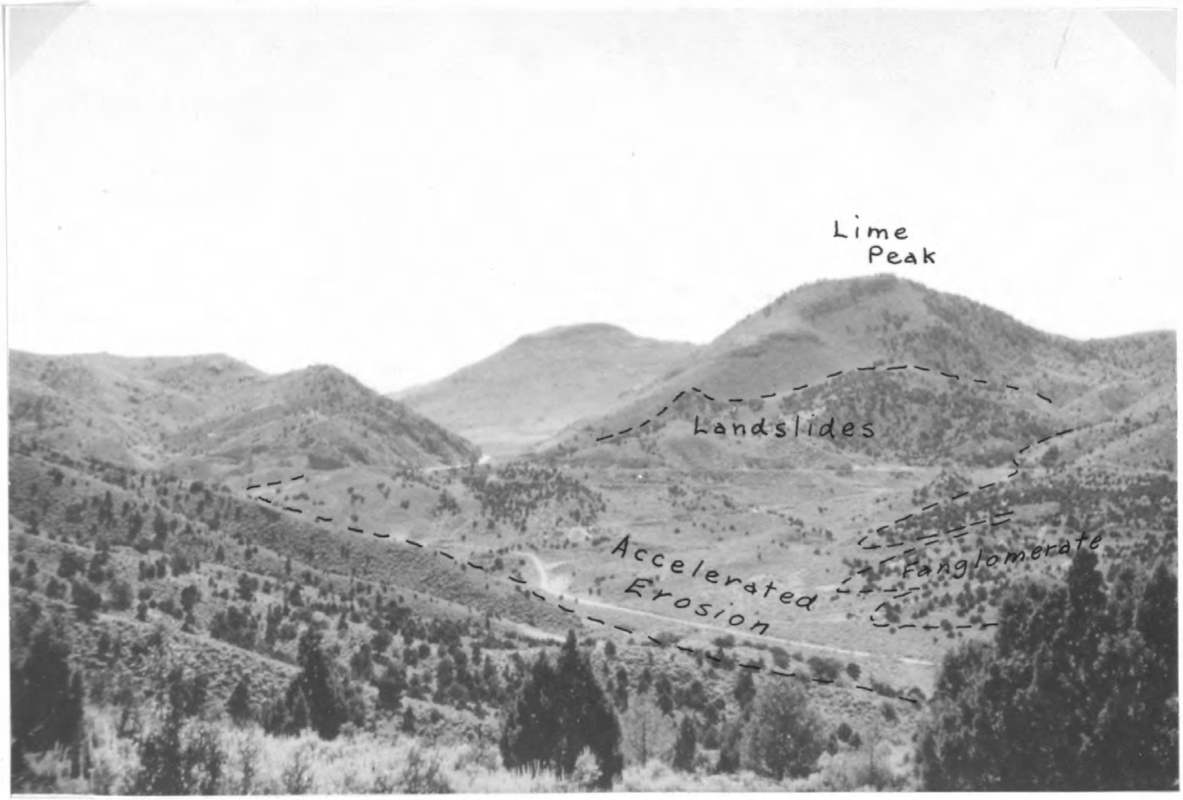


Plate XX.
The Pinyon Creek area of accelerated erosion and Lime Peak from the east.
The tree-covered landslides on Lime Peak and the nearly bare scarps are near center of right half of picture.

surrounding areas, yet much of the alteration is silicification, which has made the altered rocks harder than they were before alteration and thus does not readily explain the accelerated erosion of the area.

The Pinyon Creek eroded area probably was localized by faults. The Homansville fault probably fractured the Paleozoic rocks underlying the volcanic rocks in the area (and may have guided the cutting of the lower canyon of Pinyon Creek). A fault, which is probably the northern extension of the Goshen Valley fault (Pl. II), marks the western boundary of the eroded area. This fault localized landslides at the west end of the eroded area (See also Stream capture and landslides). Another fault marks the eastern boundary of the area. This eastern fault is in line with the East Goshen Valley fault, but its scarp, whose eastern block is upthrown, shows that in the Pinyon Creek area the movement was opposite to the movement farther south on the East Goshen Valley fault, whose eastern block is downthrown. Such scissor-like movement is common among faults of the region, and it could account for the lack of topographic expression of the East Goshen Valley fault between the Goshen Slope and the south side of Pinyon Creek.

Canyons in volcanic rocks

Canyons in volcanic rocks represent two types of topography: 1) on the western slope the smooth bedrock surfaces and filled valley bottoms belong to a submature stage of erosion, and 2) on the eastern slope, the steep-walled canyons, many with bedrock exposed in the stream channels, are youthful. The difference between the two landscapes apparently is due to the lower base level in Goshen Valley on the east side. However, it is likely that the maturity of the western slope is the result of a long period of stability on that side of the range, whereas the steeper canyons on the eastern slope indicate that uplift interrupted the stable period on the east side. The beginning of the erosion cycle that cut the submature surface on the western slope may be represented on the eastern slope by the cycle that carved the accordant spurs (see p. 81) in Burriston Canyon. Pleistocene deposits in Burriston Canyon below the spurs indicate three or more erosion cycles on the eastern side of the range since the spurs were cut. Thus most of the canyon landscape in the volcanic rocks on the western slope belongs to the present cycle, whereas the landscape in the volcanic rocks on the eastern slope is evidently the result of several cycles of erosion. Despite the differences in the landscape in the volcanic rocks of the two slopes, it seems that erosion has continued steadily though not at uniform rates since the volcanic rocks were deposited.

The only interruptions to erosion of the volcanic rocks apparently have been due 1) to cyclic reductions in relief brought about by erosion itself and to the concomitant partial burial by surficial deposits or 2) to burial by loess. Examples of both types of burial of older topography occur in the Goshen Slope area. Drill holes in the channel alluvium and in the terraces on the south side of Silver Pass Creek, in secs. 14, 15, and 22,

T. 10 S., R. 2 W., show that the bedrock channel is 30 to 40 feet below the alluvium and is about 700 feet wide, whereas the present flood plain is only about 200 feet wide. This area is probably north of the rather indefinite northern boundary of the Diamond Divide Block, and erosion of the bedrock channel probably occurred before the last uplift of that block. An area of small canyons now being exhumed from beneath the loess occurs on both sides of U. S. Highway 6 and 50 in secs. 10 and 15, T. 10 S., R. 2 W. (See also Exhumed topography.)

Accordant spurs

Accordant spurs have been recognized only in Burriston Canyon (Pl. XXI) where the ends of several ridges butting into the canyon have been beveled about 200 feet above the present bottom of the canyon. This beveling is about 30 feet above the oldest Pleistocene deposit (oac_3 gravel), and therefore the erosion cycle marked by the accordance probably is late Tertiary. Perhaps it is the same cycle during which the Ruby Hollow Surface was cut.

On the south slope of Flattop hill, the volcanic-rock peak north of Eureka, four benches may be recognized (Pl. XXI) at altitudes of 6700, 6775, 6950, and 7050 feet. These benches and many other notches and benches that occur on the volcanic rocks may be the result of old erosion cycles, but their random distribution at many different altitudes suggests that they are the result of differential erosion due to local differences in the volcanic rock.

Plate XXI. Accordant spurs in Burriston Canyon and notches on Flattop hill.

Top.- Burriston Canyon from east face of Godiva Mountain.

The accordant spurs occur about 200 feet above bottom of canyon.

Bottom.- Notches on slope of Flattop hill north of Eureka.

Arrows mark notches that may be due to differential weathering rather than to different erosion cycles.


Accordant
Spurs

Stream captures and landslides

Stream captures and landslides are not ordinarily considered related features, but they are discussed together in this report because in the Eureka quadrangle both are the result of headward erosion by the streams flowing eastward into Goshen Valley. Profiles of eastward and westward draining canyons (fig. 3, facing p. 68) show that streams draining into Goshen Valley are working headward at a faster rate than those flowing into Tintic Valley, making the divide migrate from east to west as a result of stream captures, and causing landslides.

Ancient stream piracies are not readily recognized in an area that is as rugged and is being eroded as rapidly as this area, but the localization of the present divide seems certainly to be the result of many such events. A Recent capture (Goode, 1954, p. 1375) supports that hypothesis. Near the center of sec. 33, T. 10 S., R. 2 W., about 2000 feet east of Silver Pass, a stream flowing north and northeastward worked headward along the Silver Pass fault and beheaded a stream flowing westward, thus shifting about 200 acres from the western to eastern drainage (Pl. XXII). Another capture can be predicted for the Diamond Divide area, where the steep drainage east and south of Diamond Divide is likely to behead Water Canyon and transfer about one square mile from the western to eastern drainage. Eventually, headward erosion of the eastward draining streams will move the divide into Tintic Valley, and the northern part of that valley will then drain into Goshen Valley. But this capture is not likely to occur for a long time, and new orogenic movements

Plate XXII.- Recent stream capture and slump near Silver Pass.

Top.- Recent stream capture east of Silver Pass. The abandoned channel is between jeep and cattle on hillside; the new channel is obvious.

Bottom.- Recent slump in area drained by stream that effected capture pictured above. The slump is due in part to over-steepening caused by headward erosion of capturing stream. (see also Plate XXIII.)


Slump shown
in bottom picture

may change the course of events.

Although major landslides of the area seem to have occurred at a time when the headward erosion by streams was greater than it is today, a Recent stream capture near Silver Pass caused a minor slide by the same process of oversteepening of slopes by headward eroding streams. This slide or slump consists of less than an acre of surface material on the north-facing slope of the ridge in the SE corner of sec. 33, T. 10 S., R. 2 W. (Pl. XXII). The slump is visible on an aerial photograph (CVX-20K-66) taken Sept. 24, 1952 but not on one (GS-AU 2-112) taken Oct. 13, 1943 (Pl. XXIII).

The photographs not only show approximately when the slump occurred but are additional evidence of the recency of the capture that had only to deepen the channel in the alluvium below the slump area to remove support and cause the slump.

Older landslides in the Eureka quadrangle (Pl. II) are larger than the slump just mentioned, and all slides that have been recognized probably involved bedrock. All slides are on the east-, northeast-, or north-facing slopes, inasmuch as the oversteepening was caused by eastward-flowing streams. Greater accumulation of snow on those slopes weathered the rocks faster and made it easier for headward-eroding streams to oversteepen the supporting slopes. Without exception, the scarps that show where the rock of the slides came from can be easily discerned, and the sharp lessening of downhill slope that marks the more or less hummocky surfaces of the slide blocks is characteristic of landslides here as elsewhere. The only slide that may involve an appreciable amount of

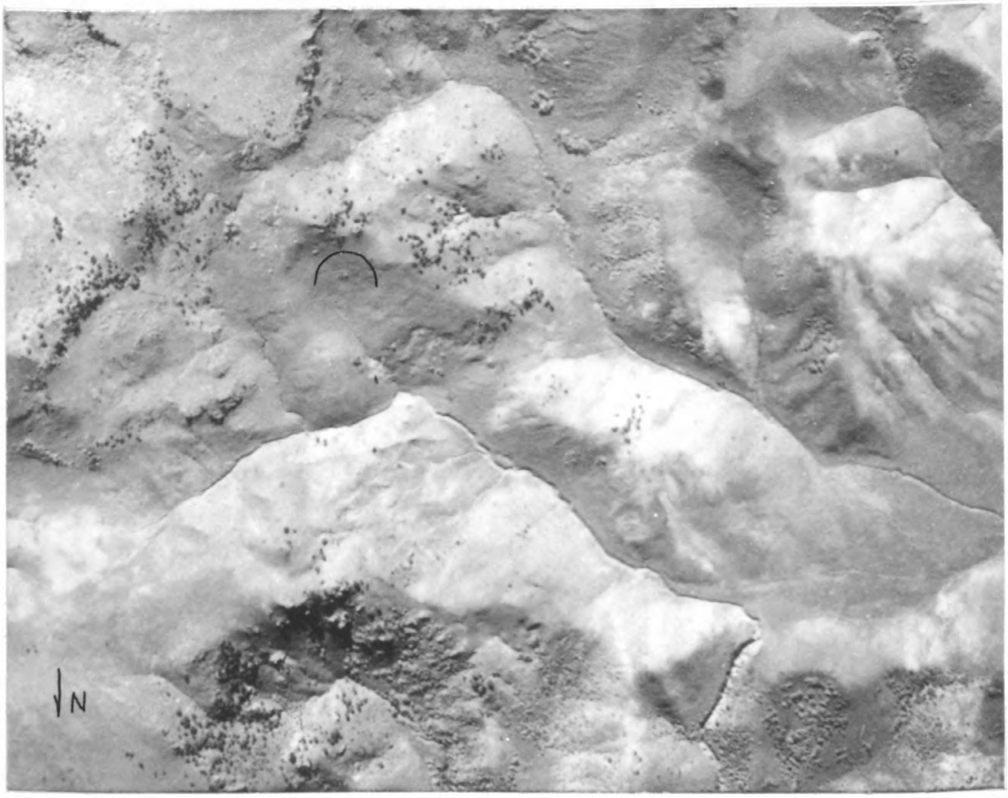
Plate XXIII. Aerial photographs of Recent slump. Slump occurred between October 13, 1943 and September 24, 1952.

Top.- Portion of aerial photo GS-AU 2 112 taken October 13, 1943, showing an unbroken slope inside inked arc.

Bottom.- Portion of aerial photo CVX-20 K-66 taken September 24, 1952, showing a slump inside inked arc.

The slump is due in part to over-steepening caused by progressive headward erosion by stream that had earlier effected a capture in lower right-hand corner of both photographs.

Plate XXIII.



Paleozoic rock is on the east face of Lime Peak (Pl. XX), where a fault between the Paleozoic and volcanic rocks (Pl. XXIV) was a contributing factor that helped to localize the slide. All other landslides are in volcanic rock: 1) on the east slope of the lava ridge in SW¼ sec. 28, T. 10 S., R. 2 W.; 2) on the north-facing side of Homansville Canyon; 3) on the north slope of Big Hill; and 4) on Latite Ridge near the center of sec. 27, T. 10 S., R. 2 W.

The only old landslide that was studied in detail to try to determine its age is the slide on the SW corner of sec. 28, T. 10 S., R. 2 W. (Pl. XXV). Several pits were dug to determine the degree of soil development on the landslide, on the scar, and on the slopes above the landslide but away from the scar. On the slide itself two soils were found; the lower soil has a strong CCa zone covered by a red-brown clay (similar to and here correlated with the pre-Wisconsin paleosol in the Rocky Mountain region as described by Hunt and Sokoloff, 1950, p. 109-110), the upper soil has a less limy zone that fits the general description of a mid-Wisconsin soil. On the scar itself only the lesser developed mid-Wisconsin soil was found, but at several places on the slope north of the scar, both red-brown clay and strong lime-zone remnants of the pre-Wisconsin soil were observed. The mid-Wisconsin soil in the scar, although a pre-Wisconsin soil is on the adjacent slope and both pre-Wisconsin and mid-Wisconsin soils are on the landslide itself, indicates that the landslide occurred after the period of strongest pre-Wisconsin soil development, and the slide therefore has been tentatively assigned an early Wisconsin age, i.e., early Lake Bonneville

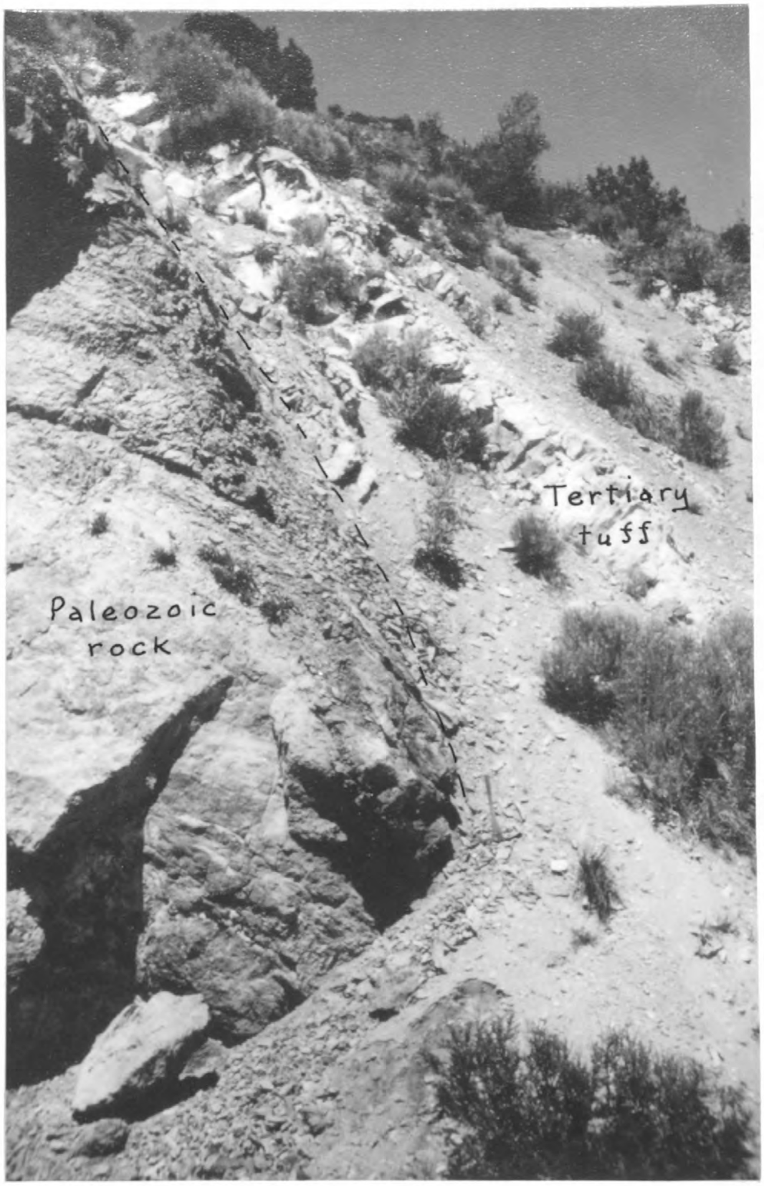


Plate XXIV.

Paleozoic rock and tuff in fault contact at railroad cut in southeast corner of Lime Peak.

This fault is probably an extension of the Goshen Valley fault. It localized the landslides on the east face of Lime Peak.

Plate XXV.
Landslide and East Tintic Mountains looking northwest from the north end of the Ruby Hollow Surface.

(Goode, 1954, p. 1375).

<u>Relict periglacial features</u>

Such direct evidence of glacial activity as U-shaped valleys, cirques, and moraines ~~are~~ is entirely lacking in the quadrangle, but the following features are abundant evidence of periglacial conditions during one or more of the Pleistocene glacial stages.

1) Large boulders. Boulders 1 to 3 feet in diameter are common in alluvium-colluvium of pre-Lake Bonneville age; boulders up to 10 feet in diameter rest on pre-Lake Bonneville deposits near the bottom of the southeastern slope of Pinyon Peak. It is believed that boulders of the larger sizes were broken from bedrock by frost riving and were moved by gravity. This activity does not seem to be going on now, and fragile cherts on the surface of many boulders of carbonate rock indicate that the boulders have been in place for a long time. (See also <u>Etching of carbonate rocks</u>.)

2) Talus. Some talus deposits consist of large angular blocks 1 to 5 feet long. These blocks show about the same amount of weathering as exposed bedrock, but no appreciable amount of fine material has sloughed off to fill the voids between the blocks. These talus deposits of coarse fragments apparently are not active today and are evidently much older than deposits consisting of freshly broken smaller rock fragments.

3) Frost-action. The poorly sorted congelifractates (deposits produced by frost-action, Bryan, 1946, p. 627) are overlain by more-uniform material about one foot thick. These younger deposits are

evidently slopewash, and are in sharp contrast to the underlying churned up deposits produced by frost-action during a climate colder than the present one.

4) Landslides. The localization of landslides on north-, east-, and northeast-facing slopes is at least in part the result of a severe winter climate. Large amounts of snow accumulated on north and east slopes and caused deeper weathering of the rocks as it melted in the spring. Eventually repeated frost-riving and thawing produced an unstable slope that slid when the slope was oversteepened by a headward-eroding stream.

The Bonneville shoreline

The Bonneville shoreline near the eastern border of the quadrangle is marked more by beach deposits of sand and gravel than it is by erosive features probably because the waves along the shore of this arm of the lake were not powerful enough to do extensive sculpturing. However, the few benches that were cut into the bedrock at the 5135-foot altitude of the shoreline clearly show the power of the waves in some places. Prominent benches are in the west-central part of sec. 24, and in the southeast corner of sec. 23, both in T. 10 S., R. 2 W. (Pl. II). The action of Lake Bonneville's waves did not cut deep benches in the pre-Lake Bonneville fans, but leaching of caliche from parts of the fans covered by lake water forms a sharp line of distinction that can be seen on the ground and on aerial photographs. Above the shoreline the caliche cover on pebbles, cobbles, and boulders is white, thick, and many fragments have appreciable surface caliche.

Arroyos

Arroyos in the quadrangle include small discontinuous gullies one to two feet wide and deep, such as were cut by spring floods after the heavy snows of 1951-52, and the larger "canyons" that are 5 to 100 feet wide and 3 to 20 feet deep in the alluvium. The larger arroyos have cut all surficial deposits and occur in all valleys and most tributaries. Although the arroyos are not so prominent as the steep canyons in the bedrock, they are the most conspicuous of all erosion features for they seemingly occur everywhere and are recognized as erosional features even by the uninitiated.

These arroyos are evidently a new feature of the area. It is said that early settlers, who arrived in the vicinity of the Eureka quadrangle probably about 1850 (McCune, 1947, p. 70), found the valley bottoms covered with grass rather than with sagebrush. Sometime between 1870 and 1880, a cycle of arroyo cutting began in the West (Bryan, 1925, p. 339). Some workers have suggested that the cycle began as a result of overgrazing (Bailey, 1935); or overgrazing and drought (Antevs, 1952, p. 376); others have thought that some sort of climatic change initiated the cutting cycle (Bryan, 1925, p. 343; Richardson, 1945, p. 17; Leopold, 1951, p. 351; and others). (For a summary of hypotheses see Antevs, 1952.) The coincidence of the introduction of cattle followed shortly by the beginning of arroyo cutting cannot be dismissed lightly, but Russell in a contemporary report (1883, p. 198) said that Sevier Lake (into whose basin

Tintic Valley drains) had "been known to become dry during the past few years" and implied that the climate became drier than it had been earlier. Perhaps both overgrazing and a climatic change upset the earlier equilibrium condition, and the cutting cycle began. Whatever their cause, the arroyos have made more exposures in the surficial deposits than all the prospecting and mining operations in this greatly productive district.

CENOZOIC HISTORY

The Cenozoic history of the Eureka quadrangle began at the end of the Laramide revolution, after the Paleozoic rocks of the area had been folded into a steep, asymmetric north-trending syncline and had been broken by a complex system of normal faults and thrusts.

Early Cenozoic history of the region that includes the Eureka quadrangle is not completely clear, and other workers have put forth theories that are not completely compatible with each other.

Tower and Smith (1899, p. 672) believed that folding of the Paleozoic rocks occurred deep below the surface during mountain building. Pre-Tertiary erosion followed the mountain building, removed many thousands of feet of upper Paleozoic strata, and exposed the tightly folded carboniferous rocks.

Gilbert (1928, p. 67) postulated that in the Wasatch Mountains a period of peneplanation followed the "post-Jurassic diastrophism."

Evidence within the Eureka quadrangle neither confirms nor contradicts Gilbert's postulate of peneplanation, but lower Tertiary(?) conglomerate and steep slopes in the Paleozoic rocks beneath the volcanic rocks are positive confirmation of Tower and Smith's theory that the Paleozoic-rock syncline had become a mountain mass before Middle Eocene volcanism. It is not known whether these pre-volcanism mountains were, as suggested by Tower and Smith, a direct result of the folding or the result of early post-Laramide fault block movements of Basin-Range type. If the peneplanation suggested by Gilbert did occur after the Laramide orogeny, it is likely that the Paleozoic-rock mountains of today were later uplifted as blocks before Middle Eocene volcanism.

Whatever their mode of uplift, the mountains of Paleozoic rock may have resulted from the first spasm of the volcanic activity, for the Paleozoic-rock mountains were still youthful when the Packard quartz latite flowed onto and covered them.

The large quantities of volcanic material deposited during Middle Eocene volcanism suggest that volcanic activity continued during an appreciable part of Middle Eocene time. More than 2000 feet of volcanic rocks have been penetrated by drill holes in the Goshen Slope area (Morris, 1957, oral communication) where the Packard quartz latite is now exposed on the surface. Lovering (Lovering and others, 1949, p. 10 and 20) has reported also an erosion surface within the Packard series; and several hundred feet of overlying tuffs, agglomerates, and flows of the Laguna Spring series attest to a long-continuing extrusive activity.

The gravel-like beds of ash and rounded boulders (tuffaceous conglomerate), prominent along the eastern flank of the mountains, are probably the result of strong erosion during the volcanic activity, and their 15° to 20° dips away from the mountains suggest that the beds were deposited around a high volcanic pile, perhaps several thousand feet higher than the present highest peak of about 8300 feet. The erosion that produced the gravel was an intra-volcanism activity, for flows overlie the gravel-like tuffs.

"The extensive eruptions .... were closed by the monzonite intrusion, which may be the equivalent to the latest of the effusive flows" (Lindgren and Loughlin, 1919, p. 103-4). The later work of Morris (1947) and Lovering (Lovering and others, 1949) indicates that volcanic activity continued after the monzonite was intruded, but the intrusive rocks occupy an important part in the volcanic series, for the stock near Silver City has a surface area of about seven square miles and may be the center of the igneous activity.

No upper Eocene, Oligocene, or Miocene rocks are known within the Eureka area, and a hiatus marks the period between the end of volcanism and deposition of the Pliocene(?) Salt Lake formation in the adjacent basins. The events that occurred during this long period can only be guessed at. Loughlin stated, "Erosion has been progressing without interruption during and ever since the periods of volcanic activity and ore deposition, carving the mountain peaks, canyons, and gulches and building alluvial cones out into the broad intermontane valleys" (Lindgren and Loughlin, 1919, p. 104). If uninterrupted erosion occurred during the 25,000,000 years of Oligocene and Miocene time (Dunbar, 1949, p. 29) up to Salt Lake time, a peneplain could be expected to form across the area; instead the area now is distinctly youthful on the eastern slope and only slightly mature on the western slope.

It thus seems more probable that, instead of the uninterrupted fast erosion that Loughlin implies, erosion was probably slowed several times during middle Tertiary time, and the top of the eroding volcanic pile was beveled once or several times before one of the succession of uplifts exposed the old pre-volcanism mountains in the western part of the quadrangle.

Although one can only speculate on events that occurred in the Eureka area during the hiatus from late Eocene to Miocene time, workers in other parts of the region have reported periods of sedimentation, erosion, volcanism, and uplift that may have affected events in the Eureka quadrangle.

Eardley (1944, p. 864) postulated that in the north-central Wasatch Mountains Oligocene volcanism (Norwood tuff), Miocene planation (Herd Mountain Surface), and Pliocene pedimentation (Weber Valley Surface) occurred before the last principal uplift of the Wasatch Mountains produced the faceted spurs along the Wasatch front. Gilbert, on the basis of the cross drainage of the Wasatch Mountains and the deposits on the east side of the range, concluded that in Eocene time the region west of the Wasatch was higher than the area east of the mountains (1928, p. 67), and he suggested that epeirogenic movements accounted for lowering of the Great Basin (or uplift of the Wasatch and the region to the east) before deposition of the Pliocene lake beds. Nolan (1943, p. 164, 165) believed that most of the Great Basin was undergoing erosion during Eocene and Oligocene time. Miocene lacustrine and alluvial deposits in the western part of the Basin indicate that they "were laid down in closed basins not unlike those now found in the region" (Nolan, 1943, p. 166), but Miocene beds have not been recognized in the eastern part of the Basin, although it is not known whether they were not deposited or are now concealed (Nolan, 1943, p. 165).

By the time the Pliocene(?) Salt Lake formation was deposited in nearby Utah Valley, that area was already developed as a structural depression (Hunt, Varnes, and Thomas, 1953, p. 14), and presumably the mountain and basin relationships were about as they are today. Relief, however, was more moderate because some uplift of the mountains has occurred since Salt Lake time.

In the Eureka quadrangle, a long cycle of erosion probably preceded Miocene-Pliocene block faulting, which Nolan reported in Nevada (1943, p. 183) and which is believed to have uplifted the East Tintic Mountains. Such a period of erosion might correlate with Eardley's Miocene planation (1944, p. 864) and might be marked in the Eureka quadrangle by the Godiva Mountain Surface for, if that surface was actually cut by stream erosion (see also High-level erosion surfaces), it could have been carved after the Paleozoic-rock peaks were first exhumed from beneath the volcanic rocks. Whether or not the Godiva Mountain Surface marks such a period of erosion, it is likely that a long cycle of erosion preceded Miocene-Pliocene block faulting, which uplifted the range. After this uplift, the volcanic rocks were rapidly stripped away from the Paleozoic-rock core, and the streams coursing over the volcanic rocks became graded to the adjacent valleys. During this period the Salt Lake formation was deposited in the valleys, and volcanism somewhere in the vicinity added volcanic debris to the fine detritus carried by the nearly-graded streams. This probably was the time when the Ruby Hollow Surface was formed (p. 76), and may also have been the time when accordant spurs were formed in Burriston Canyon (p. 81).

Toward the end of Pliocene time, diastrophism again closed one erosion cycle and began another. The Salt Lake formation was faulted and tilted, and additional uplift probably occurred along Basin Range faults. On the west side of the range, however, it appears that Tintic Valley rose with the mountains: outcrops of Salt Lake formation at an altitude of 6100 feet, some 1000 feet above the level reached later by Lake Bonneville, indicate an uplift of this part of the basin. This uplift of the range and the western valley created a steep gradient on the east side of the range, but affected the valley-mountain relationship very little on the west side of the range. The eastward-flowing streams began strong canyon cutting, and the detritus moved by them was deposited as steep fans along the eastern mountain front. Most of this uplift probably occurred at the same time that the Salt Lake beds were deformed; mountain-front alluvial fans and steep colluvial fans such as those on Pinyon Peak began to form immediately as a result of this post-Salt Lake uplift. Climatic changes--such as from warm-dry to cold-humid--may also have been a factor in the formation of the alluvial-colluvial fans. If the three pre-Lake Bonneville alluvial gravel deposits along the lower reaches of Silver Pass Creek span most of pre-Lake Bonneville-Pleistocene time, further work in the area and in the rest of the Great Basin may show some correlation between these deposits and the known cycles of pre-Wisconsin continental glaciation. Investigation of this area has produced no real evidence in favor of such correlation, but neither has it produced any evidence that would deny such a correlation.

Early in Pleistocene time, perhaps during the Aftonian or Yarmouth interglacial stage, a great blanket of loess was deposited on the area. The source of this material is unknown, but the similarity of its broken glass shards to unbroken glass shards in the Salt Lake formation (p. 28) suggests that Pliocene lake deposits supplied much material for the loess. This loess is 40 feet thick at its thickest known exposure in the Tetro Tunnel (p. 26), and it probably covered to a thickness of 15 or 20 feet all but the steepest slopes. The loess is significant to the Pleistocene erosional and depositional history of the area because it provided fine detritus for the great fans and for lacustrine deposits in the basins.

Erosion before and since the loess was deposited has been markedly different on the two sides of the range. This difference in erosion has been due to the difference in altitude of the base levels on the two sides of the range. On the west side of the range the thick loess at the Tetro Tunnel has been little disturbed since it was deposited (p. 61), and at other places on the west side of the range such as the south side of Ruby Hollow and near Diamond the loess probably is present under younger deposits, or as in Ruby Hollow and Diamond Gulch it has been reworked to form extensive fine-grained alluvial deposits. On the east side of the range most of the loess has been removed. Only thin remnants have been mapped at the surface, and exposures of buried silt cannot with certainty be correlated with the loess. However, beds and lenses of silt occur in all pre-Lake Bonneville deposits (except oal_1, whose only remnant is all gravel), and most of this silt was probably derived from the loess.

A period of erosion that preceded the flooding of Lake Bonneville basin by the Alpine-stage lake deeply dissected the fans and alluvial deposits. This erosion may have resulted from a climatic change or from uplift. We know that the climate became more humid at the beginning of the lake cycle, but deep dissection is more typical of an arid climate, so it seems more likely that dissection occurred before the climate became humid. Sufficient faults occur in alluvium near the quadrangle to indicate that moderate uplift occurred on both sides of the range. For example, on the west side of the range, a prominent fault cuts a pre-Lake Bonneville fan a few hundred feet west of the southwest corner of the quadrangle in sec. 12, T. 11 S., R. 3 W.; and on the east side of the range a fault occurrs in alluvium south of the southern border in a tunnel in sec. 14, T. 11 S., R. 2 W.

Regardless of the cause of the accelerated erosion, the dissection of the colluvial deposits produced deep gullies that have been only partly filled by colluvium of Lake Bonneville or younger age.

The overall history of the Lake Bonneville basin during Lake Bonneville and subsequent time is fairly complete, and therefore data from nearby localities are available to fill gaps in the record left by local deposits.

The waters of Lake Bonneville covered the whole eastern border of the Eureka quadrangle during the Alpine and Bonneville stages of the lake. Lacustrine deposits of both stages are prominent along the east side of the quadrangle, but no alluvial deposits have been correlated with certainty with either the Alpine or Bonneville stage of the lake. The absence of alluvial deposits of Alpine and Bonneville age on the east side of the range may be due to the greater power of the eastward-flowing streams whose steeper gradients made them capable of carrying most of the detritus well into the lake basin.

The lowest point on the west side of the quadrangle is about 800 feet above the Bonneville shoreline, and the waters of the bay of the lake at the south end of Tintic Valley probably did not come closer than 10 miles from the quadrangle. The valley gradients were lower on the west side, and more alluvium was deposited there during the lake cycles. Westward-flowing streams have done little degrading since Lake Bonneville receded, and large areas on the western slope are covered by alluvial and colluvial deposits of Lake Bonneville age.

When the level of Lake Bonneville dropped some 300 feet to the Provo level after the lake overflowed through Red Rock Pass (Gilbert, 1890, p. 260), streams from the eastern canyons formed distributary systems across the pre-Lake Bonneville fans and Lake Bonneville lacustrine deposits. Alluvium deposited from these streams partly covered the older deposits. These distributary systems persist today, and in many places it is difficult to subdivide the post-Lake Bonneville fan deposits because, although the deposits are evidently cyclic, they consist principally of gravels that are similar.

In the broad valleys and major tributaries post-Lake Bonneville deposits have partly filled the channels established after the recession of the Provo lake. These Recent deposits form smooth terraces 15 to 20 feet below the lowest pre-Lake Bonneville deposits and 3 to 12 feet above the bottoms of the arroyos that carry today's intermittent streams.

CONCLUSIONS

The conclusions reached by this study are grouped according to the main divisions of this paper, surficial deposits, geomorphology, and Cenozoic history. Most conclusions, such as migration of the divide, have only local significance, but other conclusions, such as those concerning the loess and the concentration of lime in the pre-Lake Bonneville deposits, may have regional significance.

SURFICIAL DEPOSITS

1. This study indicates that stratigraphic principles can be used to determine the sequence of deposition of discontinuous surficial deposits. Lithologic criteria are not easily established because it may be necessary to correlate many deposits by a few similarities even though they have many dissimilarities. Despite such difficulties of correlation, strict adherence to stratigraphic principles brings at least a semblance of order to the surficial deposits that "cover up the geology." More study of the mode of deposition and of criteria for correlation of great numbers of these deposits may lead to a better understanding of geologic principles. Lyell taught that "the present is the key to the past"; the Recent and Pleistocene deposits undoubtedly are the key he meant and, as our knowledge of them increases, we may learn at the same time more about the histories recorded by the older rocks.

2. The loess of pre-Lake Bonneville age probably provided the parent material on which the pre-Wisconsin paleosol of the Rocky Mountain region was developed. If this loess is as widespread as

the author suspects, such a blanket of silt could account for the great similarity of the ancient soil throughout the Rocky Mountain region. In and near the Eureka quadrangle, the silt derived from the loess has since been reworked into most younger deposits, and has provided a transported soil in an area where the climate since Lake Bonneville time has been incapable of producing an arable soil on bedrock or on alluvial gravel.

3. The high lime content of the gravels of pre-Lake Bonneville age is probably due to simultaneous air-borne deposition of fine lime carbonate and other fine-grained materials in the gravels rather than to soil-forming processes.

GEOMORPHOLOGY

1. Dynamic geologic forces have been at work building up, uplifting, and carving the Eureka area throughout the Cenozoic era. Local volcanic activity was strong in Middle Eocene time, and volcanism probably occurred along the borders of the mountains and within the mountains. Within the mountains, topographic displacements on block faults, such as the Silver Pass fault, show movements of 200 to 300 feet on faults that previously were believed to be insignificant. Erosion throughout Cenozoic time has in places smoothed and in other places deeply dissected the Paleozoic sedimentary rocks, the volcanic rocks, and the surficial deposits.

3. The most prominent effect of these dynamic forces is the westward migration of the divide. Steep canyons on the east slope attest to the strong cutting power of eastward-flowing streams;

old landslides are common on the eastern slope; and a Recent stream capture has shifted about 200 acres from western drainage to eastern drainage. The cause of this long-continuing migration of the divide is the difference in altitudes of the base levels on the east and west sides of the range. Tintic Valley on the west is about 850 feet higher than Goshen Valley on the east. The difference in altitude is attributed to uplift of Tintic Valley with the mountains during diastrophism that probably occurred in late Pliocene or early Pleistocene time.

3. Topographic prominence of the Diamond Divide Block is attributed to uplift along the bounding Silver Pass and Goshen Valley faults. No appreciable movement on these faults had been recognized by earlier workers because of the lack of evidence of stratigraphic displacement in the volcanic rocks. In this paper the topographic prominence and youthful landscape of the area within the block are accepted as evidence that displacement of about 200 to 300 feet occurred on these faults.

4. The rugged topography now exposed in the Paleozoic rocks south of Eureka probably pre-dates Middle Eocene volcanism. Steep slopes of the partly exhumed surface have apparently back-weathered only minor amounts since the volcanic rocks were stripped away.

5. Several old erosion surfaces have been named. One of the most prominent surfaces, the Ruby Hollow Surface, was carved by westward-draining streams, but stream piracies have transferred much of the surface to the eastern drainage. The Ruby Hollow Surface may have been cut in Pliocene time.

6. Periglacial, rather than glacial activity, probably occurred during Pleistocene glacial stages. The absence of cirques, U-shaped valleys, and moraines, and the presence of inactive talus slopes, old landslides, and buried frost-action deposits are the evidence that indicate periglacial conditions.

7. Three areas of anomalously strong erosion, called areas of accelerated erosion, occur near Homansville, along upper Pinyon Creek, and on the Goshen Slope. The erosion in all areas has been localized by one or more strong faults, and perhaps was aided by alteration of the rocks involved.

OUTLINE OF CENOZOIC HISTORY

1. Paleozoic rocks were folded into an asymmetric north-trending syncline that was later faulted, uplifted, and deeply dissected. Lower Tertiary(?) conglomerate was deposited. (Cretaceous-Eocene.)

2. Volcanism deposited 2000 feet or more of flows and pyroclastics. (Middle Eocene.)

3. Volcanic rocks were eroded.

4. Basin and Range block faulting occurred. (Miocene-Pliocene.)

5. Salt Lake formation was deposited, accompanied by local or nearby volcanism. (Pliocene?)

6. Salt Lake formation was deformed. Uplift of Tintic Valley and East Tintic Mountains created steeper gradients eastward to Goshen Valley. First large fans were deposited. (Pliocene-Pleistocene.)

7. Loess was deposited. (Early Pleistocene?)

8. Deposition of large fans in major valleys and along mountain fronts continued. The fan deposition probably was cyclic, and wind deposition of loess may have continued. (Pre-Lake Bonneville-Pleistocene.)

9. Minor uplift that formed scarps in fans occurred along Basin-Range faults. (Late pre-Lake Bonneville time.)

10. Fans and other alluvial deposits were deeply dissected, probably as a result of the uplift that may have been accompanied by climatic change.

11. Climate became more humid and Lake Bonneville basin was flooded.

12. Fine alluvium was deposited in valleys; Alpine formation was deposited in basin.

13. Lake Bonneville receded and later rose to Bonneville level.

14. Overflow from Lake Bonneville breached alluvial dam in Red Rock Pass, and the lake receded to Provo level.

15. Coarse alluvium was deposited during Provo stage.

16. Lake Provo dried to present remnants.

17. Recent alluvium was deposited, and later arroyo cutting began.

A MAJOR PROBLEM THAT REMAINS

This study shows that more work could be done on the surficial deposits in this area. More work would, perhaps, refine the sequence of deposition better than I have done and would prove or refute some of the tentative correlations I have made. The silt presents a problem that I feel is only partly solved, perhaps its solution has hardly begun.

I believe that the loess is not only the source of the silt but that in this loess and in the deposits derived from the loess lies the key to the problem of the number of times similar material in Recent deposits, for example, has been reworked. My sampling of the loess and other silt deposits was haphazard because I did not fully appreciate their significance until the time allowed for field work was near its end. Regular sampling of the deposits throughout the section and quantitative analyses of size, shape, rounding, and mineral suites might produce significant results.

The loess may also provide more information about the development of paleosols. I believe that the significance of the paleosol of the Rocky Mountain region would be greatly changed if it is found that the soil was developed principally on transported material rather than on weathered parent material. A blanket of loess spread throughout the region would have made easier the development of a similar soil on many kinds of bedrock, yet the loess would be unsuspected after strong soil development had disguised its original nature. Perhaps closer examination of the materials of the loess and of many samples of the paleosol would prove or disprove a common origin.

APPENDIX I

Measured sections

The measured sections that follow show lithology of deposits at a few selected localities in the Eureka quadrangle. The locations of the sections have been plotted on Plate III.

Section 1. Shaft of Original Iron King mine NE¼ sec. 20, T. 10 S., R. 2 W. The section is probably mostly loess of pre-Lake Bonneville age with lens of alluvial gravel. The top foot has been reworked from underlying units, and fresh pebbles have been added from rock outcrops topographically higher. Units 2 and 3 below show the B and C Ca zones of the typical pre-Wisconsin soil.

Surface	Feet
1. Silt with sparse subangular pebbles; dark gray; color probably due to modern leaching.-----------	1
2. Clay and silt; dark red-brown; not limy. Probably loess of pre-Lake Bonneville age. --------------	3
3. Silt and clay; light reddish brown; very limy; hard-pan in places. Probably loess of pre-Lake Bonneville age. ----------------------	4
4. Lens of bedded gravel with cobbles to 1 foot, very limy. Alluvium of pre-Lake Bonneville age. --	3
5. Silt and very fine sand with sparse pebbles to one-half inch; light yellowish brown; limy in vertical veinlets. Loess of pre-Lake Bonneville age. ------------------------------	6

Covered

Section 2. Railroad cut in NW$\frac{1}{4}$ sec. 14, T. 10 S., R. 2 W. Gravels above and below possible unconformity are of pre-Lake Bonneville age.

Surface	Feet
1. Bouldery gravel, sand, and silt; poorly sorted; boulders of quartzite, limestone, dolomite, and quartz latite up to 4 feet in diameter. Alluvium. --	4
2. Gravel; well sorted; subrounded pebbles 1 to 2 inches in diameter. Alluvium. ------------------	2
Channeling (unconformity?)	
3. Silt; very limy. Channels up to 2 feet deep are filled with gravel of unit 2. Loess? -----------	2
4. Gravel, silt, and clay; poorly sorted; slightly tabular subrounded fragments up to 5 inches long. Alluvium. --------------------------------	1
5. Gravel and fine-grained sand; poorly sorted; faint horizontal bedding; subangular to subrounded pebbles up to 3 inches are of limestone, dolomite, quartzite, and quartz latite. Alluvium. ----------------------------	4
Covered.	

Section 3. Pit in fan north edge of sec. 12, T. 11 S., R. 3 W. Alluvium and loess of pre-Lake Bonneville age. (See also Plate X.)

Surface. Loose cobbles.	Feet
1. Silt and very fine sand; light yellowish brown; very strong lime. Alluvium.	6
2. Gravel and silt; subrounded fragments up to 6 inches. Alluvium.	2
3. Silt and very fine sand; light yellowish brown; very strong lime; probably no pebbles. Loess.	9
4. Gravel and sand; rounded fragments up to 2 inches; faint bedding. Alluvium.	2 plus
Covered.	

Section 4. Shaft in NE¼ sec. 5, T. 11 S., R. 2 W. Alluvium-colluvium and loess of pre-Lake Bonneville age. Unit 1 shows result of reworking by colluvial activity or soil-forming processes.

Surface	Feet
1. Silt, sand, sparse pebbles; grayish brown	1/2
2. Gravel and sand; poorly sorted angular cobbles and finer material. Colluvium.	2
3. Sand, pebbles, sparse silt; irregular bedding. Alluvium or colluvium?	3
4. Angular cobbles, gravel, and silt with limy veinlets. Colluvium.	3
Unconformity?	
5. Silt with sand and sparse pebbles; light yellowish brown. Loess?	5 plus
Concealed.	

Section 5. Shaft in Burriston Canyon in north 1/2 sec. 20, T. 10 S., R. 2 W. Two deposits of pre-Lake Bonneville alluvium-colluvium overlying probable loess. (Deposits below upper unconformity cannot be reached for close inspection.)

Surface	Feet
1. Cobbles and boulders in limy, silty, semi-consolidated matrix; poorly sorted; angular to subrounded fragments of limestone, quartzite, and quartz latite to 1 foot in diameter. Colluvium; mudflow type? ----------------------	2
Unconformity.	
2. Silt and clay; brown, very limy; grades into unit 3 below. Loess? ------------------------	2
3. Angular cobbles and boulders to $1\frac{1}{2}$ feet with intermixed silt. Colluvium? ------------------	5
Unconformity.	
4. Silt and clay. Loess? --------------------------	2
Bedrock.	

Section 6. Shaft on colluvial slope $NW\frac{1}{4}$ sec. 32, T. 9 S., R. 2 W. Deposit is of pre-Lake Bonneville age.

Surface	Feet
1. Silt; light yellowish brown; very limy; contains lenses of angular limestone fragments to 8 inches long roughly parallel to slope. Colluvium of reworked loess with added bedrock fragments. ------------------------	10
Limestone bedrock.	

Section 7. Rail cut about 200 feet west of border of Eureka quadrangle, SE¼ sec. 25, T. 10 S., R. 3 W. Colluvium and loess of pre-Lake Bonneville age. Unit 1 probably is reworked from underlying units.

Surface	Feet
1. Silt, sand, sparse angular gravel; brown. Colluvium. ----------	1
2. Silt and angular fragments of igneous rock. Colluvium. ----------	3
3. Silt, light yellowish-brown. Loess? ----------	3
4. Silt and sparse angular gravel; poorly sorted; very limy; caliche coating on gravel. Colluvium of loess and gravel. ----------	15
Bedrock.	

Section 8. Section in prospect SW¼ sec. 27, T. 9 S., R. 2 W. Two deposits of colluvium of pre-Lake Bonneville age separated by loess. Differences in attitudes and lithologies of the colluvial deposits suggest different sources for the material.

Surface	Feet
1. Gravel and silt; subangular fragments of volcanic rock up to 8 inches. Very limy at base. Attitude of base N 23° W, 15° NE. Colluvium. ----------	2
Unconformity.	
2. Silt and clay; light yellowish-brown; limy in veinlets. Loess. ----------	3
Unconformity?	
3. Gravel; angular fragments of limestone up to 1 foot. Attitude of top N 40° W, 25° NE. Colluvium. ----------	3 plus
Covered.	

Section 9. Shaft in $NW\frac{1}{4}$ sec. 7, T. 11 S., R. 2 W. Alluvium of Lake Bonneville age overlies pre-Lake Bonneville alluvium.

Surface	Feet
1. Silt and very fine sand; light yellowish-brown; moderately limy. Alluvium of Lake Bonneville age. --	3
2. Gravel and sand; small rounded pebbles; well sorted lenses; fair bedding. Alluvium of pre-Lake Bonneville age. -------------------------	15 plus

Concealed.

Spoil from shaft shows that hole bottomed in boulder and cobble gravel.

Section 10. Auger hole in Tintic Davis Canyon in $NW\frac{1}{4}$ sec. 5, T. 10 S., R. 2 W. Probably all Recent alluvium.

Surface. Loose gravel.	Feet
1. Clay and silt; reddish-brown with limy veinlets. ----	1
2. Silt with well weathered fine gravel of volcanic rock. ----------------------------------	1
3. Clay and silt with grains of volcanic rock. --------	1
4. Silt with well weathered grains of volcanic rock. ---	2

Section 11. Pit in SE corner sec. 29, T. 9 S., R. 2 W. Probably Recent alluvium overlying alluvium of Lake Bonneville age.

Surface — Feet

1. Gravel with grayish-brown silt and sand; angular fragments up to 3 inches. Recent alluvium. ------- 1

2. Silt with lenses of bedded fine gravel up to one-half inch. Recent alluvium. --------------------- 5

3. Gravel and sand; poorly sorted; angular fragments up to 6 inches. Recent alluvium. ---------------- 4

Unconformity?

4. Silt and very fine sand; light yellowish-brown. Alluvium of pre-Lake Bonneville age. ------------- 4 plus

Concealed.

Section 12. Shaft in NW$\frac{1}{4}$ sec. 33, T. 9 S., R. 2 W. Colluvium of Lake Bonneville-Recent age overlying colluvium of pre-Lake Bonneville age.

Surface — Feet

1. Gravel with sparse sand; angular fragments 2 to 12 inches. Colluvium of Lake Bonneville-Recent age. ------------------------------------- 4

2. Gravel; rude bedding; mostly fragments 1 to 4 inches with sparse larger cobbles. Colluvium of pre-Lake Bonneville age. ------------ 10 plus

Concealed base, but spoil near pit contains silt that may be loess.

stet

APPENDIX II

Archeology

During the course of the field work the writer found many projectile points, chips, and other artifacts which indicated that Indians had camped in or passed through the area. No sites suggested repeated occupancy over long periods--rather the sites could have been places one generation of Indians found pleasant and visited twice or a dozen times; all artifacts were found on the surface as a single layer, none was found below the surface.

Most of the artifacts collected in the area have been examined by Alice P. Hunt, Research Associate of the University of Utah. She has reported that the finds show considerable range typologically. A number (Pl. XXVI, 1, 2, 3, 7, 10) probably are dart points predating the bow and arrow; some (Pl. XXVI, 4, 6) are similar to the arrow-points used by the Fremont people; the majority are recent Shoshonean (Pl. XXVI, 5).

The seemingly more significant artifacts and their descriptions are given here (Pl. XXVI and key), and all sites are located on a map (Pl. III). Additional work on the artifacts and sites and on the surficial deposits might forge a closer tie between some of the deposits and datable occupancy of the area by Indians. The sites have been registered with the Department of Anthropology, University of Utah, and the collection is available for future study.

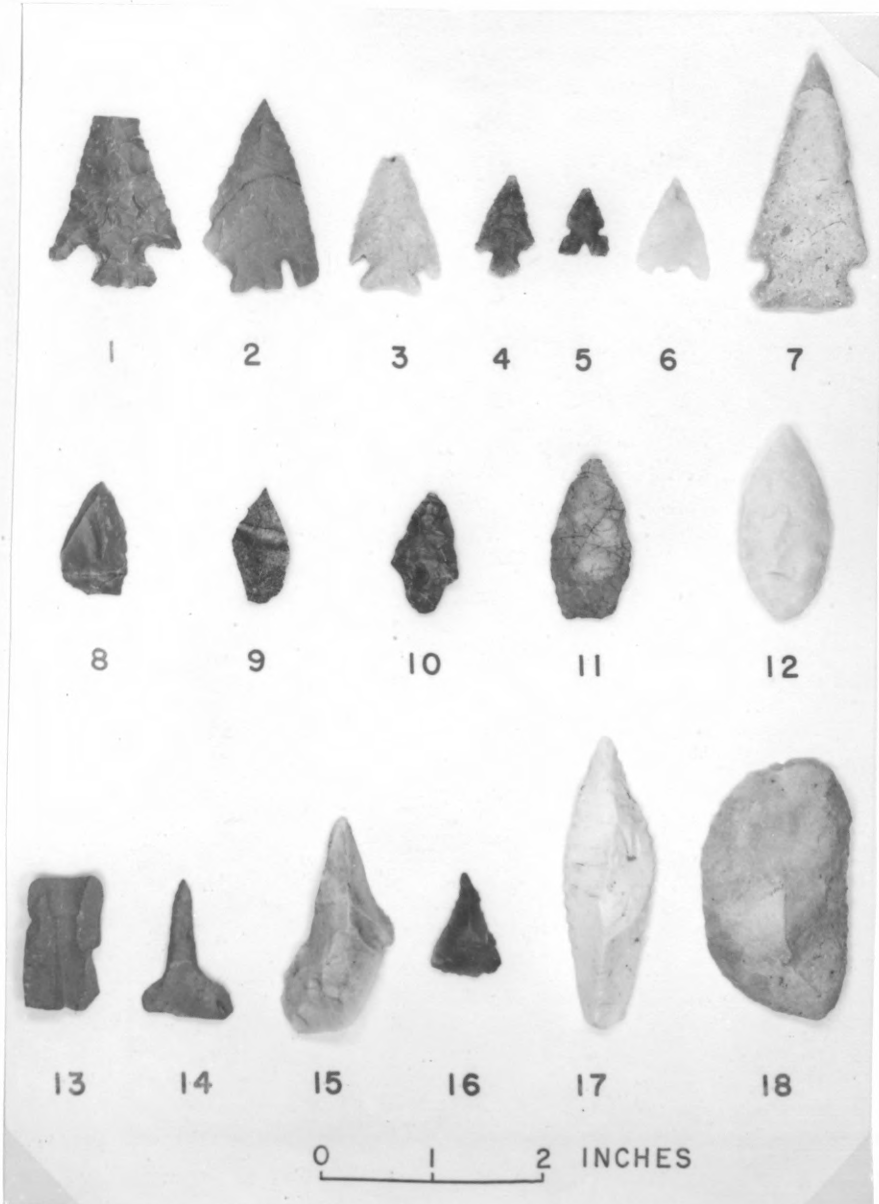


Plate XXVI
Artifacts collected in and near the Eureka quadrangle.
See key on following pages for description of pieces shown here.
(Photograph by Wendell Walker, U. S. Geological Survey)

Key to artifacts shown in Plate XXVI

Key number from Plate XXVI	Field Number	Rock type	Description	Reference page in work cited on p. 115
1.	A-5	Chert, black	Projectile point; narrow but expanding stem; long tangs; thick cross-section.	--
2.	A-26	Jasperoid, brown	Projectile point; long tangs; narrow stem.	38
3.	A-1	Silicified tuff, pink	Projectile point; medium base; medium tangs.	38
4.	A-27	Silicified tuff, gray	Projectile point; narrow stem.	38
5.	A-20a	Silicified tuff(?), gray	Projectile point, notched base.	46
6.	A-20a	Chalcedony white	Projectile point. Thin, heart-shaped, narrow stem, long tangs.	--
7.	A-2	Silicified tuff, light gray	Projectile point; wide base, short tangs.	42
8.	A-20a	Jasperoid, brown	Partly worked chip. Flaked on one edge.	--
9.	A-20a	Silicified tuff, purple	Partly worked chip.	
10.	A-27	Jasperoid, brown	Gypsum Cave type projectile point, contracting stem, sloping tangs.	29
11.	A-23	Silicified tuff, light red	Knife or unfinished projectile point.	82
12.	A-20a	Silicified crystal tuff, white	Knife, oval. Flaked along both edges.	58

Key number from Plate XXVI	Field Number	Rock type	Description	Reference page in work cited below
13.	A-25	Shale, gray	Pipestem? Fragment of a roughly cylindrical, elongate artifact with longitudinal hole.	--
14.	A-20a	Jasperoid, tan	Drill, large flange. Flaked along both edges; oval cross-section.	82
15.	A-20a	Silicified tuff, light gray	Drill? Triangular cross-section near point; very coarse flaking only--may be an unfinished tool.	82
16.	A-27	Agate, red	Drill, large flange. Triangular cross-section near point; flaked along two edges and base.	82
17.	A-24	Silicified tuff, white	Scraper, elongate, keeled. Triangular cross-section; flaked on two edges, ground along third edge about one-half inch from point.	104
18.	A-3	Silicified tuff, medium gray	Scraper, oval, concavo-convex. Flaked on both concave and convex edges.	106

Reference:

HUNT, Alice, 1953, Archeological survey of the La Sal Mountain area, Utah: Anthropological Papers no. 14, Dept. of Anthropology, Univ. of Utah, 248 p.

APPENDIX III

Water resources

Water is of great interest to the residents of the semiarid Eureka quadrangle, and although the study of water resources was not within the scope of this investigation of the geomorphology and surficial deposits, it is worthwhile to record some of the observations on water supplies that were noted during the course of field work.

The Eureka quadrangle has no perennial streams, and the few springs in the lava-covered areas provide only small amounts of water for human and stock-animal consumption.

The water problem of the area is due not so much to the lack of water as to the high permeability of the carbonate bedrock that underlies much of the area and to faults that provide underground channels in both carbonate and volcanic rocks. The 15 inches of rainfall in the vicinity of Eureka should supply plenty of water for the needs of the fewer than 2000 inhabitants, but because the rocks are highly permeable, the regional water table is 1100 to 1700 feet below the surface in the inhabited areas of the mountains, too deep for the water to be pumped to the surface economically. Locally, perched water tables occur in the volcanic rocks. None of these perched tables supplies water in large quantities, but some springs in the volcanic rocks have been developed for use by stock and for mining operations. Notable among these are the Big Gough Spring in sec. 33, T. 10 S., R. 2 W., and the unnamed springs in Dry Herd Canyon, in sec. 3, T. 11 S., R. 2 W. In some areas the surficial deposits are thick enough to provide at least temporary storage space for ground-water, in quantities sufficient to be useful.

Surficial deposits store the water used by the town of Eureka, which pumps water from wells dug into the valley fill of the basin west of Homansville Canyon (Pl. VI). This basin, however, although it drains about $2\frac{1}{4}$ square miles and has a potential average annual recharge of about 1800 acre feet of water, barely supplies the needs of the town, which should require less than 150 acre feet a year.

The reasons for the wide discrepancy between the amount of water used by Eureka and the potential recharge of the Homansville basin provide some criteria for determining ground-water potential in other areas of the region.

In order to estimate ground-water recharge to the Homansville basin, allowance must be made for losses due to evaporation, transpiration, and runoff down Homansville Canyon. If 75 percent of the potential recharge is assumed to be lost, about 450 acre feet should actually reach the local water table each year. This is three times the probable annual consumption, yet Mr. John Boss, in charge of the pumps for the town of Eureka, reported that pumping must be reduced in years when the rainfall drops to about 10 inches (two-thirds average precipitation) because the water in the wells falls too low.

The geologic map (Pl. I) shows that the alluvium in the Homansville basin probably lies on volcanic rock, which is relatively impermeable where it is unfractured. However, the basin is bounded by a fault on the southeast side (Pls. II and VI) and by another or the same fault on the east side. Furthermore, a fault parallels the surface drainage down Homansville Canyon. These faults probably drain more water from the basin than is lost by surface runoff down Homansville Canyon. Thus the 200 feet of alluvium in the basin probably acts only as a temporary reservoir, and its value as a reservoir hinges as much on the relative impermeability of the silt and clay beds that act as aquifuges in the basin as it does on the porosity of the coarser gravels.

The observations in the Homansville area suggest that the quality of an alluvial reservoir can be estimated by evaluating the permeability of the bedrock floor and the permeability and porosity of the alluvium. If the bedrock is fractured or otherwise permeable, the value of the reservoir may be greatly reduced, but the amount of reduction is likely to be less if the alluvium contains beds of fine silt or clay that slow down or prevent the percolation of water to the bedrock.

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