UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
AFFILIATED WITH
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
UNIVERSITY OF UTAH
SALT LAKE CITY, UTAH

BEAVER LAKE MOUNTAINS

BEAVER COUNTY, UTAH

Their Geology and Ore Deposits

By PATRICK JAMES BAROSH

Bulletin 68

March, 1960

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UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

The Utah Geological and Mineralogical Survey was authorized by act of the Utah State Legislature in 1931; however, no funds were made available for its establishment until 1941 when the State Government was reorganized and the Utah Geological and Mineralogical Survey was placed within the new State Department of Publicity and Industrial Development where the Survey functioned until July 1, 1949. Effective as of that date, the Survey was transferred by law to the College of Mines and Mineral Industries, University of Utah.

The *Utah Code Annotated 1943, Vol. 2, Title 34,* as amended by *chapter 46 Laws of Utah 1949*, provides that the Utah Geological and Mineralogical Survey "shall have for its objects":

1. "The collection and distribution of reliable information regarding the mineral resources of the State.

2. "The survey of the geological formations of the State with special reference to their economic contents, values and uses, such as: the ores of the various metals, coal, oil-shale, hydro-carbons, oil, gas, industrial clays, cement materials, mineral waters and other surface and underground water supplies, mineral fertilizers, asphalt, bitumen, structural materials, road-making materials, their kind and availability; and the promotion of the marketing of the mineral products of the State.

3. "The investigation of the kind, amount, and availability of the various mineral substances contained in State lands, with a view of the most effective and profitable administration of such lands for the State.

4. "The consideration of such other scientific and economic problems as, in the judgment of the Board of Regents, should come within the field of the Survey.

5. "Cooperation with Utah state bureaus dealing with related subjects, with the United States Geological Survey and with the United States Bureau of Mines, in their respective functions including field investigations, and the preparation, publication, and distribution of reports and bulletins embodying the results of the work of the Survey.

6. "The preparation, publication, distribution and sale of maps, reports and bulletins embodying the results of the work of the Survey. The collection and establishment of exhibits of the mineral resources of Utah.

7. "Any income from the sale of maps and reports or from gifts or from other sources for the Survey shall be turned over to the State Treasurer and credited by him to a fund to be known as the Survey Fund to be used under the direction of the Director of the Survey for publication of maps, bulletins or other reports of investigation of the Geological and Mineralogical Survey."

The Utah Geological and Mineralogical Survey has published maps, circulars, and bulletins as well as articles in popular and scientific magazines. For a partial list of these, see the closing pages of this publication. For other information concerning the geological and mineralogical resources of Utah address:

ARTHUR L. CRAWFORD, *Director*

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

College of Mines and Mineral Industries
University of Utah
Salt Lake City, Utah

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FEB. 28TH MDCCCL

Bulletin 68 March, 1960

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LIST OF ILLUSTRATIONS

PLATE

FIGURE

FOREWORD

The meager budget of the Utah Geological and Mineralogical Survey is now being directed toward six general types of publications:

I. Publications which form a part of a comprehensive geologic atlas of Utah--county by county.

II. Supplemental studies of the mineral potentials of state lands with a view to their more accurate appraisals for administrative purposes--such surveys to be correlated with the published atlases of each county (see "I" above) so as to give the state the greatest value for the money it has expended on the investigations by the Utah Geological and Mineralogical Survey and by other agencies.

III. Special inventory studies of state-wide significance, such as that of "The Oil and Gas Possibilities of Utah."

IV. A description of the typical rocks and minerals of Utah--a continuing effort towards a well-rounded summary of special use to college and high school students interested in this subject and to boy scouts, tourists, and "rock hounds" generally who want to become intimately familiar with the earth's crust exhibited within Utah's boundaries.

V. Special investigations of mines or specific areas where intensive study by an authority on the subject has made available to us a by-product of special value in working out the general geology, which we hope to include in our geologic atlas of the state.

VI. The rocks and scenery of boy scout camps and of other points of tourist interest within the state. The principal rendezvous for three of the four national councils in Utah of the Boy Scouts of America have already been described (see Bulletins 51, 60, and 67).

Three of our county bulletins, Numbers 52, 64, and 66, belonging to the geologic atlas of Utah series have been published (for Emery, Cache, and Daggett Counties, respectively). Washington, Uintah, and Sevier Counties are well under way. Most of the other counties are being actively investigated.

The present study, Bulletin 68 on the "Beaver Lake Mountains, Beaver County, Utah--Their Geology and Ore Deposits" by Patrick James Barosh, falls in the class of studies listed under "V" above. The material was collected by Mr. Barosh while employed as a geologist for the Utah Construction & Mining Company. It was originally made the subject of a master's thesis for the Department of Geology, University of California at Los Angeles. It was selected by the Utah Geological and Mineralogical Survey for publication at this time because:

(1) It fills a much-needed gap in the areas represented by the bulletins of the Utah Geological and Mineralogical Survey.

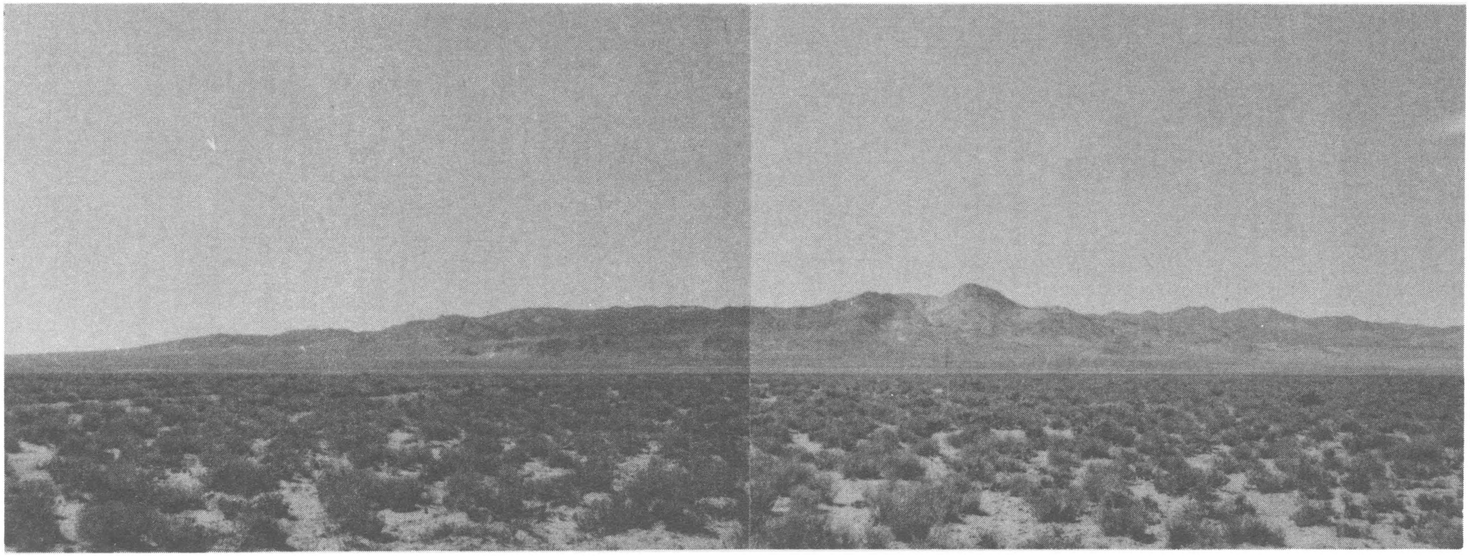
(2) It furnishes a modern correlation of the very excellent studies made by B. S. Butler of the San Francisco district, and of adjacent areas, not only with more recent investigations made of this region, but also of the Mineral Range to the southeast, and of the Cricket Mountains and other areas of Millard County to the north and northwest studied by Dr. Lehi F. Hintze and his colleagues and students at the Brigham Young University.

(3) The southeastern portion of the Beaver Lake Mountains offers one of the tantalizing prospects for an additional "porphyry" copper deposit in Utah. We, therefore, feel justified in giving it special consideration. The area is rich in its display of contact metamorphic minerals and of magnesite and some other minerals not mentioned by the author.

(4) The deep burial of some of the Beaver Lake mineral deposits in the detritus from the higher areas and their having been exhumed by later erosion, made possible by the lowering of the outlet of Beaver River, is a geomorphological record of unusual interest.

Mr. Barosh is a native of Los Angeles. He received his B. A. degree at U.C.L.A. in 1957. He spent one summer in Alaska doing exploration geology for the Utah Construction & Mining Company for whom he later did the exploration work in the Beaver Lake district that forms the basis for this bulletin. The many aspects of geologic study in this area we think makes this work a valuable contribution to the bulletin series of the Utah Geological and Mineralogical Survey.

ARTHUR L. CRAWFORD, DIRECTOR
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY



FRONTISPIECE. Figure 1. Beaver Lake Mountains looking west.

BEAVER LAKE MOUNTAINS

BEAVER COUNTY, UTAH
Their Geology and Ore Deposits[1]

by Patrick James Barosh[2]

ABSTRACT

The Beaver Lake Mountains lie in the Basin and Range province of west-central Utah, ten miles northwest of the town of Milford, Beaver County.

Paleozoic sediments and Tertiary igneous rocks are found in the area. Lower to Middle Cambrian rocks form a transgressive sequence of quartzite, shale, and carbonates. The later Middle Cambrian to the Late Ordovician has no representatives in the area, but the latest Ordovician (?) to the Devonian is represented by a dolomite sequence. This sequence is overlain by Mississippian limestone. No sedimentary rocks younger than Mississippian have been recognized in the area.

The Early (?) Tertiary is represented by volcanics, which are generally quartz latite in composition, and some granodiorite porphyry. These were followed in the Middle (?) Tertiary by a quartz monzonite intrusion which has altered part of the earlier carbonates and volcanics.

Structurally the area is complex and can be divided into two parts; the northern third which has been effected by high-angle faulting, thrust faulting, and folding, and the southern two-thirds in which the structure mainly reflects the shape of the intrusion with some modification by high-angle faulting.

The geologic record of the area appears to be one of relatively quiet sedimentation for the Early and Middle Paleozoic, which probably continued till the Late Mesozoic although no record of the latter part of this period is present, and a great deal of activity in the latest Mesozoic and Tertiary with extrusion, intrusion, thrusting, folding, and high-angle faulting.

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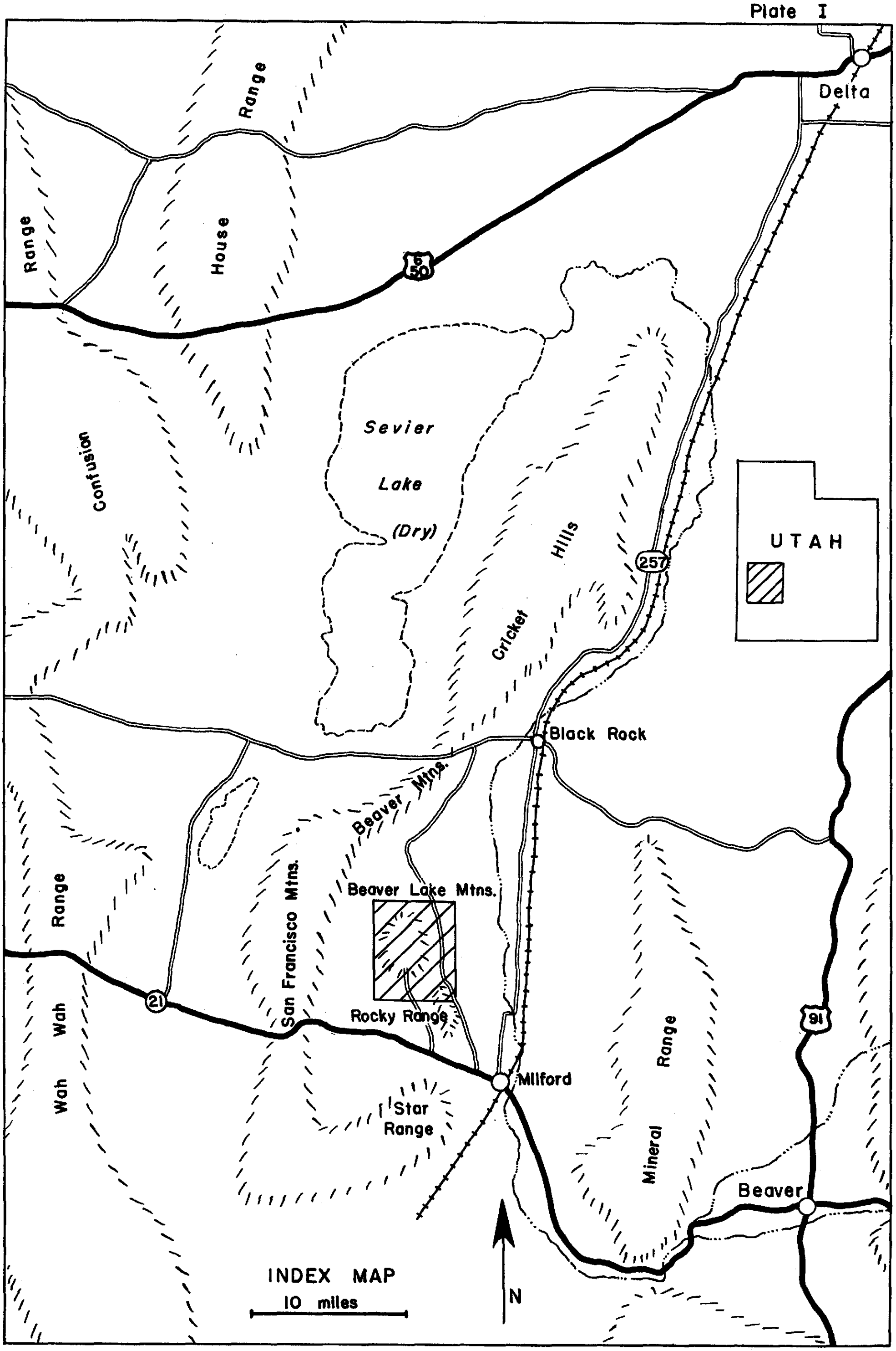
[1] Adapted from a Master's thesis submitted to the Department of Geology, University of California, Los Angeles.

[2] Exploration Geologist, Utah Mining and Construction Company.

Plate I



Delta
Range
House
Range
6
50
Sevier
Lake
(Dry)
Confusion
Cricket
Hills
257
UTAH
Black Rock
Beaver Mtns.
San Francisco Mtns.
Beaver Lake Mtns.
Rocky Range
Range
Wah
Wah
21
Milford
Star
Range
Mineral
Range
91
Beaver
N
INDEX MAP
10 miles

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Beaver Lake Mountains lie in the Basin and Range province of west-central Utah, ten miles northwest of the town of Milford, Beaver County (see index map, plate I). The mountains are readily accessible by two graded dirt roads which run northward from Utah State Highway 21 just west of Milford.

GEOGRAPHY

PHYSICAL FEATURES

The Beaver Lake Mountains form a low circular mass of hills situated on an eastward slope which runs from the San Francisco Mountains on the west to the Beaver River on the east. The relief is low, the elevations ranging from 5,500 feet at the eastern base to 6,900 feet at Lime Mountain (see fig. 1). The western flanks of the mountains are overlapped by the alluvial slope of the San Francisco Mountains, but the eastern flanks are composed of low, broad coalescing fans which extend valleyward. All drainage is eastward toward the Beaver River. A mile and a half southeast of the Beaver Lake Mountains is the small northernly trending Rocky Range (see fig. 2). There are no permanent streams in the mountains. The only good water in the mountains during the summer of 1958 was in a flooded adit on the north side of the upper end of Butch Canyon. Water of a dubious quality was found at Fairview Springs and two flooded adits just northwest of there. West Spring was only a mud hole during the time of the visit.

VEGETATION

In general the vegetation of the area is sparse and consists of relatively few species. The alluviated flanks of the range are covered by sagebrush for the most part. There are, however, patches of matchbrush in the south and southwest, and wild oats form the ground cover at the northeast corner of the range; some cliffrose occurs in the lower washes east of Lime Mountain.

In the mountains proper the vegetation is scantier but a little more varied. Sage is still prevalent, but added to it are such plants as morton tea, bunch grass, and

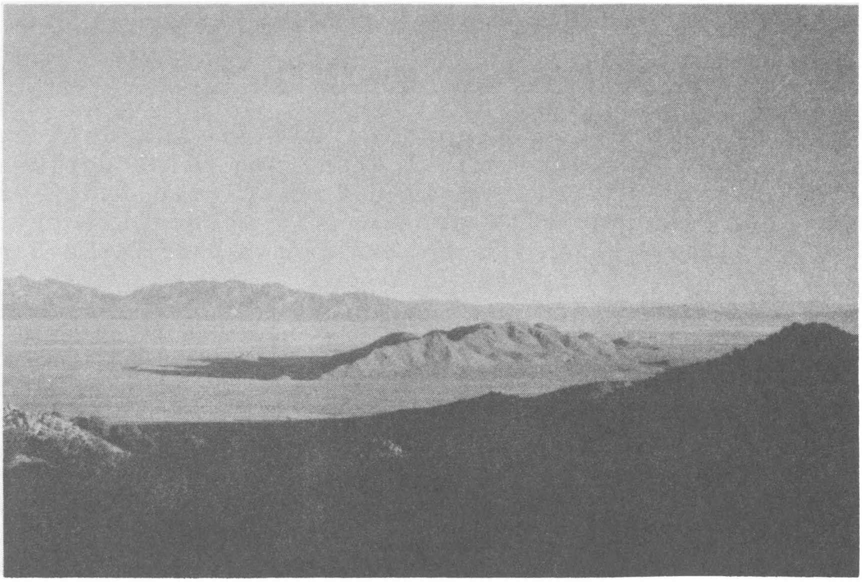


Figure 2. Rocky Range, view southeast from divide west of Fairview Springs; Mineral Range in left background and the Colorado Plateau in the far right background.

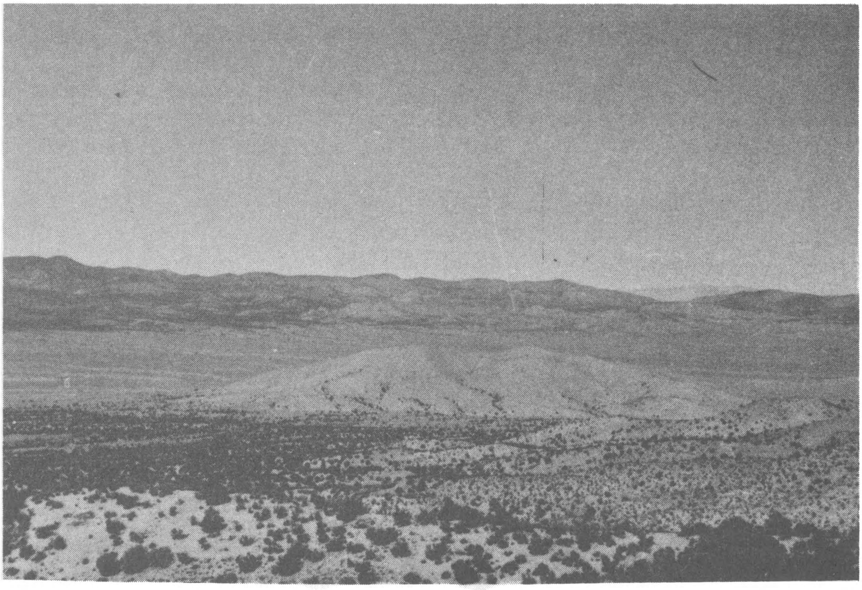


Figure 3. Quartzite Hill, looking northwest from near the Skylark mine; San Francisco and Beaver Mountains in the background.

three types of cacti: an opuntia, a mamailia, and a plata, which occur sparingly, except in the northwest where the opuntia is common. In addition, a very few yuccas are found at the north edge of the mountains.

Stands of juniper occur in many places, especially on the volcanics on the west-central side, and show a preference for the north-and west-facing slopes. A small grove of pinyons are growing high on the north flank of Lime Mountain, and a few pinyons also occur in with the junipers.

CLIMATE

The area has an arid climate, being situated in the high desert region of western Utah. During the summer the daytime temperatures are close to 100°F. with the maximum in July, but because of a nearly constant breeze and low humidity the heat is seldom oppressive. The daily temperature range is about 31°F. Evenings are cool and the nights are quite comfortable.

The first frost occurs about mid-September and the last one around the end of May. The winters are very cool with January being the coldest month, having an average maximum temperature of about 39°F. and a minimum of about 13°F.

Precipitation is meager, about 9 inches annually, and is distributed fairly evenly throughout the year with June the driest month and March the wettest. Thunder showers may be expected almost every afternoon during July and August, and occasionally they are violent causing flash floods. During the winter there is light snowfall which amounts to about 34 inches annually (modified after Woolley, 1947, pp. 56-65).

CULTURE

The most notable cultural features are the numerous prospect pits throughout the area and the numerous dirt roads that traverse the area, many of them built and still being built as assessment work on mining claims. Other than this there are some buildings at a few old mines and north of Butch Canyon, where a futile attempt to farm was once made. Two small dams, that rarely contain water, are on the east edge of the area.

PREVIOUS WORK

Very little has been published on this area. The southern two-thirds of the area was covered in the well done U. S. Geological Survey Professional Paper 80, Geology and Ore Deposits of the San Francisco and Adjacent Districts, Utah, by B. S. Butler, printed in 1913. Butler includes a rough reconnaissance map of the southern Beaver Lake Mountains, touches on the alteration of the lavas, and describes briefly a few mines--the O K mine in particular.

Other than this there have been only two short articles on the district published in 1903 (Anonymous, 1903; Perkins, 1903) and mention of some early production of a few mines is made in the U.S. Tenth Census (Huntley, 1885).

FIELD MAPPING AND PURPOSE OF THE INVESTIGATION

The field work was done during the summer of 1958 from mid-June to mid-September. Most of the area was mapped on the Frisco Special map of the U.S.G.S., enlarged to 1/24,000. The topography on this sheet is rather poor and the base elevation 81 feet too high. The northern part of the Rocky Range and the low hills to the west of it were mapped on a blue-line preliminary copy of the 7 1/2 minute quadrangle, Lund number 1 northeast, Utah, and the northern edge of the area was mapped on a planimetric stream map drawn from an aerial photograph.

The purpose of this investigation was to map the areal geology of the Beaver Lake Mountains with special emphasis on the contact metamorphic zone, particularly in regards to the distribution and amount of iron minerals.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Donald Carlisle, for his aid in the preparation of this thesis. I particularly wish to thank Utah Construction Company for permission to use the field work as the basis for this thesis and also C. J. Kundert and Calvin Farwell for greatly aiding the field research.

DESCRIPTIVE GEOLOGY

GENERAL FEATURES

Paleozoic sediments and Tertiary igneous rocks, both intrusive and extrusive, are found in the area. The Paleozoic sediments consist of dominantly carbonaceous rocks representing some part of each of the periods from the Cambrian to the Mississippian. The Lower to Middle Cambrian rocks form a transgressive sequence of quartzite, shale, and limestone. The later Middle Cambrian to the Late Ordovician have no representatives in the area, but the latest Ordovician (?) to the Devonian is represented by a dolomite sequence. This sequence is overlain by Mississippian limestone. No sedimentary rocks younger than Mississippian have been recognized in the area, and the stratigraphic record is blank until the Tertiary.

The Early Tertiary (?) is represented by volcanics, which are generally quartz latite in composition, and some granodiorite porphyry. These were followed in the Middle Tertiary (?) by a quartz monzonite intrusion which has altered part of the earlier carbonates and volcanics.

SEDIMENTARY ROCKS

Cambrian

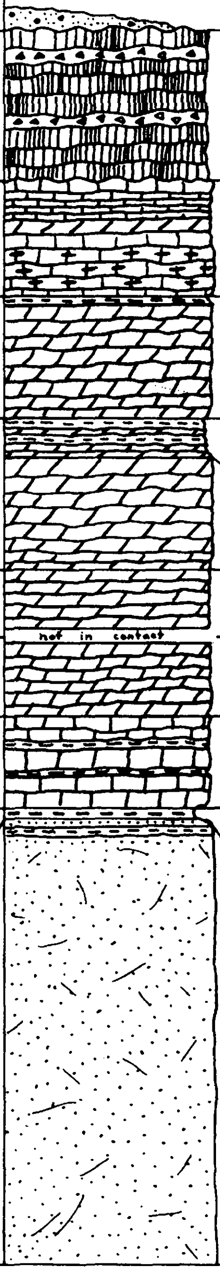
Sediments of Early to Middle Cambrian age are present at the northern edge of the Beaver Lake Mountains possibly as a thrust sheet. These sediments form a transgressive sequence with a thick basal unit of quartzite grading upward into shale which in turn gives way to limestone and some dolomite.

The Cambrian sequence at the northwest corner of the area is Prospect Mountain quartzite, Pioche shale, Millard limestone (?) and Burrows limestone (?). The designation, in this area, of the Prospect Mountain quartzite and the Pioche shale is fairly definite, but the assignment of the higher rocks to the Millard and Burrows limestones is questionable because of the possibility of faulting.

The Pioche shale is very thin here, the Busby quartzite in the Pioche shale and the Millard and Burrows limestones are thicker than usual.

COLUMNAR SECTION

Plate II

System	Series	Formation	Columnar Section	Thickness	Description
Quat.		Alluvium	 not in contact		Unconsolidated sand and gravel, including Lake Bonneville deposits
Tert.	Lower	Volcanics		1,000'+	Undifferentiated flows, mostly quartz latite, with some pyroclastics
Miss.	L.	Joanna ls.		800'+	Dark-gray cherty limestone and light-gray dolomitic limestone
Devonian		Simonson-Guilmette		800'	Dark-gray dolomite
Silurian		Lime Mountain dolo.		250'	Light-gray dolomite and dark-gray shale
				750'+	Light-gray dolomite
Ord	U.	Beaver Lake d		400'+	Dark-gray mottled dolomite
Cambrian	Middle	Burrows ls.		480'+	Light- to medium-gray dolomite
		Millard ls.		600'	Dark-gray limestone with slight shale
	Lower	Pioche sh.		55-70'	Green sericitic shale and quartzite
		Prospect Mountain quartzite		3,000'+	White to light-gray quartzite

Vertical Scale

0' 1,000' 2,000'

Prospect Mountain Quartzite

The Prospect Mountain quartzite is a fairly resistant unit which forms Quartzite Hill and two small isolated ridges east of it in the northwest part of the area (see fig. 3).

This formation is a fine-grained dense quartzite that generally varies from white to light gray, but locally may be pink or purplish in color, and changes near its upper contact to a dark olive green. Weathering usually causes only a very slight darkening of the surface. Bedding is hard to distinguish, except near the upper contact, and the quartzite usually appears massive, but where bedding is seen the beds are one to two feet thick. In some places thin, dark subparallel laminae show cross-bedding in the quartzite. The rock is moderately to highly fractured and generally weathers to fist-size angular fragments which cover up most of the unit on the surface.

The quartzite is sheared and brecciated in many spots, especially along the southern side of Quartzite Hill and in the two ridges to the east of it. It is in these brecciated zones that the rock takes on pink and purple colors. Some silicified fault breccia zones, a foot or two wide, are more resistant than the undisturbed rock, standing out as low walls; they may be responsible for some of the ridges on hills where they crop out. The undistrubed quartzite is a harder rock than the breccia, but the breccia more than compensates for this in having much fewer fractures.

The lower contact of the Prospect Mountain quartzite in this area is probably a thrust fault and an unknown amount of the lower part of this unit is not present. The upper contact is not exposed, but appears to be conformable and gradational with the overlying Pioche shale. Near the upper contact the quartzite changes to dark olive green or greenish-brown in color and is well-bedded in about one-foot beds with some thin interbedded dark-green shales. In the Pioche shale there are interbedded dark-green shales. In the Pioche shale there are interbedded dark olive-green quartzites, and it appears that the Prospect Mountain quartzite grades into the Pioche shale as the shale-sandstone ratio increases.

A minimum thickness of 3,000 feet was measured along the axis of the anticline from the southwest part of the outcrop area which appears to be very close to the top of the unit, northeast to the intersection of the stream and the road, it was assumed that there is no major displacement along the breccia zones crossed.

This formation can safely be considered Prospect Mountain quartzite because its lithology and thickness are similar to recognized Prospect Mountain quartzite in the San Francisco and Beaver Mountains only a few miles away, and the overlying rock unit is the same in the Beaver Mountains.

The Prospect Mountain quartzite is considered to be of Late Precambrian and Early Cambrian age in western Utah (Wheeler, 1948, p. 20). The quartzite is unfossiliferous, but the conformably overlying Pioche shale of western Utah carries a fauna of late Early Cambrian or early Middle Cambrian age, and it seems probable that the Prospect Mountain quartzite was laid down during the Early Cambrian, the lower part perhaps being deposited during the Late Precambrian in thick sections (Wheeler, 1943, p. 1810-11).

Pioche Shale

The Pioche shale is poorly exposed. It has been uncovered only along one gully on the north side of Quartzite Hill, except possibly for a small patch of similar appearing shale that is in complex relationship with Cambrian limestone on the south side of the hill. The narrow covered area between the Prospect Mountain quartzite and the Cambrian limestone along the northwest side of Quartzite Hill is probably underlain by Pioche shale. The unit consists of interbedded shale and quartzite in about equal proportion. The shale is gray-green, sericitic, and very fissile, usually disintegrating into paper-thin flakes when disturbed. They generally occur in beds about four inches thick. There is also a slight amount of brown sericitic shaly sandstone which is gradational between the shale and the quartzite.

The quartzite is fine-grained dark olive-green with some sericite along the bedding planes and weathers dark brown along fractures. It is well-bedded, forming beds five inches to a foot thick, a few of which bear ripple marks on their surfaces.

From the base of the unit upward there are twenty feet of alternating quartzite and shale, five feet of quartzite, fifteen feet of shale, and fifteen feet of quartzite.

Neither the upper nor the lower contacts are exposed, but attitudes in the shale are similar to those of the units above and below, and the contact with the underlying Prospect Mountain quartzite appears to be gradational. The upper contact with the Millard limestone (?) is probably conformable, but as the Pioche shale is thinner than usual, there is the possibility of an unconformity or a fault.

The exposed thickness is about fifty-five feet and the total could not be much more than seventy feet. This poses a problem since there is 519 feet of Pioche shale seventeen miles north in the Cricket Hills (Hintze and Migliaccio, 1957) and 600 feet in the Wah Wah Range twenty miles to the west (Wheeler, 1948, fig. 5). This implies a thinning of the unit south and eastward, either from original deposition or erosion, or else omission of some of the section by faulting. Faulting seems least likely since either a curved fault following the strike of the beds or two faults would be necessary. The Pioche does vary somewhat in thickness, being only 265 feet thick in the House Range (Deiss, 1938, p. 1139) and 25 to 100 feet thick fifteen miles east of the area in the northern Mineral Range (Liese, 1957). Since no unconformity at the top of the Pioche shale has been recognized in the region, the best explanation for the thinning of the unit is that this area is near the eastern edge of the depositional basin of the Pioche shale.

No fossils were found in the unit at this locality, except for some unidentifiable impressions on the top of one bed, but in other localities in western Utah and eastern Nevada fossils found in the shale show it to be astride the Lower Cambrian-Middle Cambrian boundary (Wheeler, 1948, p. 25).

This formation can safely be considered Pioche shale as it resembles it lithologically, occupies a similar position stratigraphically, being above a thick quartzite and below Cambrian limestone, and is only a few miles from recognized Pioche shale.

Millard Limestone (?)

This unit forms a few low outcrops above the Pioche shale on the northwest side of Quartzite Hill and probably the east-west ridge and small outcrops of brecciated limestones east of Quartzite Hill.

The Millard limestone consists mainly of limestone with some shale. On the northwest side of Quartzite Hill the limestone is generally dark gray, with a few medium-gray beds; weathered colors are somewhat lighter, except for several brown-weathering beds near the base of the unit. In the lower half of the unit the limestone is algal and several beds have small dolomitic patches. The dolomitic patches, one-half to one inch long, are usually yellow-brown and give the gray limestone a rather distinctive appearance. Beds, two to five feet thick, are fairly distinct in the limestone. A thin shale horizon, in about the middle of the section, contains abundant trilobite fragments. This shale is medium gray to brown and weathers brown.

East of Quartzite Hill the lithology is very similar, but the complexity of the structure prevents a matching of beds with any reliability. In general the sequence is similar just east of the hill. Around the small syncline the limestone is dark gray, north of the road it is algal, and near the quartzite there is a very small patch of shale similar to the Pioche shale.

The east-west ridge is made up of dark- to medium-gray algal limestones with some gray, brown-weathering shale, especially towards the east end.

The upper and lower contacts are both concealed. The attitudes are similar to those in the units above and below; the upper contact may well be conformable, but there is some doubt about the lower one (see discussion under Pioche shale).

Trilobite fragments found in shale on the north side of the syncline at the east end of the east-west ridge were identified as Glossopleura sp., confirming a Middle Cambrian age for the limestone. Other trilobite fragments found could not be identified, and some small inarticulate brachiopods from the syncline just east of Quartzite Hill could only be dated as Cambrian.

The limestone northwest of Quartzite Hill occupies the same stratigraphic position as the Millard limestone, apparently overlying the Pioche shale and being overlain by a light-gray dolomite which is probably the Burrows limestone. It is lithologically similar to the Millard limestone as are most Cambrian limestones of this region. Because of the possibility of a fault contact between this formation and the Pioche shale and its uncertain stratigraphic position, it can only be questionably considered Millard limestone.

In the Cricket Hills, seventeen miles north, the Millard limestone is only 260 feet thick (Hintze and Migliaccio, 1957), but in the Wah Wah Range, twenty miles to the west, the Millard limestone equivalents measure 561 feet (Wheeler, 1948, fig. 5) which matches closely the 600 feet of this section measured northwest of Quartzite Hill. The Millard limestone in the Cricket Hills, however, is underlain by 113 feet of Busby Formation (Hintze and Migliaccio, 1957), composed of interbedded sandstone, shale, and limestone, which was not recognized here. The sandstones apparently tongue out southward (Wheeler, 1948, p. 29), and their stratigraphic position could be occupied by only limestone and some shale here.

The _Glossopleura_ sp. found in the Cambrian limestone east of Quartzite Hill is elsewhere found in both the Chisholm shale, equivalent to about the middle part of the Millard limestone, and a shaly horizon in the Burnt Canyon limestone, which is the next formation above the Burrows limestone. The rocks at the east end of the east-west ridge could therefore be either Millard or Burnt Canyon limestone, but the Burnt Canyon limestone in the Cricket Hills contains a great deal of shale (Hintze and Migliaccio, 1957) and shale is only minor here. There is also the possibility, because of the faulted and folded nature of the rocks, that limestone of more than one formation may be present in this ridge.

Burrows Limestone (?)

This formation crops out in two small patches in the northwest corner of the area where it apparently overlies Millard limestone. The contact with the Millard limestone is concealed, but the attitudes are similar on both sides and it is probably a depositional contact. No overlying formation is exposed and the Burrows limestone (?) is regarded as the highest Cambrian unit exposed in the area.

This formation consists of light-gray dolomite, with some medium- and dark-gray dolomite in the northern outcrop, which weathers a little lighter than the fresh rock. The dolomite is faintly laminated in part and is fairly well bedded into beds about three feet thick.

The Burrows limestone is unfossiliferous, but is dated elsewhere as Middle Cambrian on the basis of its position between two fossiliferous Middle Cambrian limestones (Wheeler, 1940, p. 29).

In about half of its exposures the Burrows limestone consists of light-gray dolomite (Wheeler, 1943, p. 1791), and it was originally named the Burrows dolomite by Wheeler (1940, p. 27), who later changed it to the Burrows limestone (Wheeler, 1943, p. 1791). It is often the only unit in the Middle Cambrian succession that is dolomitic.

The exposed thickness of the Burrows limestone amounts to about 480 feet and the total thickness can only be estimated, but it is probably not much more than this judging by the measured thickness elsewhere. In the Cricket Hills it is only 260 feet thick (Hintze and Migliaccio, 1957). Near Pioche the thickness ranges from 100 to 400 feet, depending upon the local amount of the post-Burrows degradation (Wheeler, 1943, p. 1818), and an unconformity may be responsible for the range in this region also.

The assignment of these rocks to the Burrows limestone is tentative and is based upon their stratigraphic position above the Millard limestone (?) and a lithology similar to the Burrows limestone. Although its exposed thickness is greater than usual, it is within a reasonable range.

Upper Ordovician(?)-Silurian

Two formations have been assigned to this interval, a dark-gray dolomite containing abundant Halysitidae and an overlying light-gray unfossiliferous dolomite. These correspond to at least part of the Fish Haven (U. Ord.) - Laketown (Sil.) sequence, but are probably not directly equivalent. The division between the Fish Haven and Laketown dolomites is made on a time boundary, the Ordovician-Silurian (Richardson, 1913, p. 410), while that between the dolomite units of this area is based on lithology. For this reason new formation names are assigned here. The lower dark-gray Beaver Lake dolomite is probably equivalent to both the upper part of the Upper Ordovician Fish Haven dolomite and the lower part of the Silurian Laketown dolomite. The upper light-gray dolomite, Lime Mountain dolomite, is probably equivalent to the upper part of the Laketown dolomite and perhaps in part to the Devonian Sevy dolomite.

Beaver Lake Dolomite

This formation crops out in the northern part of the area around the northern base of Lime Mountain and the ridges to the northwest of it. Also, the metamorphosed rocks on the west flank of Lime Mountain are considered an altered equivalent of the Beaver Lake dolomite.

In general this unit consists of dark- to medium-gray mottled or laminated dolomite, which weathers a lighter gray, with a few beds of edgewise conglomerate. The formation shows fair bedding, the beds usually being about ten feet thick. Fossils are conspicuous in much of the formation and occur in two different ways; as fine white lines describing sections of small horn corals, crinoid stems, and shells, and as large silicified horn corals and tabulate corals. In addition to these there are small silicified masses that may have been fossils.

A section exposed on the west side of the ridge trending northward from Lime Mountain towards the Galena mine is as follows from the exposed base upward. The base of this section is in fault contact with altered dolomite. Above the base is about sixty feet of dark-gray mottled fossiliferous dolomite. Within it are a few laminated beds and also two ten-foot edgewise conglomerate beds containing subangular dolomite fragments averaging three inches in diameter with very little sandy dolomite matrix. Next is a medium gray unit about sixty feet thick composed of dark-gray dolomite which weathers light to medium gray, much of which is laminated. The laminations are usually subparallel, suggesting crossbedding, or slightly wavy, but some laminations describe miniature folds that suggest slump structures. Near the middle of this unit there is a twenty-foot bed of edgewise conglomerate. There is very little matrix in the conglomerate and the clasts consist mainly of wavy laminated dolomite with some dark-gray mottled dolomite. These clasts are angular to subangular and range up to three feet by one and a half feet in size. Above this is about seventy feet of mottled dark-gray fossiliferous dolomite with a fifteen-foot silicified zone at the base, possibly a fault zone. This mottled dolomite lies below the Lime Mountain dolomite with apparent conformity.

The base of the Beaver Lake dolomite is not exposed and the thickest measurable section is 200 feet on the northwest side of Lime Mountain. How much thicker the unit may be is not known, but its minimum exposed thickness is estimated at 400 feet.

Fossils found in this formation are Catenipora sp. and other unidentified Halysitids, Favosites sp., Syringoporid corals, Rhynchonellid brachiopods, large and small horn corals and crinoid stems. The Halysitid _Catenipora_ sp. bears a resemblance to _C. pulchellus_, a late Devonian species.

The Halysitidae restrict the unit to the Late Ordovician and Silurian. This is the only definite age restriction. The formation may contain both Upper Ordovician and Silurian strata since in the Snake Range the Ordovician-Silurian boundary has been found within a sequence of dark-gray dolomite below a light-gray dolomite (Rush, 1951a, p. 13). The section described from the northwest side of Lime Mountain is very similar to the description of the lower half of the Laketown dolomite at Gold Hill, which was considered Middle Silurian by Edwin Kirk (Nolan, 1935 , p. 18), and perhaps the Middle Silurian may be the upper age limit for the Beaver Lake dolomite.

Metamorphosed Equivalent

The altered rock on the west and south sides of Lime Mountain are considered to be the altered equivalent of the Beaver Lake dolomite. On the south flank of Lime Mountain light-gray dolomite with a slight amount of tremolite and silicic masses that may have been fossils is noted (see fig. 10). This is at about the right stratigraphic horizon for the top of the Beaver Lake dolomite, and it appears that this is essentially a bleached equivalent.

On the west side of Lime Mountain a folded and faulted section of metamorphosed dolomite crops out (see fig. 6). The dolomite here is a mixture of medium-gray and white beds three to five feet thick. The medium-gray dolomite is fine-grained with faint banding and has poorly developed slaty cleavage. The white dolomite is massive with a sugary texture. Throughout much of the rock are nodules and irregular masses of tremolite, usually about fist size, and also some irregular elongate stringers. At two places on the west side of Lime Mountain recognizable Beaver Lake dolomite appears to grade into this altered rock. Moreover, tremolite nodules, which are characteristic of this altered dolomite, also occur in recognizable Beaver Lake dolomite at one location on Lime Mountain. These tremolite nodules are developed only in the altered dolomite around Lime Mountain and are possibly restricted to the metamorphosed Beaver Lake dolomite.

Some of the highly altered dolomite along the intrusive contact south of Lime Mountain may also be Beaver

Lake dolomite, although tremolite nodules are not present (see discussion under metamorphosed Lime Mountain dolomite).

Lime Mountain Dolomite

This formation forms the top of Lime Mountain and the ridge to the east, the top of the ridge containing the Galena mine, and a slope east of the Galena mine.

The Lime Mountain dolomite consists of two members, a thick lower member of light-gray dolomite and a thin upper member of light-gray dolomite with interbedded shales. The lower member is fine-grained light-gray dolomite, except for two medium-gray beds near the base, which weather a little lighter. Near the Galena mine the rock is faintly mottled by slightly darker ovals whose elongation is parallel to the bedding. On steep slopes and bluffs the dolomite appears well-bedded in ten- to fifteen-foot beds, but on gentle slopes bedding is hard to distinguish and the dolomite appears massive.

The upper member is present northeast of the Galena mine. Here the dolomite changes upward from a massive dolomite into dolomite that is well-bedded in one- to three-foot beds with some interbedded shale which increases in amount upward culminating in a fifty-foot shale unit at the top of the formation (see fig. 8). The dolomite is fine-grained, light gray, and weathers slightly lighter. The shale is dark gray and silicic in part and weathers light reddish-gray to reddish-brown. It occurs in layers about four feet thick composed of two- and three-inch beds. There is no complete measurable section of the Lime Mountain dolomite because the base and the top of the formation occur in different fault blocks. Correlation between the blocks is not possible and it is not known whether there is overlapping or missing section. About 300 feet of the formation is exposed above the Beaver Lake dolomite on Lime Mountain. Another 950 feet crops out east of the Galena mine, the topmost 250 feet forming the upper member, but attitudes are hard to find in the lower member and there could easily be faulting there. If no faulting is assumed, a minimum thickness of 1,000 feet can be assigned.

The lower contact with the Beaver Lake dolomite is apparently conformable. The upper contact is poorly exposed, but similarity in attitudes across the contact suggest a conformable relationship.

No fossils were found in the Lime Mountain dolomite. As it overlies Halysitidae-bearing rocks, is lithologically similar to the upper part of the Laketown dolomite, and is overlain by dark dolomites of probable Devonian age, it is tentatively considered Middle or Late Silurian in age or both. There is, however, the possibility that the Silurian-Devonian boundary lies within the upper part of the formation since the Devonian Sevy dolomite locally is hard to distinguish from the Silurian rocks (Campbell, 1951, p. 22) and conceivably the upper member of the Lime Mountain dolomite is equivalent to the Sevy dolomite.

Metamorphosed Equivalent

On the south slope of Lime Mountain the dolomite is metamorphosed and locally has a poorly developed slaty cleavage. The fresh rock here is also light gray, but the weathered surface has a buff cast. A few white beds with a sugary texture occur at the bottom of the slope. The rock at the southern base of Lime Mountain is cut by a closely spaced network of north-south vertical joints and small faults, and the dolomite along many of them is stained dark brown.

The moderate to highly metamorphosed dolomite farther south along the intrusive contact is probably mostly Lime Mountain with some Beaver Lake dolomite. The altered Lime Mountain dolomite on the south side of Lime Mountain is not noticeably different from the altered dolomite near the intrusive contact. The metamorphosed rock here is white to light-gray dolomite, much of it coarse-grained, and mineralized in lenses along the intrusive contact. This altered rock differs from recognizable metamorphosed Beaver Lake dolomite in not having the abundant tremolite nodules and fine banding developed in it, but some of it may well be Beaver Lake dolomite.

Devonian

Simonson Dolomite-Guilmette Formation(?)

The ridge next north of the Galena mine is formed of dark-gray Devonian dolomite. Dark-gray dolomite forming the ridge two-thirds of a mile east of the Galena mine is probably also Devonian, although lithologically it is somewhat similar to the Beaver Lake dolomite. This latter dolomite, however, in as much as it is apparently overlain by limestone similar to that overlying the Devoniian dolomite north of the Galena mine, is probably equivalent to the upper part of the Devonian dolomite there. These rocks are here referred to as the Simonson dolomite-Guilmette formation.

The unit north of the Galena mine comprising approximately 800 feet of beds is composed of medium- to dark-gray light-gray weathering dolomite and minor sandy dolomite. Some of the beds contain small irregular masses of calcite, and in the upper part there occur jasperoid beds that appear to have been a medium-gray, sandy dolomite originally (see fig. 16). The dolomite is fairly well-bedded, the beds ranging from two to fifteen feet in thickness and averaging about four feet.

The dolomite east of the Galena mine is similar to that described above. It is mainly dark gray with some medium-gray dolomite in three-foot beds and, in places it contains small irregular calcite masses apparently developed about fossils. Some beds contain small horn corals and crinoid stems and are reminiscent of the Beaver Lake dolomite. Near the easternmost thrust fault the dolomite is very brecciated and silicified. Just south of this dolomite are metamorphosed carbonate rocks that may be a metamorphosed equivalent.

The lower contact of the Simonson dolomite-Guilmette formation (?) is poorly exposed. No difference in attitude across the contact is discernible, and it may be a conformity with the upper member of the Lime Mountain dolomite. The upper contact with Lower Mississippian limestone appears to be conformable in the area studied, but it may be disconformable, as the Upper Devonian Pilot shale normally present below the Mississippian limestone is absent. The Pilot shale is probably truncated by the Mississippian Joanna limestone in the House and Confusion Ranges (Campbell, 1951, p. 23), and its equivalent the Mowitza shale is present in the Star Range a few miles south of here (Butler, 1913, p. 34-35).

No fossils were found in the dolomite north of the Galena mine and only unidentifiable horn corals and crinoid stems were found in the dolomite east of the Galena mine. However, since this unit overlies the Lime Mountain dolomite, which is thought to be Silurian, matches the general Devonian lithology of the region, and is overlain by Lower Mississippian limestone, it is reasonable to consider it Devonian in age.

This succession is in general a correlative of the Devonian section of western Utah in being dark dolomite overlying the lighter Silurian rocks (Rush, 1951b, p. 45; Campbell, 1951, p. 22). It most probably is equivalent to either or both the Simonson dolomite and the Guilmette formation. It is probably equivalent in part to the Red Warrior limestone of the Star Range (Butler, 1913, p. 33-34).

Mississippian

Joanna Limestone

The Joanna limestone, the youngest sedimentary unit in the area, underlies a small area northeast of Lime Mountain and also caps the north end of the ridge of Devonian dolomite. This unit is somewhat folded and faulted making proper stratigraphic order hard to determine.

In general the Joanna is composed of dark- to light-gray fossiliferous limestone and some dolomitic limestone that is locally cherty. At the base of the unit, where it caps the Devonian dolomite, it is dark- to medium-gray fossiliferous limestone in beds two feet thick. The lowest part of the section northeast of Lime Mountain is a light-gray dolomite overlain by a thick sequence of dark-gray limestone and some dolomitic limestone both of which contain irregular chert lenses and bands parallel to the bedding; the limestones are fairly well-bedded in layers around five feet thick. Above these limestones is a dark-gray limestone unit consisting of three- and four-inch beds that is cut by a fine network of calcite veinlets and capped by a fossiliferous reddish-weathering slightly shaly medium-gray limestone. The beds next above are medium- to light-gray limestone and dolomitic limestone that are well-bedded in two- and three-foot beds.

The lower contact may be a disconformity as was discussed under Devonian. The upper contact is not exposed.

This formation is structurally deformed making thicknesses hard to determine, but there appears to be about 800 feet exposed.

Horn corals and gastropods were found in the limestone capping the Devonian dolomite. The horn corals were identified as <u>Enygmophyllum</u> sp. which occur most commonly in rocks of Early Mississippian age in the western United States. In the limestone northeast of Lime Mountain <u>Fenestella</u> sp. and large horn corals are very common throughout. <u>Lithostrotion</u> sp. and <u>Syringopora</u> sp. were found in the cherty limestone and in the shaly limestone <u>Juresania</u> sp. (?), spiriferid brachiopods, bryozoan zoaria, and crinoid stems up to one inch in diameter were found . From these collections the limestones are assigned a Mississippian age.

The designation of these beds as Joanna limestone is based on lithologic similarity to the Joanna at the type section, being in general a dark cherty Mississippian limestone with practically no shale. The Joanna limestone here is much thicker than in the Confusion Range, but it may be truncated there by the overlying Chainman shale (Campbell, 1951, p. 23). The formation is probably equivalent to part of the 1,500 feet of Topache limestone in the Star Range (Butler, 1913, p. 35-36).

Undifferentiated Paleozoic

Undifferentiated Carbonates

Due to metamorphism attendant upon intrusion and the faulting in the area, there are several patches of carbonate rock, mainly dolomite, that have not been assigned to any formation or age other than Paleozoic. These undifferentiated carbonates occur in three general areas; the west-central part of the mountains, the section northwest of Lime Mountain, and the northeast portion of the mountains.

The largest area of undifferentiated carbonate is in the central and western part of the Beaver Lake Mountains. The carbonate is metamorphosed to varying degrees and is usually very light gray probably due to the bleaching effect of the intrusion. There are a few brown-weathering white to pink quartzites noteably near the volcanic contact northwest of hill 6870. Some mineralization occurs along the intrusive contact, and near the contact the carbonate is often coarsely recrystallized, calcite rhombs up to one inch in diameter being developed. The rock is generally highly fractured and largely covered by its own debris with the result that very few attitudes can be obtained and no beds followed. Butler (1913, plate 1) felt that this rock might be the altered equivalent of the Mississippian Topache limestone in the Star Range.

The undifferentiated carbonate northwest of Lime Mountain is generally light-gray dolomite, with some medium-gray dolomite and limestone. The dolomite here is largely similar to the Lime Mountain dolomite, but the structure here is complicated and undeciphered due to poor exposures, and the rock appears to be from more than one unit.

Four patches of undifferentiated carbonate rock occur in the northeast part of the mountains. East of Lime Mountain are exposures of altered light- to dark-gray dolomite that may be equivalent to either the Beaver Lake dolomite or the Simonson-Guilmette sequence.

East of the thrusts are some slightly to highly metamorphosed carbonates that are medium to light gray depending upon the amount of metamorphism. These carbonates occur largely as roof pendents in the quartz monzonite and are mineralized sporadically along the contacts; the two small southernmost pendents consist entirely of silicate skarn minerals. Under the northern exposures of the thrust, the carbonate is only slightly altered and is medium gray in color. North of the granite outcropping there is a small area of mostly unaltered medium- to dark-gray carbonate.

The undifferentiated carbonate west of the eastern thrusts at their northern exposures and the carbonate above the thrust at the north end of the Joanna limestone are similar, both being medium- to dark-gray dolomite. The dolomite is fairly well-bedded in two- to five-foot thick beds. Both dolomites are finely fractured near the thrusts with silica fracture fillings that give a honeycombed appearance to the rock in places; the west half of the unit north of the Joanna limestone is disturbed with each outcrop having an attitude somewhat different from the next one to it.

Quaternary

The Quaternary is represented in the area by several types of material, unconsolidated, except for caliche. These deposits consist of two general types of alluvium, some caliche and Lake Bonneville sands and gravels. They have not been differentiated in mapping and are all shown as Quaternary alluvium on the geologic map (plate IV).

Alluvium

The alluvium is very extensive, covering nearly two-thirds of the area and is a variable heterogeneous mixture. In a broad sense, it can be divided into two main types, Beaver Lake and San Francisco alluvium, plus a small amount of remnant upland gravels.

Beaver Lake Alluvium

The Beaver Lake alluvium is by far the most extensive alluvial formation in the area, and it appears to have been derived from the Beaver Lake and Rocky Ranges. It consists mainly of silt, sand, and gravels with only a small percentage of pebbles and larger clasts. Coarse material is found only along stream channels and near the northern Rocky Range. Around the areas of quartz monzonite the alluvium consists mainly of arkosic sand. This alluvium characteristically is host to a moderate cover of sagebrush.

San Francisco Alluvium

Along the west edge of the area is the lower part of the alluviated east-sloping flank of the San Francisco Mountains which ends against the west slope of the Beaver Lake Mountains. The alluvium on this slope presents a different appearance from the Beaver Lake alluvium as it contains a much higher percentage of coarse clastic debris, specifically cobbles and boulders of Prospect Mountain quartzite, and there is a thinner cover of sagebrush.

Remnant Upland Gravels

Northwest of hill 6870 there are many low subparallel finger-like ridges extending northwest into the alluvium. These ridges are composed of volcanics in the foothills and valleyward they become covered with clastic material. The clastic material contains much pebble- and cobble-, and some boulder-, sized debris and has a much lower percentage of fine material than is found in the gullies between the ridges. This material is composed mainly of volcanics with some carbonate rocks, in addition to a noteable amount of quartzite, which occurs only sparingly mountainward. This quartzite-bearing alluvium also occurs in a few places farther up the mountain flanks and on the top of two volcanic hills where there is no possibility of downhill movement of quartzite under present conditions. This alluvium appears to represent remnants of an older more extensive cover of alluvium, similar in origin to the San Francisco alluvium.

Caliche

At the west and south sides of the mountains a few small patches of caliche are exposed along stream channels and in small valleys. The caliche occupies a position directly over the bedrock and beneath the alluvium. Much of the caliche overlies volcanics and consists of angular volcanic fragments in a light-gray calcium carbonate matrix which resembles a lithic tuff. At one place on the south side of the range, the calcium carbonate matrix is stained black and the rock looks like asphalt. In the valley west of the O K mine and in Ram

Skull Canyon the caliche is very resistant forming small "cement" ledges which overhang the more easily eroded volcanics.

Lake Bonneville Deposits

Shore line features of Lake Bonneville occur along the east edge of the area and deposits in the form of beach sands and gravel bars are found there. In general the bars are covered with subangular to subrounded gravel ranging from pea to pebble size and averaging about three quarters of an inch. Roughly, the gravels are composed of two-thirds quartzite and one-third volcanics. The small areas of sand are light gray and generally fine-grained. The distribution and interpretation of these deposits are discussed under geomorphology. Gilbert (1880, p. 397) assigned a Late Pleistocene age to Lake Bonneville.

IGNEOUS ROCKS

Over two-thirds of the exposed rocks in the Beaver Lake Mountain area are igneous. These are about equally divided between volcanics and quartz monzonite and both are considered Tertiary in age, the volcanics being earlier and in a large part altered by the quartz monzonite intrusive. Minor amounts of granite and dike rock occur associated with the quartz monzonite and some granodiorite porphyry, which is similar to some of the volcanics, may represent an old volcanic conduit.

Tertiary

Volcanics

A wide variety of volcanic rocks is found in the area, flows of quartz latite being the commonest type. The volcanics occur in three general places: the west central part of the mountains, the south part of the mountains, and in the southeast part of the area, west and east of the Rocky Range. The volcanics in the west central area are unaltered, the ones in the south are largely altered, and the volcanics in the southeast are relatively unaltered.

Several areas mapped by Butler (1913, plate 1) as granodiorite porphyry in the vicinity of the Rocky Range are underlain by volcanics. This was shown by the finding of flow breccias at these locations (see fig. 4). The granodiorite porphyry is very similar to much of the rock classed as volcanic, and possibly some of the mapped volcanics are intrusive; some of the mapped granodiorite porphyry may include extrusive rocks.

The volcanic rocks are mainly flows, with some pyroclastics which vary in appearance and composition in the western part of the area. In general the lavas are dark-gray, with some maroon, medium-gray and greenish-gray, porphyritic rocks that usually weather gray-brown to brown and range in composition from latite to andesite with quartz latite probably the most common. The phenocrysts are medium-grained subhedral to euhedral crystals in a dark-gray very fine-grained matrix and constitute twenty to fifty percent of the rock. The phenocrysts consist mainly of light-gray feldspars with quartz and some accessory augite, hornblende, olivine, and biotite. The quartz, augite, and hornblende are locally important; the olivine occurs in the rocks in the south and southeast parts of the area where it composes four to five percent of the rock and locally up to twenty percent; and biotite is present in some specimens in minor amounts. Some of the volcanics, particularly on the east side, contain a minor amount of magnetite. A minor amount of black fine-grained basalt was found at two locations and some flow breccia occurs on both sides of the northern Rocky Range and at one place in the Beaver Lake Mountains. The breccia contains a variety of subangular to rounded volcanic fragments, up to three inches, in a medium-gray porphyritic matrix. The lavas are generally massive, flow banding being rare.

Light- to medium-gray crystal tuffs are found at the western edge of the area. Some tuffaceous-looking lava may be included with these. Crystal fragments consisting of feldspar, quartz, and biotite usually constitute thirty to seventy-five percent of the rock, though a minor amount of tuff has only ten percent crystal fragments, along with a few percent of small volcanic fragments in a very fine-grained, light-gray matrix. Biotite locally forms as much as thirty percent of the rock. The crystal fragments indicate a composition in the dacite-andesite range.

Some maroon crystal tuff and some green lithic tuff which contains sixty percent angular volcanic fragments one quarter of an inch to one inch in size crop out on the southeast side of Quartzite Hill. Similar greenish lithic tuff occurs along the south side of the quartz monzonite west of hill 6870.

Figure 4. Flow breccia just south of the small dam east of the Rocky Range.

Much of the volcanic rocks in the southern part of the Beaver Lake Mountains, between the two main quartz monzonite outcrops, has been altered. The altered rocks appear to constitute a broad shallow (?) roof pendent. The alteration is clearly related to the intrusion, the volcanics away from the intrusion being unaltered.

The altered volcanics range from ones that merely have been bleached to highly altered ones composed almost entirely of silica or silica and sericite. Andalusite is present in some of the most highly altered rock (Butler, 1913, p. 79). The southwest part of this area is especially siliceous and at places the siliceous rock has a granular appearance and may be mistaken for sandstone in a hand specimen. Along the south wall of Butch Canyon there is a silicic zone that may represent a fault. The alteration is further discussed under metamorphism.

The colors of the altered rock vary from the light gray of the bleached rock through the light buffs and browns of the more highly altered rocks. Often the rocks are light-buff with dark-brown patterns commonly in the form of concentric circles. In the highly silicic rocks the colors are generally light grays on a fresh surface and dark reddish-brown on a weathered surface.

The volcanics have also been subjected to contact mineralization at several places south of hill 6870 and at a few locations south of the O K mine in what appear to be small mineralized roof pendents of volcanics. Another contact metamorphic zone occurs at the western base of Porcupine Hill.

The volcanics unconformably overlie the Paleozoic carbonate rocks. The contact with the carbonate rocks is poorly exposed and the amount of discordance between the two is not known, but one hill of carbonate dipping about fourty degrees was capped by volcanics which appeared to be flat-lying.

The contact of the quartz monzonite with the volcanics is intrusive. This is shown by the alteration of the volcanics, which decreases away from the intrusive, by contact mineralization, gradational contacts in places, and by one quartz monzonite dike that cuts the volcanic rocks.

It is difficult to judge the thickness of the volcanics because of the lack of attitudes and the high probability of undiscovered faults. Estimates from the surface extent suggest the volcanics are probably over 1,000 feet thick. This same volcanic series was assigned a thickness of 4,800 feet in the San Francisco Mountains (East, 1956).

The volcanic rocks can be dated only as younger than the Paleozoic carbonates and older than the quartz monzonite intrusive, which is not thought to be younger than middle Tertiary due to the amount of erosion that has taken place. However, these volcanics can be considered part of the extensive volcanics of the neighboring areas: Wah Wah, San Francisco, Star, and Mineral Ranges. In the Wah Wah Range the volcanics are younger than the Jurassic Winsor formation (R.C. Speed, personal communication). In the southern end of the Mineral Range the volcanics overlie sediments assigned to the Cretaceous Claron conglomerate and are considered early Tertiary in age (Earll, 1957). In view of this the volcanics are tentatively assigned an early Tertiary age.

Granodiorite Porphyry

The granodiorite porphyry is recognized only in the southeast corner of the area where it forms an eastern bulge in the central part of the Rocky Range. This porphyritic rock is very similar to some of the volcanics and would probably be classed as an extrusive if the intrusive nature of its southern contact were not seen. Butler has stated (1913, p. 51) "the two rocks are so similar in character that a separation is practically impossible." Immediately south of the mapped area the granodiorite is intrusive into carbonate rocks assigned to the Triassic Harrington formation by Butler (1913, plate 1). The contact is mineralized in part, and the rock has been mined for its magnetite and copper content.

In view of the marked similarity of the granodiorite porphyry to the volcanics, it is reasonable to suppose that the volcanic rock represents an intrusion along the base of the volcanics or perhaps a plug or volcanic conduit.

The granodiorite porphyry is a dark-gray to greenish-gray rock with fine- to medium-grained phenocrysts of feldspar, some ferromagnesium minerals and quartz set in a very fine-grained dark groundmass. The phenocrysts form up to sixty percent of the rock. The composition of the rock is in the granodiorite-diorite range, but more closely approaching granodiorite on the average.

The contact between the granodiorite porphyry and the volcanics is either not exposed or not recognized. Some volcanics may occur in the granodiorite porphyry. The quartz monzonite is intrusive into the granodiorite porphyry. The western contact with the quartz monzonite is rather sharp, but along the northern contact there are numerous dikes extending into the granodiorite porphyry fifty to a hundred feet forming a contact zone about fifty feet wide.

The age relationship of the granodiorite porphyry is similar to that of the volcanics, it being younger than the Triassic Harrington formation (Butler, 1913, p. 64) and older than the quartz monzonite. The age relationship to the volcanics is not known, but Butler (1913, p. 52) states that "what appear to be dikes of the granodiorite are present in the lavas of the Rocky Range, and it is believed to be younger than the flow rocks." The granodiorite porphyry is here assigned somewhat arbitrarily the same age as the volcanics (early Tertiary). It may be younger than the volcanics and it may be related to them in some way. Liese (1957) found some dark granodiorite in the northern Mineral Range, eleven miles east of the area. He believes this could represent an earlier magmatic differentiation of the main granite stock, which is assigned a middle Tertiary age, and it is therefore possibly early Tertiary in age. He states also that it might be related to the granodiorite porphyry of the Rocky Range.

Quartz Monzonite

The quartz monzonite crops out in four areas: the northeastern, where it is composed of several patches separated by altered carbonate or alluvium; the central, which has an arm extending to the southwest; and the southern parts of the Beaver Lake Mountains; and the northern part of the Rocky Range. The quartz monzonite probably also underlies most of the alluvium on the east and south sides of the mountains.

The intrusive is medium-gray, with some light-gray, medium-grained equal granular rock which ranges from granite to quartz diorite and averages quartz monzonite approaching granodiorite (see fig. 5). Accessory minerals include biotite, hornblende, augite, magnetite, apatite, and sphene. Quartz content ranges from ten to thirty percent, but is usually fifteen to twenty percent. Biotite ranges from one to fifteen percent and is generally five to eight percent. Hornblende locally forms up to twenty percent, but usually composes about five percent, and augite locally forms a few percent. Magnetite is present up to about five percent and apatite and sphene form two percent or less. The quartz monzonite forms rounded outcrops and boulders that disintegrate into arkosic sand covering the ground in the areas of the intrusive. In the northern Rocky Range the intrusive is a little coarser than average and slightly more resistant. Jointing is fairly well developed in the quartz monzonite. On East Ridge the dominant jointing is about east-west and nearly vertical. Around Fairview Springs it is north-south.

In a few places, particularly on East Ridge, the quartz monzonite contains scattered dark-gray, rounded segregates of fist size that are slightly more resistant than the quartz monzonite and weather out as knobs on it. These segregates are fine- to medium-grained slightly porphyritic areas of a much higher concentration of ferromagnesium minerals.

Schlieren commonly occur in the intrusive near the volcanic and granodiorite porphyry contacts. Their general appearance is fine-grained, gray-green bands and whispy streaks of chloritic material. A few gray bands have the appearance of streaked-out quartz monzonite, and some of the bands may represent zones of movement rather than schlieren. However, in the Rocky Range, it was fairly definite that these streaks were schlieren since they were only plentiful near the contact and they were similar in color to the granodiorite porphyry.

Figure 5. Quartz monzonite cut by aplite dikes on East Ridge.

A darker, finer-grained type of quartz monzonite that weathers into angular fragments occurs along the contact in Butch Canyon and forms the hill at the end of the canyon. It has less quartz and more pyroxene than usual and probably represents a border phase of the intrusive. A somewhat similar contact phase is described from the eastern margin of the quartz monzonite in the San Francisco Mountains (East, 1956).

The quartz monzonite has intruded the carbonates, volcanics, and granodiorite porphyry, altering a great deal of the intruded rock, and is probably responsible for all of the mineralization in the area. The intrusion appears to have been at least partially a forceful emplacement as carbonates which are flat-lying on Lime Mountain become folded southward toward the intrusion and are steeply dipping or vertical against it. The intrusions in the San Francisco Mountains (East, 1956) (Butler, 1913, p. 70), Star Range (Butler, 1913, p. 71), northern Mineral Range (Liese, 1957), and in the House Range (Gehman, 1958, p. 12) are also thought to have been, at least partially, forceful intrusions, since they appear to dome the intruded rock. This may be characteristic of the Tertiary intrusions of the region. The presence of schlieren in the quartz monzonite indicates some digestion of the country rock, and the absence of carbonates below the volcanics in the southern part of the area could be the result of a large amount of assimilation.

The quartz monzonite is the youngest igneous rock of the area except for some dike rock. As the volcanics and granodiorite porphyry are thought to be of Tertiary age the intrusion is conceivably late early Tertiary or younger. On the other hand, it seems likely that the intrusion occurred at least prior to the latest Tertiary to allow for sufficient time for the high-angle faulting and for erosion to uncover it. In view of this, the quartz monzonite is tentatively assigned a middle Tertiary age. In the San Francisco Mountains the quartz monzonite intrusion has similar geologic relationships, being probably part of the same general intrusion, and is considered middle Tertiary in age by East (1956). He assigned the volcanics a possible late Oligocene age and considered a later age for the intrusive improbable since time was needed for faulting and erosion to take place. At Gold Hill the quartz monzonite intrusion probably took place between the late Eocene and early Oligocene (Nolan, 1935, p. 48) and the intrusion at Iron Springs, fifty miles south of here, is thought by Butler (1920, p. 571) to have post-dated latitic lavas, which overlie sediments of Late Cretaceous or Eocene age or both (Mackin, 1947, pp. 8-9). The monzonite intrusive in the Tintic district is late Eocene or post-Eocene in age, and the intrusion in the Oquirrh Range is probably the same age (Gilluly, 1928, p. 1118).

Quartz Diorite Porphyry

Dikes of quartz monzonite porphyry are found within the quartz monzonite at two places: on East Ridge and south of the Skylark mine. In both places they strike east-west and appear to be vertical. The dikes line up and may lie along the same zone of weakness in the quartz monzonite, although they may be separated by a thrust fault. The quartz diorite porphyry is more resistant than the quartz monzonite and is a ridge former.

The dikes are medium-gray porphyritic quartz diorite slightly darker than the quartz monzonite. They darken unevenly on weathering in such a way as to bring out the porphyritic texture and give the rock a speckled appearance. Also in places the rock has a marked pitted surface from the weathering-out of the feldspar. The phenocrysts are medium-grained plagioclase with some quartz, hornblende, augite, biotite, and epidote in a fine-grained groundmass probably consisting mainly of quartz. Most of the rock has been propylitized with the majority of the hornblende, augite, and biotite replaced by chlorite and calcite; most of the plagioclase, as well, is partially altered.

The contacts are chilled over a five-foot contact zone. The rock becomes more noticeably porphyritic and darker, grading into fine-grained black rock right at the contact.

The quartz diorite porphyry can be dated only as post-quartz monzonite intrusive. Its relationship with the granite and associated dike rocks is unknown. The quartz monzonite intrusive near the dike south of the Skylark mine is dioritic in composition and possibly the dike may represent some of the inner still molten intrusive that worked its way up into the solidified shell along a zone of weakness. If so, the quartz diorite porphyry is only slightly younger than the main body of quartz monzonite and can be assigned a middle Tertiary age also. Perhaps the dikes are related to later volcanic activity, such as the late Tertiary (?) volcanic activity in the Mineral Range (Liese, 1957), and are late Tertiary in age. At Gold Hill, porphyry dikes which cut quartz monzonite are considered to be of the same general age as the intrusion, and aplite dikes, which are also present there, are in general younger than the porphyry (Nolan, 1935, p. 48). Butler (1913, p. 63) believed that in the San Francisco and adjacent districts the basic and siliceous dikes in the quartz monzonite were introduced very soon after its solidification. In view of this and the fact that no other evidence of later volcanism was found, the quartz diorite porphyry is tentatively assigned to the middle Tertiary.

Granite and Associated Dikes

Small bodies of granite occur at several places in the quartz monzonite in the central and northeast parts of the mountains. The granite is associated with numerous small aplitic dikes and a few quartz veins that cut the quartz monzonite. This relationship is shown on East Ridge and in the northeast where a number of dikes apparently radiate from small bodies of granite. Some associated pegmatite occurs as separate dikes, small lenses in the granite, and as local variations in the aplitic dikes. Similar dike rocks occur in the Notch Peak intrusive in the House Range (Gehman, 1958, pp. 20-23) and in the granite intrusive of the Mineral Range (Liese, 1957).

Granite

The granite is light gray, which allows it to be differentiated from the quartz monzonite, fine- to coarse-grained and composed almost entirely of feldspar and quartz with only very minor biotite, hornblende, and a trace of magnetite. Some of the feldspar shows a fine micrographic intergrowth with quartz. Quartz makes up about twenty-five percent of the rock, but locally ranges up to fifty percent. The contact of the granite with the quartz monzonite is gradational over a few feet and the granite, like the quartz monzonite, weathers into rounded outcrops and boulders.

Aplite Dikes

Numerous aplite dikes cut the quartz monzonite, especially on East Ridge, near the granite in the northeast and west of the head of Butch Canyon (see fig. 5). They also cut the granodiorite porphyry near the quartz monzonite contact on the crest of the Rocky Range and the lavas on Porcupine Hill. These dikes are generally less than two feet wide and are not shown on the geologic map (plate IV).

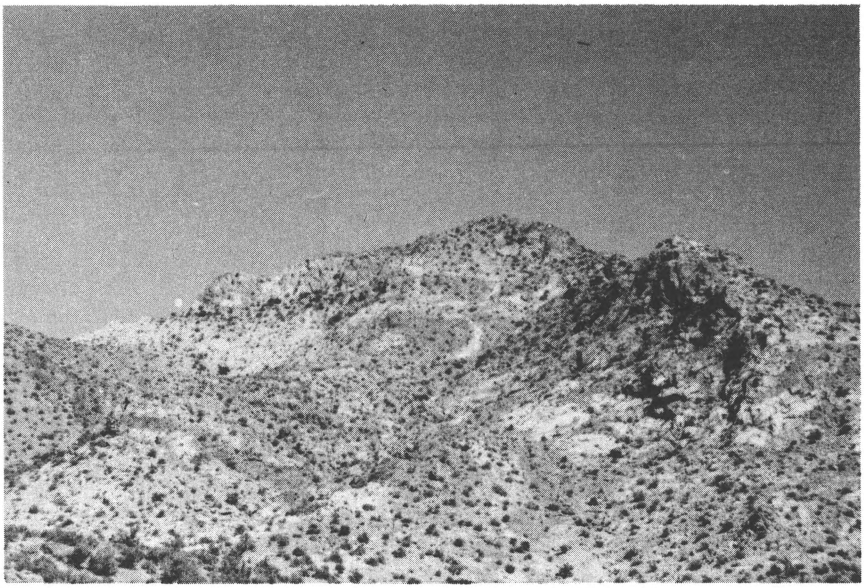


Figure 6. Altered Beaver Lake dolomite on the west side of Lime Mountain.

The aplites are light gray to pinkish and generally fine-grained, but in some places coarse-grained, consisting of orthoclase and quartz with some plagioclase and minor biotite. At least one dike contains occasional books of muscovite, averaging one half inch across, and another contains small blebs of chalcopyrite. Quartz forms about thirty percent, but ranges up to fifty percent and, in the coarser-grained rocks, some of the quartz is intergrown with the orthoclase forming a micrographic texture.

The contacts are both sharp and gradational, but more commonly gradational over a few millimeters. Generally the dikes have a fine-grained equigranular texture that varies only slightly, but in some there is textual zoning. A few dikes grade from aphanitic chilled borders to fine-grained rock, and a number have fine-grained borders that grade into a narrow pegmatitic zone along the central part of the dike.

The dikes range from an inch to over two feet in width and are more resistant to erosion than the quartz monzonite, standing out from it slightly. On East Ridge the dikes, in general, follow the jointing in the quartz monzonite.

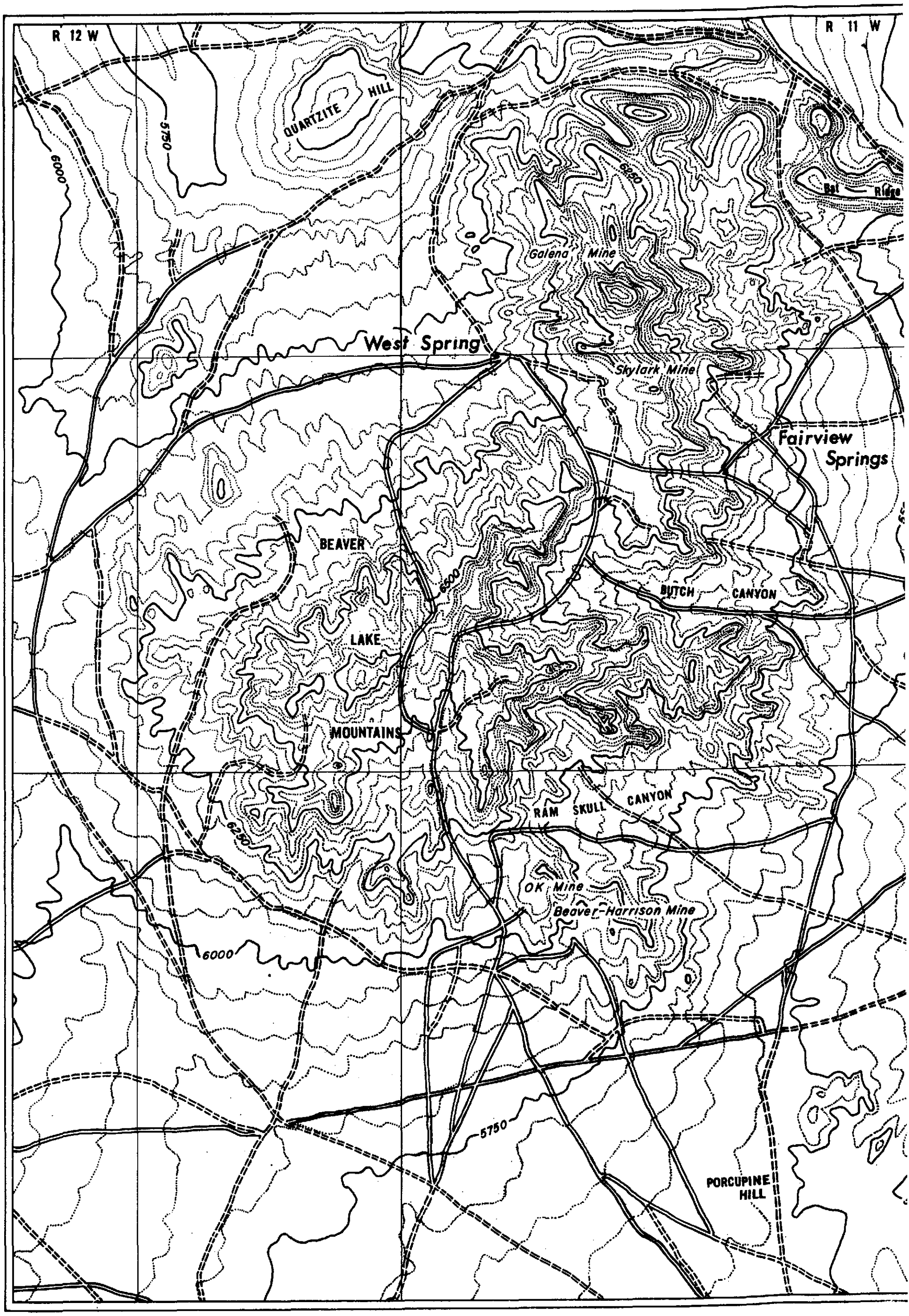
Pegmatite Dikes

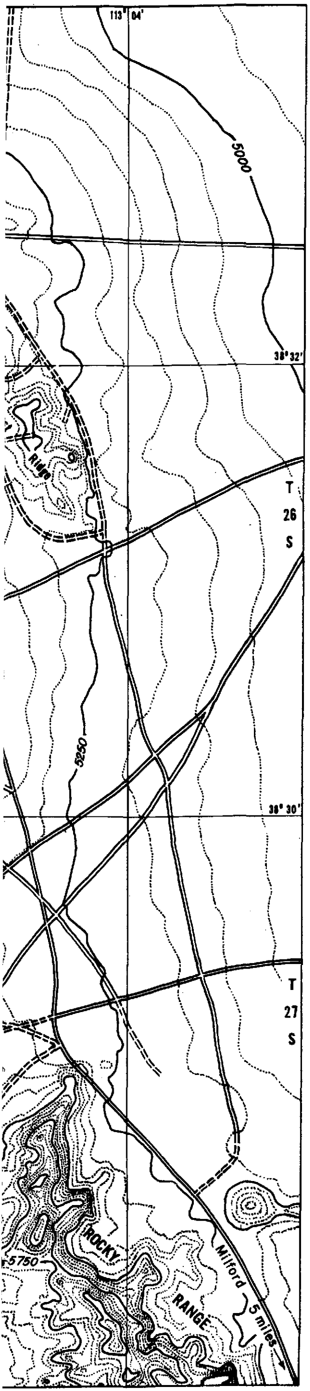
Pegmatite dikes of simple mineralogical composition are found in two places at the intrusive contact: in Ram Skull Canyon and on the crest of the Rocky Range. Pegmatitic lenses also occur in the granite of the northeast part of the area and pegmatitic zones are found in the center of some of the aplite dikes.

The pegmatite in Ram Skull Canyon is poorly exposed in an area about fifteen feet in diameter and its relationship to the surrounding altered volcanics and quartz monzonite is not definitely known, but the pegmatite is presumed to have intruded them both since elsewhere dikes that are locally pegmatitic do so. It is composed mainly of orthoclase and quartz with some plagioclase, muscovite, and tourmaline. Quartz forms about twenty-five percent and occurs both in massive form and in graphic intergrowths with the feldspar. Muscovite constitutes about five percent and forms books up to three inches across. Tourmaline is present in a few hand-size slightly vuggy masses of black needle-like brittle crystals.

The pegmatite in the Rocky Range occurs as a zone of pockets a foot to one and a half feet wide. It is similar to the other, but instead of tourmaline it contains a few chloritized masses of hornblende in crystals up to two inches long. Some of the quartz occurs as crystals up to one and a half inches long, and some specular hematite is present as fist-size masses and fine coatings on the quartz.

The few pegmatitic lenses in the granite, about one by four feet in size, consist almost entirely of coarse-grained orthoclase and quartz with the orthoclase crystals ranging over three inches in size. The quartz occurs in both massive and crystal form, the crystals being perpendicular to the walls of the lenses and up to two by five inches in size. The pegmatitic gradations from the aplite dikes consist of coarse-grained feldspar and massive quartz in varying proportions. Gehman (1958, p. 24), in describing similar pegmatitic zones in aplite dikes in and near the quartz monzonite intrusion of the House Range, points to evidence that suggests that the pegmatite may have resulted entirely by the recrystallization of the original aplite.


R 12 W
R 11 W
QUARTZITE HILL
5750
6000
6500
Bat Ridge
Galena Mine
West Spring
Skylark Mine
Fairview Springs
BEAVER
LAKE
MOUNTAINS
6500
BUTCH CANYON
RAM SKULL CANYON
6250
OK Mine
Beaver-Harrison Mine
6000
5750
PORCUPINE HILL



TOPOGRAPHIC MAP OF THE BEAVER LAKE MOUNTAINS, UTAH

CONTOUR INTERVAL 50 FEET

On this plate and the "double spread" that follows (Plate IV), the Survey has attempted by dividing the "topography" from the "geology" to retain as much as possible of the detail originally shown on Plate I of the author's thesis. Had not the combined data been thus divided, the crowding made necessary by the reduced scale would have obscured and made much of the graphic relationships worthless.

The topography has been taken from the U.S.G.S. special sheet on the San Francisco Mountain region. This topography extends northward to an east-west line just north of the Galena mine. The topography north of this line has been extended by free-hand extrapolation from such general information as was available to the draftsman.

The "double spread" of Plate V shows geologic sections along lines indicated on the map of Plate IV, but at twice the scale. This plate was copied directly from the plate of sections prepared by the author for his thesis and would have had to be redrawn to render the printing legible had the sections been reduced to the same scale of the map shown on Plate III of this bulletin.

PLATE III

Quartz Veins

A few massive quartz veins occur near the granite in the northeast and at the contact on the crest of the Rocky Range. These veins are a foot or less in width and appear to be gradational from the more pegmatitic dikes.

Age

The granite and the associated dikes may represent an acid differentiate of the intrusion, whose period of solidification extended beyond that of the main body. This differentiate may have worked its way upward through fractures developing in the cooling quartz monzonite. The pegmatitic and quartz veins could represent the more aqueous part and the last to solidify, perhaps replacing some of the earlier rock. If so, these rocks can be considered only slightly younger than the quartz monzonite and can also be considered of middle Tertiary age. Butler (1913, p. 63) felt that intrusion of basic and siliceous dikes following extensive intrusion of a rock of medium composition may be said to be the ordinary occurrence.

STRUCTURE

Structurally the area is complex and can be divided into two parts: the northern third which is structurally complex being effected by high-angle faulting, thrust-faulting, and folding and the southern two-thirds in which the structure mainly reflects the shape of the intrusive with some modification by high-angle faulting. This division may be more apparent than real, because many structural features may be obscured in the southern part of the area.

SHAPE OF THE INTRUSION

The structure in the southern two-thirds and the northeastern parts of the area is mainly a reflection of the shape of the quartz monzonite intrusion with much of the volcanic and carbonate rocks occurring as pendents in the intrusive. Many features of the intrusive have an east-west trend. In the northeast section pendents of carbonate have an east-west trend and are formed of nearly vertical east-west striking beds. The intrusive contact south of Lime Mountain is generally east-west and apparently dips moderately to steeply northward. The volcanics and altered carbonate south of West Spring generally dip moderately to the northwest and have a southwest trend, although the trend of the outcrop is thought to have been more east-west before the high-angle faulting took place since there is an apparent left lateral displacement. This also applies to the southwest trending arm of quartz monzonite. The volcanics south of Butch Canyon form a shallow (?) east-west pendent in the quartz monzonite. Southeast of Blueacre the area consists of scattered pendents of volcanics in quartz monzonite with no apparent trend.

The east-west trending features are probably the result of the intrusion having followed earlier structural trends, at least partly, since the pendents in the northeast and the contact south of Lime Mountain are approximately parallel to the strike of the intruded carbonates.

FAULTING

Both thrusting, which is becoming recognized as common in the Basin and Range, and high-angle faulting, which has long been recognized as a characteristic of the Basin and Range, occurred extensively in the area. The thrusting probably occurred in two periods, both earlier than the high-angle faulting which is generally more important here. No other periods of faulting could be distinguished, and all the faulting is ascribed to these three periods.

THRUSTING

Several thrust faults are observed or inferred in the northern part of the area. A thrust which brings Devonian dolomite and altered and unaltered carbonate over altered carbonate and quartz monzonite is exposed in the northeast part of the area (see fig. 7). The dip of this thrust is about twenty-five degrees to the west and the thrust plate has a brecciated zone up to sixty feet wide at its edge. At its northern exposed end this thrust is overlain by two other probably related thrusts with the second thrust plate partially altered to jasperoid.

A thrust occurs north of the Joanna limestone west of the above thrust. The upper plate is unaltered carbonate and the lower plate Joanna limestone. Evidence for

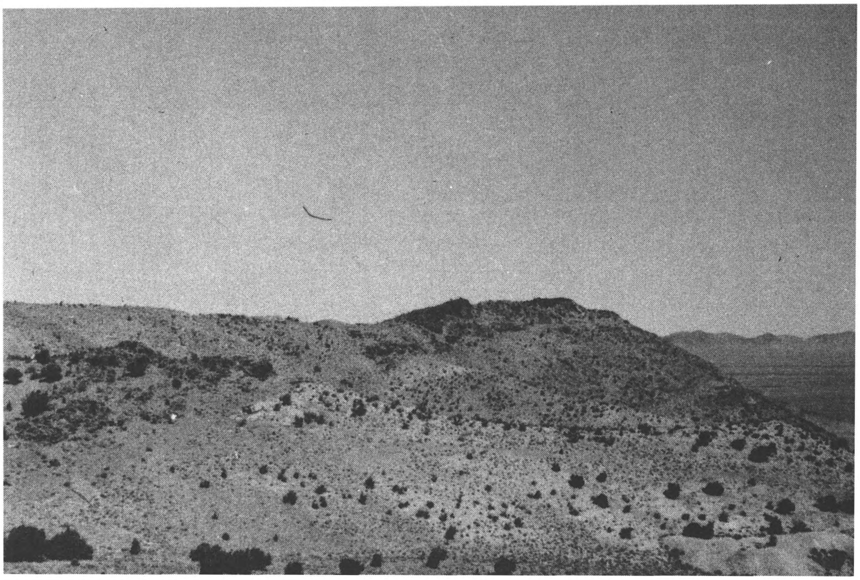


Figure 7. Thrust fault in the northeast part of the mountains, view north; ridge in the middle ground composed of brecciated unaltered dolomite on the left over steeply dipping altered carbonate.

this was a silica-filled fractured zone that could define a north-dipping plane and a small (?) overturned syncline below this fracture zone that probably represents a drag fold. The syncline was overturned to the south indicating southernly movement.

In the northwest, a north-northwest dipping thrust is inferred to lie beneath the Prospect Mountain quartzite, although it is not exposed. This inference is based upon recognition of regional relationships. A thrust occurs at the base of the Prospect Mountain quartzite apparently wherever it is exposed in this region: in the Wah Wah (R. C. Speed, personal communication), the San Francisco Range (Hintze, 1949, p. 49) (East, 1956), and in the northern Mineral Range (Liese, 1957). This inferred thrusting is supported somewhat by the brecciation of the Prospect Mountain quartzite on the south side of Quartzite Hill and the ridges to the east and the broken up nature of the Cambrian limestone in the valley southeast of Quartzite Hill. There is evidence for a fault on the east side of Quartzite Hill in that the southeast limb of the anticline is apparently missing. This apparent break could very well be explained by a high-angle fault.

In view of thrusts being present at the base of the Prospect Mountain quartzite on both sides of the area and the brecciation of the quartzite, a thrust is inferred beneath the Prospect Mountain quartzite. Thrusting, however, might better explain the complex faulting and the overturned syncline in the Millard limestone east of Quartzite Hill.

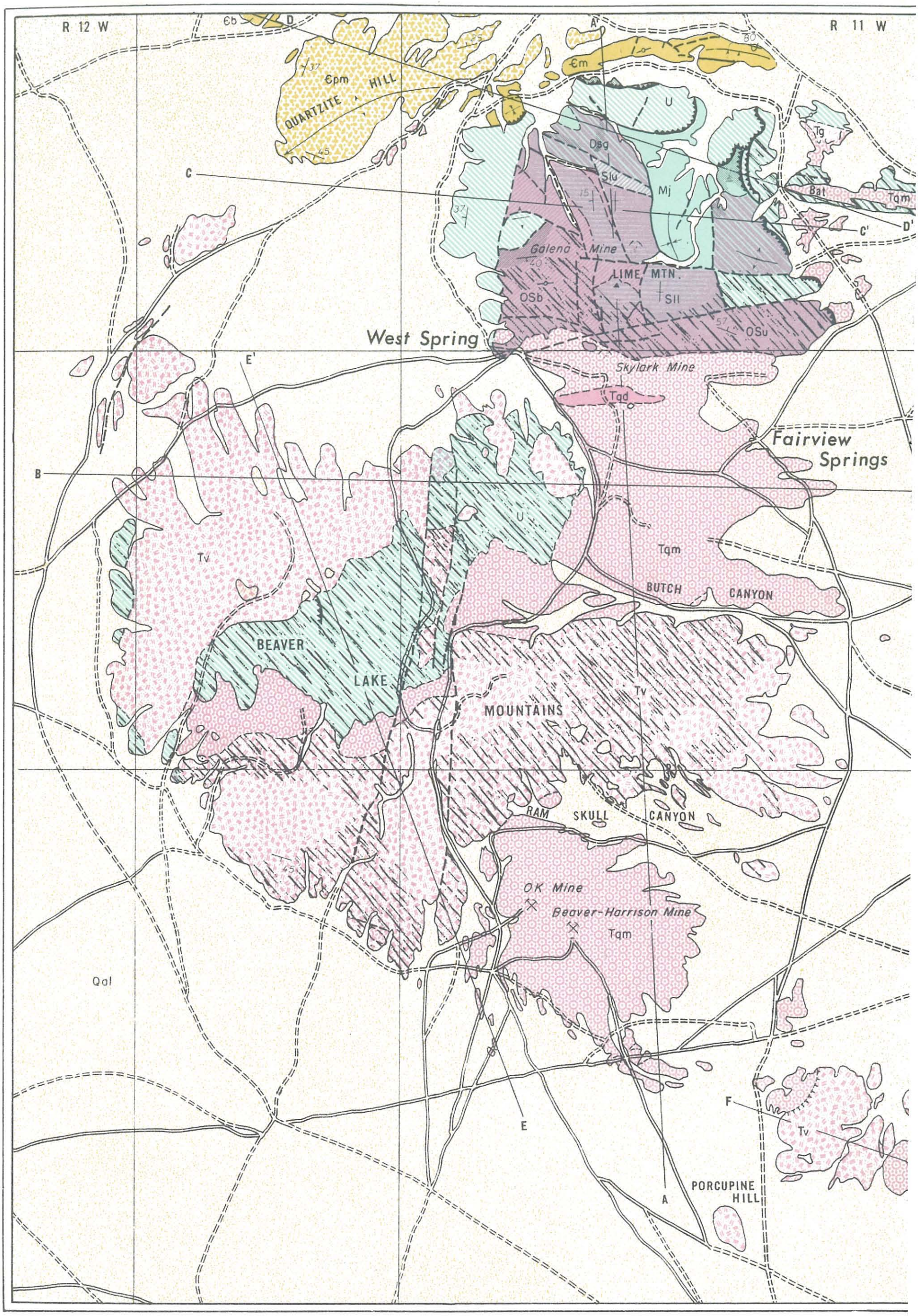
Another thrust fault, approximately parallel to the thrust beneath the Prospect Mountain quartzite, is inferred south of the Cambrian limestone east of Quartzite Hill. This highly faulted and folded yet continuous belt of Cambrian limestone may represent a broken imbricate slice below a main thrust plate at the base of the Prospect Mountain quartzite. However, the distribution of rocks can be just as readily explained by high-angle faulting south of the Millard limestone. This conjectured thrust is placed along a brecciated zone just east of Quartzite Hill and a jasperoid zone farther east, features which could also be the result of high-angle faulting. The idea of an imbricate slice has been entertained in an effort to explain the faulted and folded nature of the belt of Cambrian rocks; as imbricate slices of Cambrian limestone occur in the Wah Wah Range beneath a thrust plate of Prospect Mountain quartzite (R. C. Speed, personal communication), this is not an unreasonable postulate providing there is a thrust beneath the Prospect Mountain quartzite.

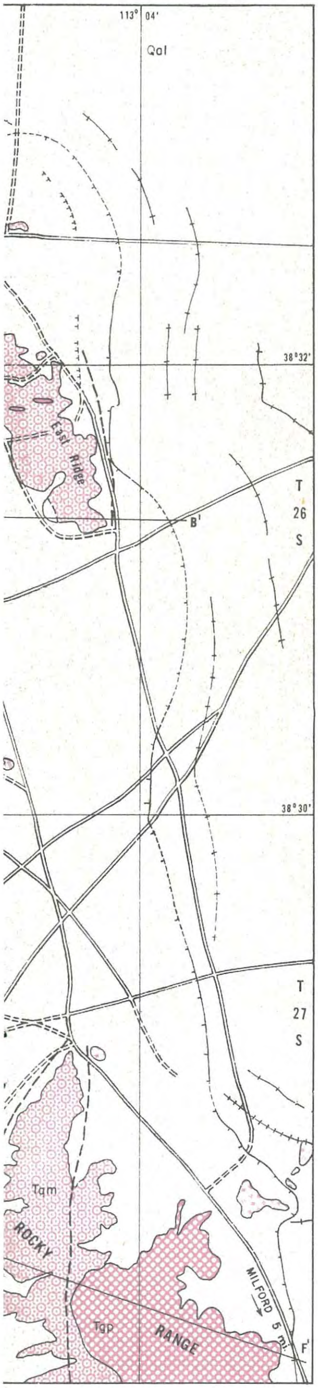
A small outcrop of limestone northwest of Lime Mountain is bounded by high-angle faults on its north and west sides and by a jasperoid zone on the southeast that could represent either another high-angle fault or a thrust.

A thrust was observed north of hill 6870, where several quartzite beds were cut off by a fault, the slickensided surface of which dips very shallowly. This thrust could not be traced far into the altered carbonate.

Age of the Thrusting

The thrusting is thought to have occurred in two periods: pre-volcanic and post-intrusive-pre-high-angle faulting, although there is only proof for the later age. The easternmost thrust which cuts altered carbonate and quartz monzonite is clearly post-intrusive and apparently pre-high-angle faulting, and the two thrusts above it at its northern end are thought to be part of the same general thrusting, because of their close physical relationship, and therefore the same age.


R 12 W
R 11 W
Ꞓb
D
A'
Ꞓpm
QUARTZITE HILL
Ꞓm
U
Tg
Dsg
Slu
Mj
Bat
Tqm
C
C'
D'
Galena Mine
LIME MTN.
OSb
Sll
OSu
West Spring
Skylark Mine
Tqd
E'
Fairview Springs
B
Tv
Tqm
BUTCH CANYON
BEAVER
LAKE
MOUNTAINS
RAM SKULL CANYON
OK Mine
Beaver-Harrison Mine
Qal
E
F
A
PORCUPINE HILL



GEOLOGIC MAP OF THE BEAVER LAKE MOUNTAINS, UTAH

1/2 1/4 0 1/2 1 1 1/2 2 miles

Geology by P. J. Barosh, 1958

EXPLANATION

QUATERNARY

Qal
ALLUVIUM
Unconsolidated sand and gravel (including Lake Bonneville deposits)

IGNEOUS ROCKS

TERTIARY — Middle

Tg
GRANITE

Tgd
QUARTZ DIORITE PORPHYRY

Tqm
QUARTZ MONZONITE

TERTIARY — Lower

Tgp
GRANODIORITE PORPHYRY

Tv
VOLCANICS

SEDIMENTARY ROCKS

UNDIF. PALEO.

U
UNDIFFERENTIATED CARBONATE
Light-to dark-gray dol. and ls.

MISSISSIPPIAN — Lower

Mj
JOANNA LIMESTONE
Dark-gray cherty ls. & lt-gray dol. ls.

DEVONIAN — Middle

Dsg
SIMONSON DOL.-GUILMETTE FM.
Dark-gray dolomite

SILURIAN

Slu
Upper Member
Lt.-gray dolomite & dark gray shale

Sll
LIME MOUNTAIN DOLOMITE
Lower Member
Light-gray dolomite

SILURIAN

OSu
UNDIFFERENTIATED LIME MTN. and BEAVER LAKE DOLOMITE

ORD. — Upper

OSb
BEAVER LAKE DOLOMITE
Dark-gray mottled dolomite

CAMBRIAN — Middle

€b
BURROWS LIMESTONE
Light- to medium-gray dolomite

€m
MILLARD LIMESTONE
Dark-gray limestone

CAMBRIAN — Lower

€pm
PROSPECT MOUNTAIN QUARTZITE
White-to light-gray quartzite

METAMORPHIC ROCKS

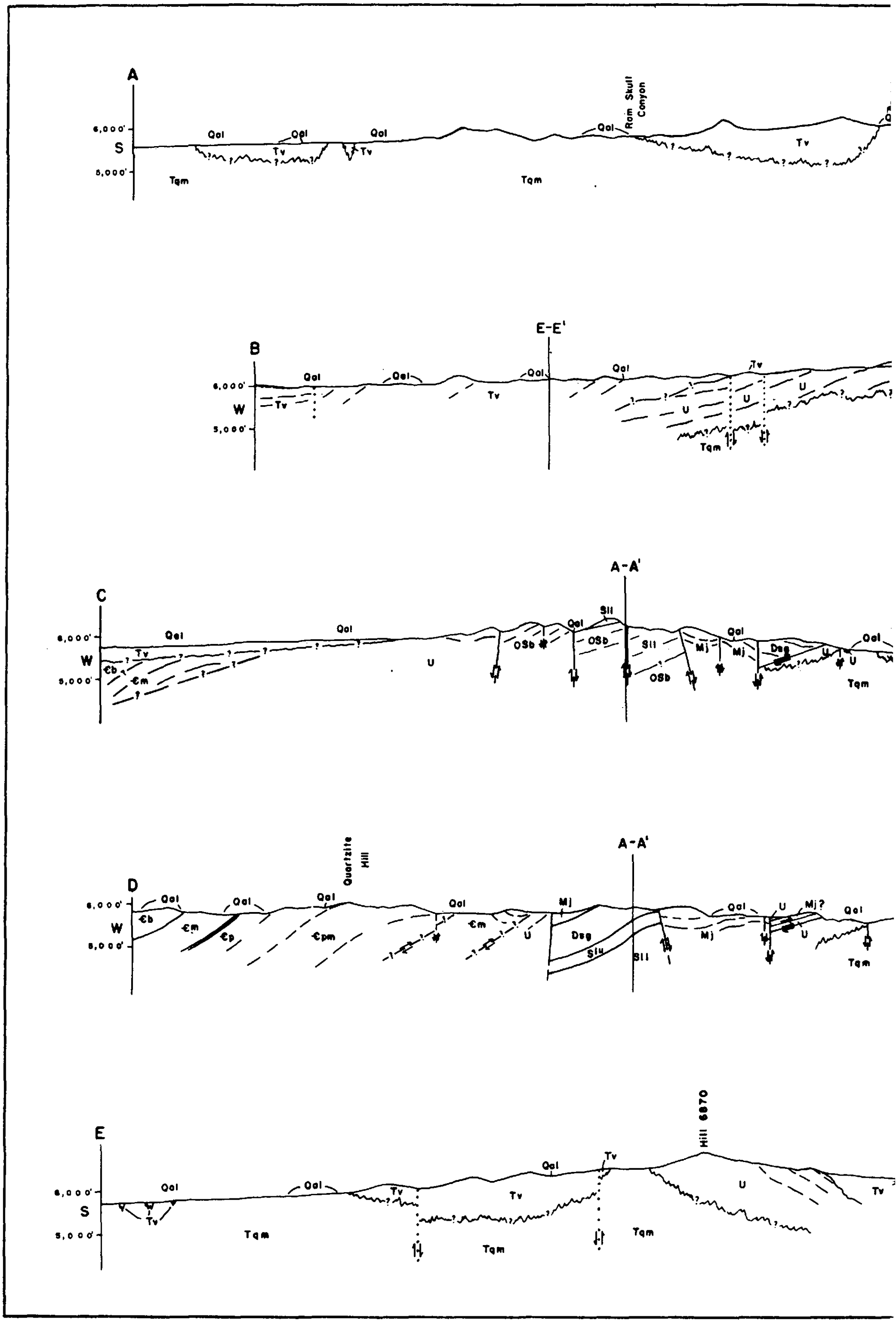
JASPEROID

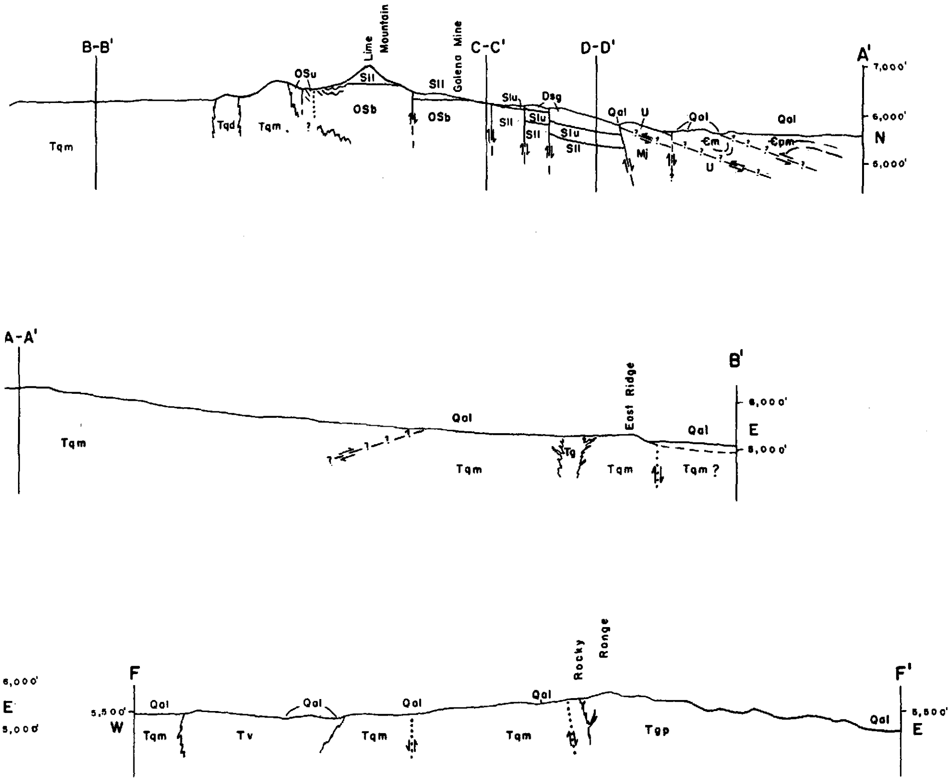
METAMORPHOSED ROCKS other than JASPEROID

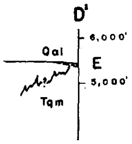
Highest mappable shoreline of Lake Bonneville, dashed where approximately located
Possible higher shoreline
Lower shoreline features
Bars
Faults
Thrust faults
Strike and dip of beds 10
Horizontal beds
Vertical beds
Overturned beds 17
Anticline plunging
Syncline plunging
Overturned syncline

Geologic sections shown on plate V.

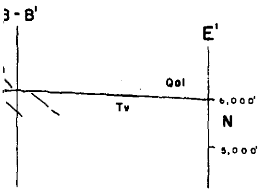
PLATE IV


A
6,000'
S
5,000'
Qal
Tv
Tqm
Ram Skull Canyon
B
E-E'
W
U
C
A-A'
Cb
Cm
OSb
Sll
Mj
Dsg
D
Quartzite Hill
Cp
Cpm
Slu
Mj?
E
Hill 6870





GEOLOGIC SECTIONS OF THE BEAVER LAKE MOUNTAINS, UTAH



The inferred thrusting involving the Cambrian rocks is thought to have occurred during the pre-volcanic period because of its field relations with the volcanics and correlations with near-by thrusts. The volcanics by the south side of Quartzite Hill would appear to overlie the inferred thrust, unless it is very sinuous here.

Since the possible thrusts in the northwest have been largely inferred from thrusts in near-by areas, it is most probable, if they exist, that they are of similar age. In the San Francisco Mountains the thrust at the base of the Prospect Mountain quartzite is apparently younger than the volcanics (East, 1956). Liese (1957) dates the thrust at the base of the Prospect Mountain quartzite in the northern Mineral Range as pre-Cretaceous (?) in age since Indianola (?) conglomerate of Cretaceous (?) age unconformably overlies the thrust plate. Liese sets the date of the thrusting between Late(?) Jurassic and Early Cretaceous time by reference to the first period of thrusting in the House Range where Christiansen (1952, pp. 732-736) found two periods of thrusting: the first one Late Jurassic to Early Cretaceous involving Precambrian rocks over early Paleozoic strata, and the second in early Laramide time involving Precambrian over Indianola (?) conglomerate. However, Hintze (personal communication) considers the thrusting of this region Laramide in age and Maxey (1946, p. 353) dated the thrusting in the Pavant Range, which involved a thrust plate of Lower Cambrian quartzite to Upper Cambrian limestone, as post-Jurassic-pre-Eocene (?). Some of the thrusting in the southern Wah Wah Range involves Cambrian limestones over Jurassic Winsor formation (R. C. Speed, personal communication). At Gold Hill, Nolan (1935, pp. 63-64) found four periods of thrusting; three earlier than the quartz monzonite stock and one later. The first two periods are tentatively classed as of Cretaceous or early Eocene age, the third is considered to be of Eocene age, and the fourth must date from late Eocene or early Oligocene time.

In view of the above discussion, it is thought that there were two periods of thrusting in the Beaver Lake Mountains: the first period, involving an inferred thrust plate of Cambrian rocks, tentatively assigned a Cretaceous age, and the second, involving a thrust plate of middle Paleozoic rocks, considered late middle or early late Tertiary in age. It is quite possible, however, that all the thrusting took place during one period with possibly the main movement being along the inferred thrust at the base of the Prospect Mountain quartzite, and the other thrust representing relatively minor imbricate slices in the rocks being overridden.

HIGH-ANGLE FAULTING

High-angle faulting, mainly normal, is one of the most important structural features in the Beaver Lake Mountains; in view of the absence of north-south lineation of the mountain mass, typical of the Basin and Range, north-south faulting is perhaps not as important as usual in this province. Perhaps the east-west trends of the intrusive retarded the development of north-south faulting.

The high-angle faults generally have a northernly trend, although several transverse east-west faults are recognized in the northern part of the area. The most noteable north-south fault zone cuts the carbonate-volcanic-intrusive complex in the central part of the range. Possibly the fault bounding the undifferentiated carbonates west of Lime Mountain is a northern continuation of this zone. The apparent movement across this zone is left laterally and relatively down on the west side. There also may be a fault just west of this zone where the southwest arm of quartz monzonite makes a sharp bend north. At the west edge of the mountains is a patch of altered carbonate which was probably brought relatively upwards by a reverse fault against the volcanics. North of this is another fault between a hill of steeply dipping dark volcanics and gently dipping light tuffaceous volcanics at its western base. A fault is placed east of East Ridge in agreement with Butler (1913, p. 73) since the rock here weathers easily and faulting is the most probable answer for the steep bluff along the east side of the ridge. The steep northern end of the Rocky Range is inferred to be fault bounded on geomorphic evidence also.

The north end of the area is cut into blocks by a number of faults with maximum displacement probably less than 1,000 feet (see fig. 8). It is interesting to note that along section A-A' (plate V) all the high-angle faults north of Lime Mountain are stepped down to the north. The transverse faults south of Lime Mountain have been inferred along topographic breaks and are considered to be relatively minor faults. A silicic zone in the volcanics along the south wall of Butch Canyon might represent another transverse fault.

Age of the High-Angle Faulting

High-angle faulting was one of the latest events to take place in the area as it has affected all rock types and other structures, except the Lake Bonneville shore

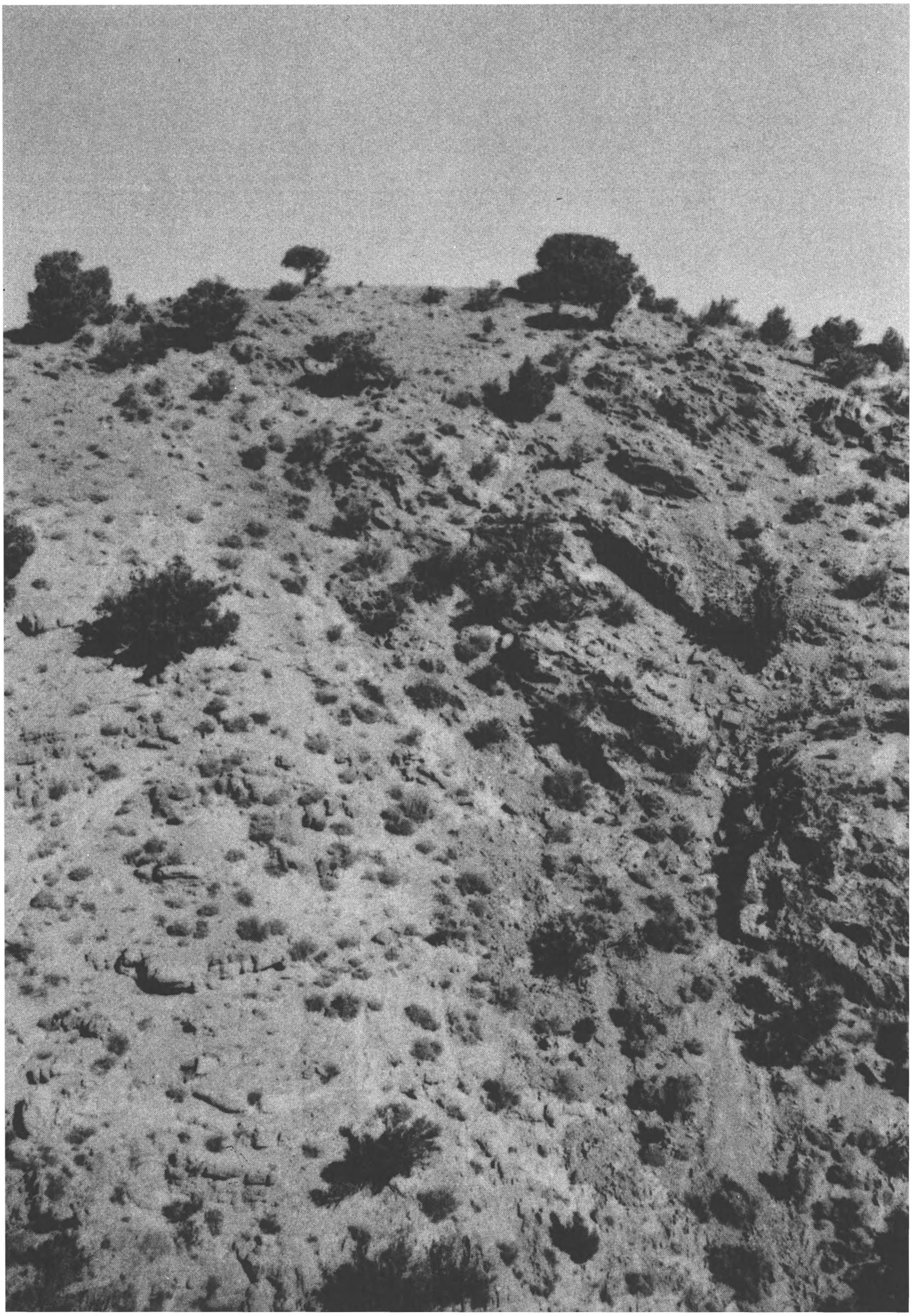


Figure 8. Normal fault separating the upper member of the Lime Mountain dolomite on the left from Joanna limestone on the right, view northwest in canyon northeast of the Galena mine.

line features. It is therefore post-intrusion and post-thrusting, but pre-Lake Bonneville. Since the intrusive is considered middle Tertiary in age and the area had undergone extensive erosion prior to late Pleistocene Lake Bonneville, the faulting is thought to have occurred during the late Tertiary.

FOLDING

Folding appears to be a minor structural feature in the mountains as a whole, although it is very severe in places. The folding is largely confined to the Cambrian rocks and the altered carbonate rocks south and west of Lime Mountain. The folding in the Cambrian rocks may be related to thrusting while that near Lime Mountain appears to be related to the intrusion. Folding may be present in the altered carbonate in the south and northeast parts of the area, but attitudes are scarce there. The area may also be involved in some large-scale regional folding.

FOLDS IN THE CAMBRIAN ROCKS

The Cambrian rocks at the north edge of the area show a great deal of folding. The Prospect Mountain quartzite forms a large west-southwest plunging anticline with much of its south limb missing. The Cambrian limestone east of Quartzite Hill is broken into numerous fault blocks many of which are tightly folded into isoclinal and overturned folds (see figs. 9 and 11). This belt of limestone appears to be synclinal and may be a disrupted southeast continuation from the anticline through Quartzite Hill.

These folds are cut by the inferred thrusts and are therefore earlier than the first period of thrusting. Perhaps the folding and thrusting were about contemporaneous with large folds developing and then rupturing into thrusts and the small tight folds developing during the thrusting in one continuing episode.

FOLDS BY LIME MOUNTAIN

The several small folds on the south side of Lime Mountain appear to be related to the intrusion and may have been formed by forceful emplacement of the quartz monzonite. The carbonate on top of Lime Mountain is

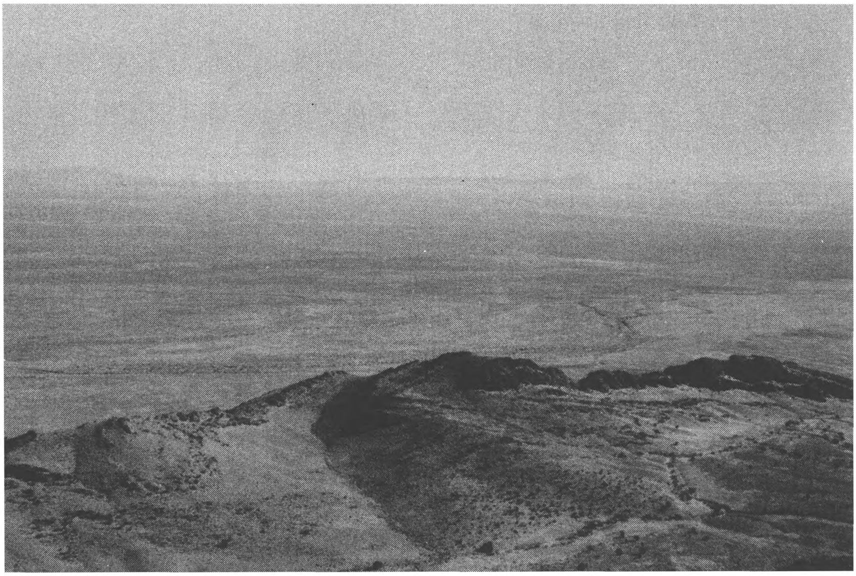


Figure 9. Overturned syncline in Millard limestone at the northeast edge of the mountains, looking northeast; recent volcano in background.

Figure 10. Small folds in altered Beaver Lake dolomite on the south side of Lime Mountain, view east.

flat lying and unaltered, but towards the south, near the intrusive, the carbonate becomes altered and is folded into several small east-west trending folds (see fig. 10). At the quartz monzonite contact the carbonate is highly metamorphosed and dips nearly vertical.

On the west side of Lime Mountain are several small folds in metamorphosed Beaver Lake dolomite. These folds may also be related to the intrusion, although no relationship can be seen in the field other than the folds being in metamorphosed rock.

These folds are considered to have been contemporaneous with the intrusive which has been assigned a middle Tertiary age.

REGIONAL FOLDING

Some large-scale, regional, north-south folds plunging gently to the northwest occur in this part of western Utah, at least in the areas of Cambrian rocks. A north-south syncline traverses the central and northern Wah Wah Range (R. C. Speed,personal communication). An anticline is present at the western edge of the San Francisco Mountains (Butler, 1913, p. 70) (East, 1956) which lines up northward with the anticline along the west side of the House Range and the east side of the Fish Springs Range (Gehman, 1958, p. 12). The Prospect Mountain quartzite capping the San Francisco Mountains continued northeastward under a north-south syncline of Middle Cambrian rocks that form the Cricket Hills, and the San Francisco Mountains appear to represent a remnant of an intervening anticline between the Wah Wah Range and the Cricket Hills. What effect this regional folding had on the Beaver Lake Mountains is not known, but if there is no intervening break, the Beaver Lake Mountains apparently lie on the west limb of the Cricket Hills syncline.

This regional folding is thought to have occurred after the first period of thrusting, since the thrust plane is apparently folded in the Wah Wah Range and the San Francisco Mountains, and pre-quartz monzonite (Butler, 1913, p. 70). The north-south folds in the Canyon Range are thought by Christiansen (1952, pp. 733-36) to have developed as gentle folds during an Early Cretaceous orogeny and later intensified during an early Laramide orogeny with thrust surfaces being folded. He believed that these two orogenies involved most of western Utah and eastern Nevada (1951, pp. 69, 79-80). In view of this, the folding is tentatively dated as Cretaceous and slightly younger than the first period of thrusting.

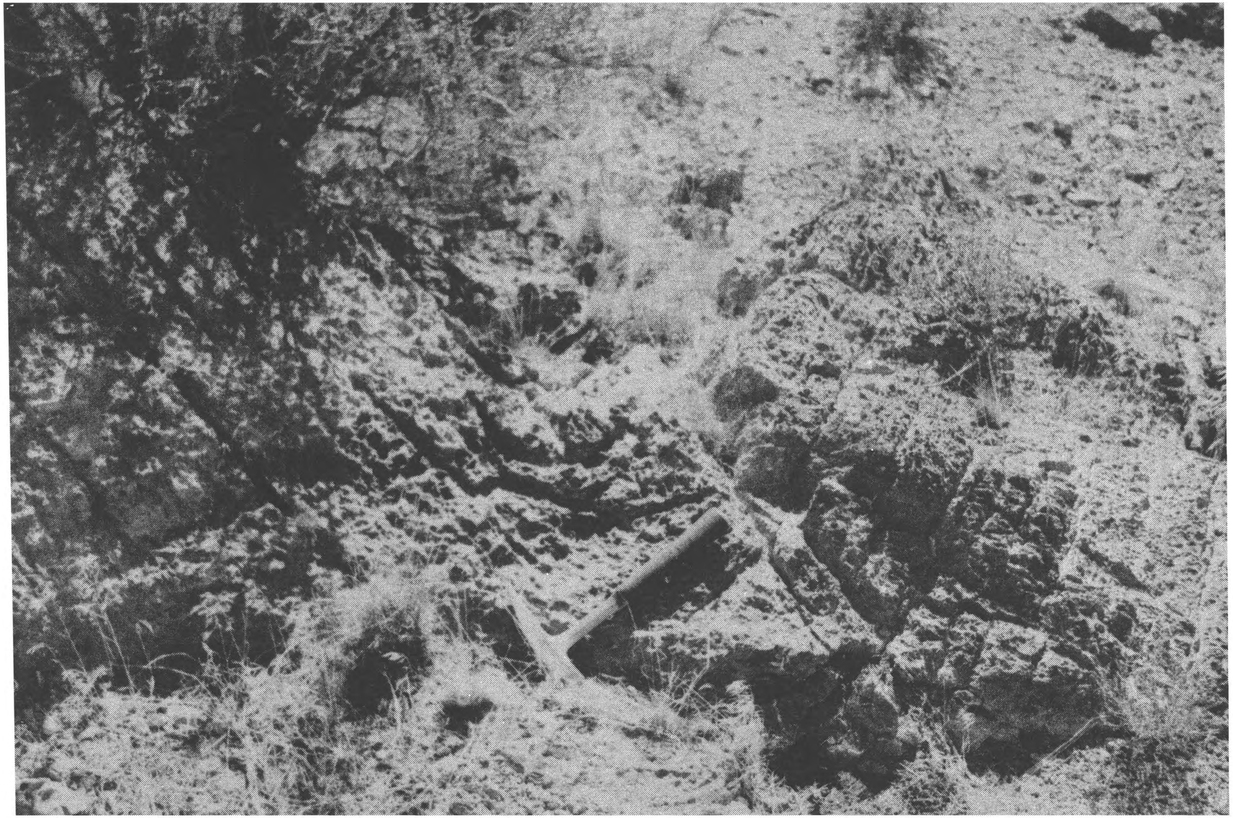


Figure 11. Isoclinal syncline in the Millard limestone at left edge of Figure 9, view eastward and down plunge.

GEOMORPHOLOGY

The Beaver Lake Mountains are not the simple geomorphically old mountains that Butler (1913) pictured, but are more complex with evidence indicating that the mountains are being uncovered rather than buried. Also, the mountains are situated on an east dipping slope from the San Francisco Mountains, and this slope along with the San Francisco Mountains has had a great deal of influence on the geomorphic development of the range. Varied features found in the area include stream captures, pediments, and shore line features of Lake Bonneville, which once covered the eastern edge of the area.

The geomorphology of the area is complex and varied reflecting the different underlying rock types and structure. Neither structure nor stratigraphy is the outstandingly dominant geomorphic control in the mountains, but rather a combination with structure being the main control of the northern part of the mountains and stratigraphy the more important control in the southern part. In an over-all view, structure is probably mainly responsible for the development of the range since it seems to be the dominant control in the northern part of the area where relationships are clearer, but it is apparently not nearly as important here as it is in the neighboring ranges.

STRUCTURAL CONTROLS

In the northern part of the area practically all of the valleys are fault controlled by high-angle faults along with two thrusts. Parts of other thrusts have resulted in ridges because of the silicification of brecciated rock along them. The north end of the Rocky Range is also inferred to be principally fault controlled from the steep-sided linear ridge of quartz monzonite. These are the most rugged parts of the area.

The north-south fault zone thru the southern part of the mountains follows the larger valleys and was located partly on geomorphic evidence. Perhaps some of the other valleys in this part of the area are fault controlled either directly or indirectly through silicified fault zones.

Folding appears to have little topographic representation except possibly for Quartzite Hill, since it appears to be somewhat anticlinal.

STRATIGRAPHIC CONTROLS

The unaltered carbonate and the quartzite appear to be the most resistant rock types, forming Lime Mountain and Quartzite Hill respectively. Highly altered carbonate on the other hand is less resistant, forming the low areas south of Lime Mountain, although this might be aided by faulting, and in the northeast. The unaltered volcanics are moderately resistant and the altered volcanics vary in resistance depending on the amount and type of alteration. The poorly resistant highly altered volcanics along the intrusive contact are responsible for the development of Butch Canyon, Ram Skull Canyon, and the canyon west of the O K mine. Some of the very silicic altered volcanics are fairly resistant and a silicified zone is responsible for the steep south wall of Butch Canyon. This later zone, however, may mark a fault and may not be strictly a stratigraphic control.

The quartz monzonite is relatively nonresistant to weathering and has a north-south grain in some parts that reflects the main joint direction. The quartz monzonite near the carbonate contacts, however, appears to be more resistant. It forms the ridge upon which the Skylark mine is located and the east-west ridge between two carbonate pendents in the northeast part of the area. In other places quartz monzonite has been planed to pediments.

PEDIMENTS

A smooth pediment surface is developed on the quartz monzonite from the head of Butch Canyon north to West Spring. This west-dipping plane ends against carbonates and alluvium to the west, and to the east it extends to the divide. The pediment is unbroken except for a low ridge formed of quartz diorite porphyry which differs from the quartz monzonite by weathering into angular fragments instead of disintegrating directly into sand. The pediment is only developed on the quartz monzonite, and it is generally covered by a few inches to a foot of arkosic sand. Presently the extent of the pediment is being diminished. Formerly the pediment extended farther to the east, but since the gradient east of the divide is much steeper, erosion is more active there and the divide has and still is migrating westward. Also, the upper end of Butch Canyon is being extended into the pediment from the south and has formed a pass through the mountains there.

From the top of the divide, a ragged escarpment faces eastward. This escarpment may represent a fault-line scarp from a fault to the east, perhaps the southern continuation of the thrust in the northeast, or it could be a pediment divide with the pediment to the east now largely buried by the debris being eroded from the bluff. At the base of the escarpment there are narrow patches of an irregular pediment which is probably retarded in its development by the debris being eroded from above. A small narrow pediment is also developed on the west side of East Ridge. The bluff on the east side of the ridge is probably a fault-line scarp as Butler (1913, p. 73) also noticed.

DRAINAGE PATTERN

The Beaver Lake Mountains have a definite two sidedness in its drainage pattern due to being situated on a slope. On the west side of the range there are numerous small incised stream channels in gullies or feebly developed canyons that trend westerly into two main channels at the intersection of the west slope of the Beaver Lake Mountains and the east slope of the San Francisco Mountains. The slope from the San Francisco Mountains has noticeably larger incised stream channels on it. One of the main channels trends north and then east around the northern end of the range. The other trends south and east around the south end of the Rocky Range, but apparently at one time it went north of the Rocky Range. Thus the drainage from the west side makes anywhere from a 90° to a 180° turn.

The stream pattern of the east side of the range is quite different. The streams are fewer in number, larger, pass thru larger canyons, and trend directly eastward towards the Beaver River. Some complications of the drainage are discussed in the following section.

EXHUMATION AND PRESENT DEVELOPMENT

The western part of the mountain mass is now apparently being uncovered due to an increased stream gradient to the east. The strongest evidence for this is the "upland gravels" which occur in patches on the lower western volcanic slopes. These "gravels" contain cobbles and boulders of quartzite, many of which could not have arrived there by downslope movement under present conditions. As these boulders of quartzite are a conspicuous characteristic of the alluvium from the San Francisco Mountains, it seems logical that at least the western flanks were buried by debris from the San Francisco Mountains.

The features of the west flank are thought to have developed as the San Francisco slope receded from the west flank by headward erosion of the tributaries to the main trunk streams.

The east side of the range has probably never been buried, since no streams are superimposed across the mountains as might be expected, and canyons are much better developed than on the west side of the range. Also, the east base of the Beaver Lake Mountains consists of very low, broad, smooth coalescing fans on which the stream channels branch and diminish downslope with deposition taking place. For example, a well-developed stream channel, three to four feet deep, emerges from Butch Canyon, continues part way down the fan, and suddenly rises above the general level of the ground on a sort of dry land "delta" and branches into small gullies.

The deposition rather than excavation on the east side is thought to be due to the lack of a major stream passing there since the excavation appears to proceed by headward erosion from the larger streams. The toe of the fan from Ram Skull Canyon is just beginning to be eroded by the stream at its base. The mountains are now in the position whereby excavation of the west side is taking place and deposition on the east side.

The drainage is in a state of transition in the south part of the area due to more rapid excavation farther south. The streams on the south side of the mountains possess an assymetrical pattern in that their tributaries are from the north and the streams appear somewhat perched. It appears that originally the southwest part of the area drained through the gap between the Beaver Lake and the Rocky Ranges, but the drainage was captured at a point south of the O K mine and presently drains around the south end of the Rocky Range. This present drainage will be someday moved farther south as its capture by the Big Wash to the south appears imminent. The stream presently flowing north of the Rocky Range will likely lose its headwaters by capture in the vicinity of Porcupine Hill.

Stream captures in the northeast part of the area may also be related to the exhuming of the western side of the mountains. A northeast flowing stream northeast of Lime Mountain has captured the headwaters and incised the valleys of both a northwest and an eastward flowing stream (see fig. 12). Also, the stream which drains the east side of Lime Mountain is incised in its course and has two right-angle bends which may be the result of having captured its present headwaters just as its original headwaters were captured from it by the aforementioned stream.

The cause of this increased gradient is thought to be the result of a change in base level from the Milford Valley to that of the Sevier Desert. Milford Valley is postulated to have been a basin of interior or only slightly exterior drainage, such as the valley west of the Wah Wah Range. With this as the local base level, the west flank of the Beaver Lake Mountains was buried by debris shed largely by the San Francisco Mountains. Milford Valley was then tapped by headward erosion of the Beaver River north of Black Rock, or if exterior drainage already existed it was greatly speeded up and Milford Valley changed from an area of deposition to one of excavation.1/ The changes wrought by this excavation are due perhaps from the excavation having taken place rather subtle, slowly, or from the masking effect of erosion or the Lake Bonneville deposits. A tapping of this sort, with headward erosion the main mechanism, should be able to account for the increased gradient without the need of postulating any regional tilting.

In summary, the west side of the Beaver Lake Mountains are being exhumed while on the east side deposition is taking place in the form of fans along the base of the range. The debris from the northwest Beaver Lake Mountains and the northeast part of the San Francisco slope is being carried to the northeast and deposited in a large fan between the Beaver Lake Mountains and the Beaver Mountains. Along the northeast part of the Beaver Lake Mountains, the valleys are being deepened and the debris deposited at the base of the hill in low

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1/ This change, quite possibly, resulted from the clogging of the drainage north of Black Rock by volcanic debris--pumice, ejecta, and lava flows that accumulated in this region. Subsequently, entrenching through this clogged drainage permitted resumption of degradation and the exhuming of the old topography in the Beaver Lake district. -- Arthur L. Crawford.

Figure 12. Stream capture, view southeast up beheaded valley northeast of Lime Mountain; stream, hidden in canyon at the middle left, has captured and incised the head of the valley. Lime Mountain in the upper right.

fans. The east-central part of the San Francisco slope and the southwest part of the Beaver Lake Mountains once drained north of the Rocky Range, but now drain south of them and will eventually drain farther south into the Big Wash. The southeast part of the area is drained north of the Rocky Range by a stream which is excavating and depositing its load northeast of the Rocky Range. On the east side of the mountains the streams are deepening their valleys and depositing their loads in broad fans at the base of the range.

LAKE BONNEVILLE SHORE LINE FEATURES

Milford Valley was once occupied by an arm of Lake Bonneville and many shore line features are preserved along the east edge of the area. This part of Lake

Bonneville was filled only during the highest stage of the lake. The Provo stage did not flood Milford Valley (Gilbert, 1890, p. 128). Various features preserved include beaches, bars, and a delta.

The highest mappable shore line follows approximately the 5,110 foot level, as read from the preliminary 7 1/2 minute quadrangle Lund Number One Northeast, Utah. This matches fairly closely with Dennis (1944) who found the shore line from Pumice to Milford consistently at about 5,120 feet above sea level. Most of the shore line features are easily missed on the ground, but show up quite well on aerial photographs. They have a rather scalloped pattern reflecting the underlying alluvial fans.

In the southern part of the area, the shore line is represented by a 10-foot wide sandy strip which looks like an old road because there is little vegetation on it (see fig. 13). It has a slightly steeper gradient than the general slope, and for this reason it has a few more gullies than usual. The shore line is hard to find on the ground in the central part of the area. At the northern edge of the area is a narrow assymetrical ridge about five feet high which slopes steeply on the downhill side and gently on the uphill side, that, perhaps, was built in the outer edge of the surf zone. Just east of this ridge a row of very small, gravel-covered hills trend northeast obliquely to the shore line. These are thought to be pre-Lake Bonneville in origin and thinly veneered by lake gravels.

In the southeast corner of the area, a hill of volcanics protruded into the lake forming a headland. From this headland a ridge of volcanics extended northeast into the lake to form two islands. From the outer island a sand bar curved northwest almost to shore enclosing a small lagoon between it and the shore (see fig. 14). This lagoonal basin has since been utilized as a site for a small dam. On the east side of the "headland" and "islands," a wave-built sand flat extends out 500 feet and suddenly drops off forming a fifteen-foot bluff.

A small lagoon also existed north of Bat Ridge, where a small embayment was once formed at the intersection of two alluvial fans. A gravel bar across the bay probably transformed the head of the bay into somewhat of a lagoon. There are two parallel gravel bars here about 400 feet apart that may represent two different levels of the lake. These have been modified and now also serve as small dams.

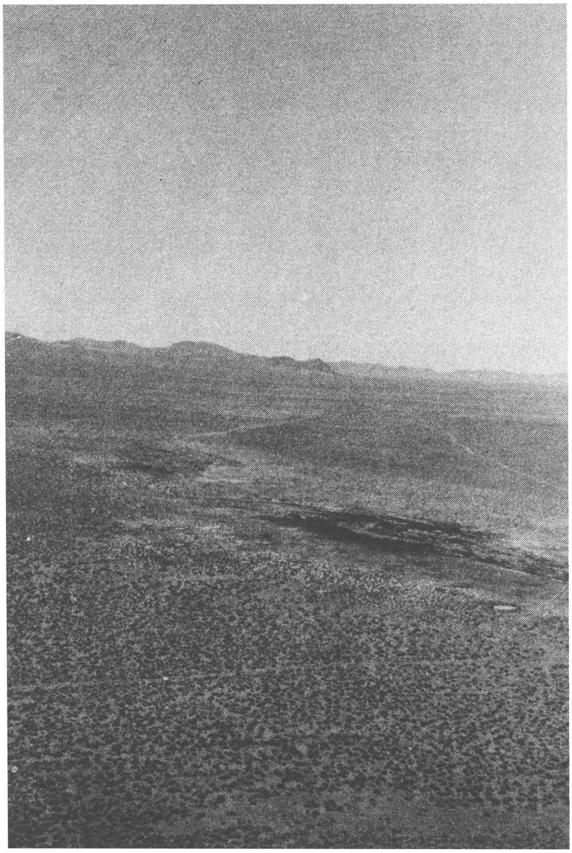

Figure 13. Lake Bonneville shore line, light streak in center curving off to the lower right; view north from knoll west of the Rocky Range.

Where the stream that flows between the Rocky Range and the Beaver Lake Mountains enters what was once the lake, what appears to be a delta has formed, part of which is inside the eastern edge of the area. This depositional area is much more irregular than a fan, being rather lobate in plan with a hummocky surface and has an irregular terrace built at the head of it. This delta covers about three square miles and has faint traces of shore lines across parts of it.

Faint traces of what may represent a higher lake level occurs near East Ridge, and traces of successively lower shore lines occur to the east down to the Beaver River.

There appears to have been little change since Lake Bonneville vanished from Milford Valley. Some of the shore features show only moderate gullying and others are covered in places with but a thin veneer of alluvium.

GEOLOGIC HISTORY

The geologic record of the area appears to be one of relatively quiet sedimentation for the early and middle Paleozoic which probably continued till the late Mesozoic, and a great deal of activity in the latest Mesozoic and Tertiary with extrusion, intrusion, thrusting, and high-angle faulting in perhaps one continuous orogenic sequence.

PALEOZOIC

In general the Paleozoic rocks of the area record an era of fairly quiet subsidence and marine deposition which took place on the eastern side, of a geosyncline that extended west into California. The Cambrian rocks form a transgressive sequence of quartzite-shale-carbonate, and carbonate deposition predominated throughout the rest of the Paleozoic. Any deformation during this period is thought to have been in the form of broad upwarps.

MESOZOIC

No Mesozoic rocks are exposed in the area, but to judge from nearby Mesozoic sediments, deposition continued to be predominately carbonate into the early Mesozoic and then changes to mainly clastic deposition that was largely of continental origin by Mid Jurassic. Towards the end of the era, uplift, along with folding and thrusting, occurred followed by deep erosion. It is during this time that the Cambrian rocks were folded and thrust and the thick Mesozoic cover was removed. Christiansen (1951, p. 79) believes the uplift started in the Late Jurassic and culminated in Early Cretaceous time with a recurrence of folding and thrusting in Early Laramide time. In the area just west of the Wasatch Plateau, an uplift may have started in the Late Jurassic or Early Cretaceous followed closely by two orogenic pulses with the major orogeny in early Laramide time (Spieker, 1949, pp. 78-79). By the end of Cretaceous time, mountains had been built by thrust faulting and folding in the Basin and Range Province adjoining the Colorado Plateau (Hunt, 1956, pp. 55-56). It appears then, that while the disturbance may have started earlier, Late Jurassic or Early Cretaceous, the main part probably occurred during the Late Cretaceous and by the close of the Mesozoic the area was mountainous and being eroded.

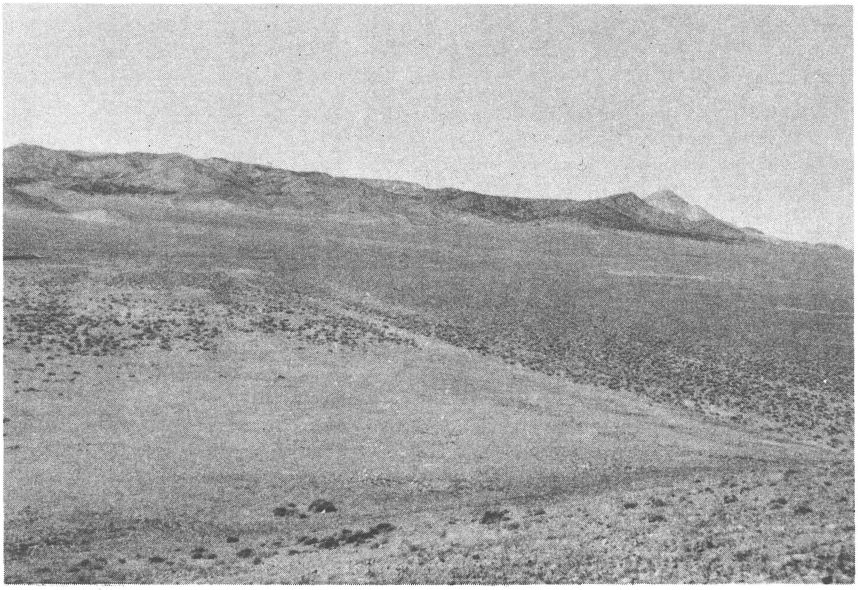

Figure 14. Offshore bar, view northwest along a sand bar from an "island" east of the Rocky Range toward the shore line through the center of the picture and the Beaver Lake Mountains beyond, ancient lagoon in the left foreground.

CENOZOIC

The early Tertiary (?) was a period of volcanism. A great amount and variety of volcanics were spread out on the surface, and locally volcanics may have been extruded from a vent in the Rocky Range as represented by the granodiorite porphyry.

Following the volcanism, the area was intruded by a stock of quartz monzonite in the middle Tertiary (?). The intrusion was at least partially forceful, folding the sediments by Lime Mountain and perhaps tilting the sediments and volcanics to the northwest in the vicinity of hill 6870. This shallow intrusion altered much of the carbonates and volcanics and was also responsible for the mineralization in the area.

After the intrusion the area underwent a second period of thrusting which cut the altered carbonate and intrusive in the northwest. Perhaps it was at this time that the north-south regional folding took place.

Block faulting typical of the Basin and Range occurred in the late Tertiary, and it was probably at this time that the present Beaver Lake Mountains were formed. The block faulting may be the result of a relaxation of the earlier compressive forces which caused the thrusting and regional folding.

At the end of the Tertiary, the Beaver Lake Mountains were an emergent range that was being eroded and buried by its own waste and waste from the San Francisco Mountains with Milford Valley being an enclosed basin and serving as the local base level. This continued until at least the west flank of the range was covered. Then, during the early or middle Pleistocene, the local base level changed through transformation of Milford Valley from interior to exterior drainage northward into the valley of the Sevier Desert. This brought about a stripping away of the alluvial cover of the west and south sides and a deepening of the eastern trending valleys at the north side of the mountains, a process which is continuing today.

In the late Pleistocene Lake Bonneville filled Milford Valley during its highest stage (Gilbert, 1890, plate 3) and added a few shore line features to the east of the area that have been little modified since.

There has been little change since Lake Bonneville receded from the valley. Gilbert (1890, plate 46) proposed a slight eastward tilting of the area since Lake Bonneville, but Dennis (1944) found that there is little or no post-Bonneville deformation indicated by shore lines in the Escalante Bay of Lake Bonneville. The general absence of recent fault scarps in Escalante Valley furnishes additional evidence that there has been little recent deformation (Dennis, 1944).

The Beaver Lake Mountains should continue to be uncovered and this will be especially noticeable on the south flank where the alluvium is already fairly thin.

CONTACT METAMORPHISM

The quartz monzonite intrusion has altered the earlier rocks for varying distances from its contacts and mineralized them in places along its contacts. The alteration in the carbonates falls readily into two types, mineralogically and geographically: simple hydrothermal metamorphism with recrystallization and rearrangement of

Figure 15. Altered Beaver Lake dolomite with tremolite nodules on the west side of Lime Mountain in the center of figure 6.

components with little or no addition of material, and contact mineralization with recrystallization and the addition of material, mainly iron and silica. The alteration of the lavas is less clear cut, and the amount due to surface alteration is unknown, but in general there appear to be three types: simple hydrothermal metamorphism with little or no addition of material, with mainly silica added, and with mainly iron and silica added.

ALTERATION OF THE CARBONATE ROCKS

HYDROTHERMAL METAMORPHISM

This is by far the major type of alteration in the carbonate rocks. The effect of the intrusion has been mainly from its heat, with little if any addition of material, which has produced bleaching, recrystallization, and rearrangement of components already present. The altered rock is generally a white to light-gray recrystallized carbonate. On the west side of Lime Mountain some tremolite is present in fist-size nodules and irregular bands, also two small nodules of hematite and one limonitic pseudomorph after pyrite were found (see fig. 15).

These altered rocks have apparently undergone some compression. On the west side of Lime Mountain where one outcrop of dark-gray mottled dolomite grades into the altered rock, the mottling becomes flattened and elongated grading into banding in the altered rock. Also near here a large horn coral in the altered rock has an eliptical cross section, perhaps from being compressed.

In the northern part of the area are several places where silica has replaced carbonate to form jasperoid (see fig. 16). This silicification is not thought to be related to the quartz monzonite intrusive since some of the jasperoid appears to be controlled by the later high-angle faulting.

CONTACT MINERALIZATION

A rather narrow zone is present sporadically along most of the quartz monzonite-carbonate contact in which there has been an addition of material from the intrusive, mainly iron and silica. This skarn zone is present in small pods along most of the contact south of Lime Mountain, at a few scattered spots along the contacts on Bat Ridge, mainly on the east end of the north side, as

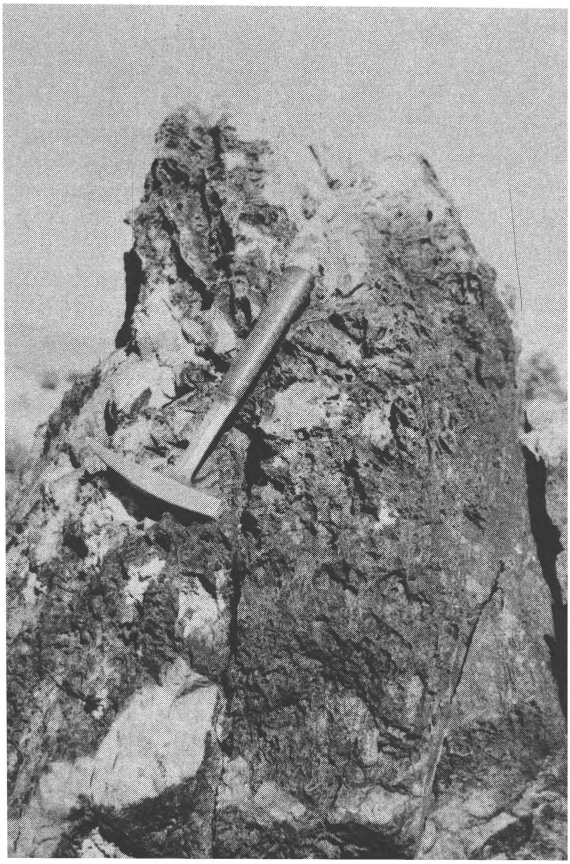

Figure 16. Jasperoid, light patches at top partially silicified carbonate, dark area in center dark reddish-brown network of silica veinlets around silicified carbonate, light patches at bottom light-gray "quartzite"; replaced Devonian dolomite north of Lime Mountain.

completely mineralized pendents south of Bat Ridge and along the southwest extension of the central intrusive body, mainly toward the west end. In general this zone is less than ten feet wide, but reaches over fifty feet in places.

This zone is very irregular in size, distribution, and mineral content, but displays continuity in placement along the intrusive contact, general mineral suite, and in showing an addition of material from the intrusive. Often these deposits are roughly banded approximately parallel to the contact, but massive and disseminated occurrences are also common.

This is mainly an epidote-magnetite-garnet zone with a variety of other minerals in minor amounts, but the mineralized zone shows a very wide range in proportion and number of minerals present. The most typical assemblage is a banded to laminated rock composed chiefly of epidote and magnetite with a mixture of other minerals. In the mineralized pendents south of Bat Ridge, the skarn consists mainly of epidote and garnet with only a very minor amount of magnetite and at many places along the contacts garnet is the chief contact mineral.

At places the mineralization is monomineralllic. In the center of the north side of Bat Ridge there is a small lens of magnetite with little or no other contact minerals, except possibly for some calcite. Towards the west end of the southwest arm of quartz monzonite the contact appears very shallow with small patches of the intrusive exposed north of the main contact. In this area small masses of crystalline garnet occur in vugs within the altered carbonate and vesuvianite and garnet occur along the main contact. A lens of specular hematite, the Black Rock mine, is present north of West Spring lying entirely within the altered carbonate but close to two intrusive contacts (see fig. 17). Perhaps this is the result of the more usual magnetite forming solutions having been directed a little away from the contact into a more oxidizing environment in the carbonate and changed to hematite. Some galena float was found by a shaft north of the Black Rock mine, but the relationships of this mineral are unknown.

Minerals recognized in the contact zone are garnet, epidote, magnetite, hematite, muscovite, calcite, quartz, tremolite, chalcopyrite, pyrite, tourmaline, diopside, vesuvianite, and cuprite. Butler (1913, pp. 87, 191) further lists pyrolusite and native copper. Secondary copper minerals malachite, azurite, and chrysocolla are fairly common, and chalcedony is found in places.

This mineralized zone is not present along the contact near the head of Butch Canyon. Here there appears to be a narrow silicic zone along the contact which may have been early and precluded further mineralization.

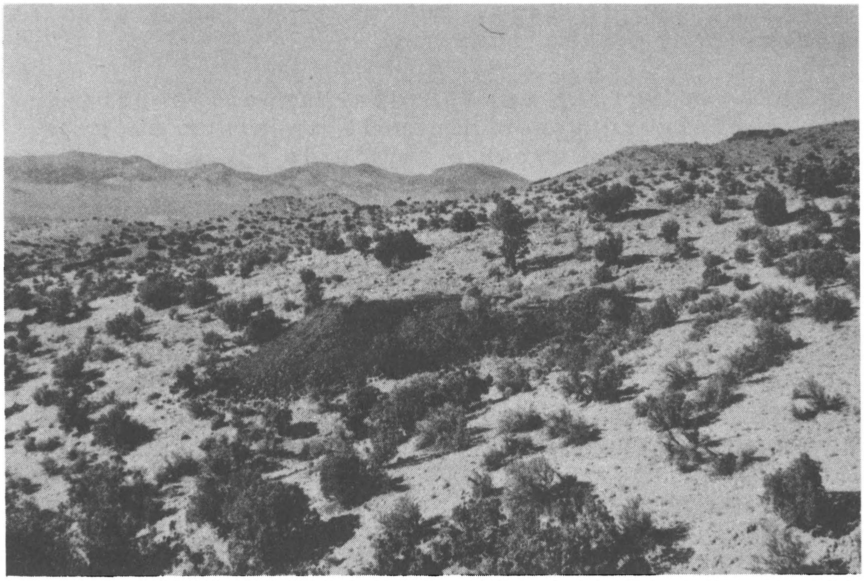

Figure 17. Black Rock mine, view north from near West Spring.

ALTERATION OF THE LAVAS

The alteration of the lavas does not fall into clear-cut types as does that of the carbonates. The changes in the lavas are gradational and irregular in distribution; whether or not material has been added, subtracted, or remained constant is hard to determine, as is the amount of change due to surface alteration. In general the alteration can be considered to be of three types: simple hydrothermal metamorphism with no change in material or little addition or loss of material, addition of silica, and the addition of iron and silica.

Most of the altered volcanics occur in the belt of volcanics between Blueacre and Butch Canyon and grade into unaltered volcanics at the east and west edges of the range. Also some mineralized pendents of volcanic (?) rock occur south of the O K mine, and the west side of Porcupine Hill is mineralized.

Much of the irregularity of distribution of the types of altered volcanics is probably due to the combination of the volcanics being largely underlain by quartz monzonite at shallow (?) depths and topography.

HYDROTHERMAL METAMORPHISM

The first observable change from the unaltered volcanics is a bleaching of the rocks. At the west and east sides of the volcanic area south of Butch Canyon and along the higher ridges, the volcanics are not visibly altered and, in some cases, can be traced into the altered rock. For example, a nearly black lava capping one of the eastern ridges can be followed downward into bleached rock. The change at the contact is not a gradual lightening, but rather one where light-gray spots appear and coalesce within a few feet to form a light-gray rock with white phenocrysts.

As the alteration progresses, the feldspars and ferromagnesian minerals break down into silica and sericite until the rock is composed essentially of these two components. At two locations there is some tourmaline in the altered rock, and Butler (1913, p. 79) reports the presence of andalusite in the most highly altered volcanics.

> Under the microscope the rocks are seen to have undergone changes normal to hydrothermal alteration.....The biotite, which is the ferromagnesian mineral most often seen, is altered to quartz and a colorless mica and possibly some serpentine, though the magnesium appears to have been largely removed in alteration. The iron ore has been altered in some places, and where pyrite or specularite are not present, it has apparently been removed and probably deposited where these iron minerals are abundant. In other places iron ore is present in highly altered rock, apparently having suffered little change. The feldspars first show sericitization along cleavage surfaces, and eventually the whole crystal is converted into a feltlike mass of sericite and quartz crystals. The groundmass of the fine-grained rocks also suffers sericitization (Butler, 1913, p. 78).

Reiser and Crawford (1934, p. 137) describe similar alteration of the lavas a little to the west of the area on the east flank of the San Francisco Mountains.

> A part of the rock in the volcanic ridges west and north of the O K mine (and in Ram Skull Canyon) has suffered unusually severe alteration.. Under the microscope, as in the field, the most highly altered rocks have quite as much the

> appearance of altered sediments as of volcanic rocks, being composed principally of irregular grains of quartz and foils of muscovite together with a mineral in small, irregular grains..... The mineral corresponds in optical properties closely with andalusite, though the pleochroism is less marked than is usual in that mineral. The quartz grains contain numerous small globular masses with rather high index that appear to be the same mineral. These were included in the quartz during crystallization, and as such inclusions do not occur in the quartz grains of the fresh rock they indicate that the quartz resulted from crystallization during the metamorphism.....Carbonate is usually present in small, but varying amounts (and)...apatite is rather abundant. (Butler, 1913, p. 79).

Other minerals are present which are probably kaolinite, diaspor, magnetite, rutile, and fluorite.

Two partial analyses made for Butler (1913, p. 79) showed a marked decrease in magnesia, lime, and soda with only a slight decrease of potash in an altered quartz-muscovite volcanic rock, but all four oxides have been greatly decreased in highly altered quartz-andalusite-muscovite volcanic rock. From this and microscopic work Butler (1913, pp. 80-81) concludes that as long as there was sufficient potash or soda in the rock to unite with the alumina that was liberated by the breakdown of the feldspars and the removal of the lime or alkali, the more aluminous mica was formed. Any further removal of potash and soda after these elements were all in mica left an excess of alumina which usually formed the aluminum silicate andalusite or in some places probably the hydrous aluminum oxide diaspore.

Reiser and Crawford (1934, p. 137) found some alunite in silicified lavas just west of the area and it may well be present within the area. They felt that the alunite was secondary; the lavas first were altered by mineral solutions from the quartz monzonite intrusion, then later the sericite was replaced by alunite due to the action of meteoric solutions.

SILICIFICATION

Butler (1913, pp. 80-81) thought that solutions altering the volcanics effected a progressive subtraction of certain of the constituents and a rearrangement of those remaining with the apparent increase in silica being undoubtedly due only to a concentration. This may be true for the most part, but in places the altered rock appears to consist essentially of silica and an addition of silica seems probable.

The altered volcanics are especially siliceous in the southwest part of the mountains. The rock is light gray, aphanitic to fine-grained, and weathers red-brown. It ranges from a dense massive rock to a vuggy rock that resembles a coarse sandstone. In places the silicic rock contains small grains of specular hematite sometimes in minute vugs.

At the southwest edge of the mountains, the highly silicic altered volcanics are cut by fractures which exhibit every stage of filling by silica from open fractures with a fine druzy quartz lining to ones filled with aphanitic silica. Druzy quartz was also found lining fractures in the unaltered lavas on the hill above. Here the volcanics were silicified and later fractured with silica-bearing solutions following the fractures.

A silicic zone is present along the south wall of Butch Canyon that is linear in shape and may follow a fracture or a fault zone. If so silicification here may be later than the metamorphism of the volcanics.

CONTACT MINERALIZATION

Contact mineralization somewhat equivalent to that in the carbonate rocks occurs along the quartz monzonite contact at a few places where there has been the addition of iron from the quartz monzonite intrusive. Mineralization occurs at two places on the west side of the mountains, the west side of Porcupine Hill and in several pendents of volcanics south of the O K mine. At the contact on the west side of the mountains is a very small deposit of specular hematite, showing crystal faces up to three inches across, and nearby was a small deposit of secondary copper minerals. Other than this the quartz monzonite-volcanic contact is either concealed or barren in the mountains.

On the west side of Porcupine Hill is a well-developed contact mineralized zone. The quartz monzonite is not exposed at the surface, but float is found on mine dumps, and it is probably present at a very shallow depth. Here there is a great deal of micaceous material with some magnetite and epidote in gently dipping bands and also secondary malachite and azurite.

A mile south of the O K mine are a few shafts and several trenches in some poorly exposed mineralized pendents that were probably originally volcanic rock. A variety of rock types is present. One trench exposed garnetized rock, magnetite, epidote, and micaceous material with faint vertical banding, but otherwise the mineralized rock was less like the other contact mineralized zones. It generally consists of heterogeneous rocks in varying stages of decomposition with minor amounts of magnetite, epidote, sericite, chalcopyrite, and calcite.

ECONOMIC GEOLOGY

A great deal of effort has been spent and is still being spent in the Beaver Lake Mountains in trying to find worthwhile mineral deposits. This is evidenced by the hundreds of prospect pits, adits, shafts, and the more recent trenches. However, there are no mines operating at the present, and to date there has been only some copper and a little iron produced.

The mineral deposits are in contact mineralized zones bordering the quartz monzonite intrusive and in brecciated zones within the quartz monzonite. The possibility that the intrusive in the southern part of the area carries enough disseminated copper to constitute a "porphyry copper" deposit is being explored. The Beaver Lake Mountains are in a good geographical position for exploitation if a worthwhile deposit is found since the Union Pacific Railroad passes just a few miles to the east and freight yards are present in Milford.

HISTORY

The Beaver Lake Mountains, forming the Beaver Lake mining district, are located in one of the oldest mining areas of the state. There has been a great deal of mining activity in the mountains, but so far the miners have gotten little for their effort. Actual production during the early days of the district was fairly well confined to three mines: the Black Rock, Skylark, and O K mines. The Black Rock and Skylark produced a few hundred tons of iron ore, used for smelter flux, in the late 19th century. The O K copper mine was in operation from 1900 to 1907. By the end of 1901 the O K was reported to have produced 1,145 tons of ore averaging 40 per cent copper and giving returns of $95,000. The rich ore developed had been all taken out by 1902. If these figures are correct, the total output of copper has been nearly 1,000,000 pounds and the total value in excess of $100,000. (Butler, 1913, p. 189).

Since 1913 small mines have been in operation on the east side of Lime Mountain in the altered carbonate and at the northeast end of Bat Ridge in the contact zone. Nothing of the production is known, but it is presumed to have been very small. At present there are a number of claims being held in the mountains, mainly the restaking of old mines and prospects. Almost all of the thinly alluviated slope south of the mountains has been claimed and a number of trenches dug in hopes that the quartz monzonite intrusive may form a "porphyry copper" deposit. Just south of the area in the Rocky Range, the Old Hickory mine was operating until recently. It was getting values of copper, tungsten, and iron from the contact zone of both the quartz monzonite and granodiorite porphyry with carbonate rocks.

CHARACTER OF DEPOSITS

CONTACT DEPOSITS

Contact mineralized deposits, mainly along the carbonate quartz monzonite contact, but also along the volcanic-quartz monzonite contact, form the largest group of deposits. These occur as small lenses along the quartz monzonite contact, probably localized by some irregularity at the contact. In general the mineralized rock is banded; the main ore minerals are magnetite and chalcopyrite in a gangue of contact silicates. These deposits resulted from the metamorphism of the country rock by the quartz monzonite intrusion along with the addition of iron, silica, and a little copper from the intrusion. The larger deposits of this type are found at the Skylark mine, Black Rock mine, northeast part of Bat Ridge, along the west side of Porcupine Hill, and in the volcanic pendents south of the O K mine.

Skylark Mine

The Skylark mine appears to be the largest contact mineralized deposit. The mineralized zone is over twenty feet wide at the shaft. It lies within a body of altered carbonate which is probably surrounded by quartz monzonite and was therefore more susceptible to alteration than the carbonate which was bordered by quartz monzonite on only one side. The deposit is a banded magnetite-epidote rock with an admixture of other minerals including quartz, chalcopyrite, pyrite, cuprite, muscovite, calcite, and garnet.

Black Rock Mine

This mine is north of West Spring (see fig. 17). It consists of a lens of almost pure specular hematite that is about ten feet wide at the top of the shaft but is not exposed on the surface away from the shaft. This deposit is entirely within altered carbonate.

Northeast Part of Bat Ridge

A lens of magnetite and calcite is present at the contact between the altered carbonate and quartz monzonite at the central part of the north side of Bat Ridge. Next to the contact there appeared to be about 10 feet of massive magnetite with very little calcite, followed by eight feet of altered limestone with about 20 per cent magnetite disseminated in it as coarse-grained, 1/4 inch, octahedra and small massive patches. The contact is mostly covered by float, but with the aid of a dipneedle the lens was estimated to be about 100 feet long.

Farther east, at the northeast end of the ridge, is a skarn zone along the contact which is similar to that at the Skylark mine, except that it appears to be smaller and contains more garnet and mica and much less magnetite. The contact mineralized zone is cut by a number of small (?) faults. An adit penetrates the skarn zone parallel to the contact for about 150 feet and a shaft is sunk into the zone farther east.

BRECCIA FILLING-FISSURE DEPOSITS

Mineral deposits, following brecciated zones or small fissures, occur in the quartz monzonite. Copper minerals form the main ore minerals and occur with a great deal of quartz. This type of deposit is found in the quartz monzonite around the south edge of the mountains with the O K mine forming the principle deposit.

O K Mine

The O K mine is in a brecciated zone in the quartz monzonite. Quartz has been deposited in the fissures with the ore minerals, then deposited around quartz crystals or in fractures cutting the quartz. The quartz is usually present as crystal linings of fissures, but completely filled fissures of crystalline or massive quartz are common. The principle ore mineral is chalcopyrite which occurs along with molybdenite and several secondary copper minerals.

The mine has fairly extensive underground workings wherein Butler (1913, p. 125) found that the brecciated zone had a chimney shape with maximum diameter of over 100 feet. Branching veins extend away from the "chimney" and have a much higher proportion of chalcopyrite than the main body.

Molybdenite and chalcopyrite were found as original minerals in an apparent aplitic dike exposed in the lower part of the mine (Butler, 1913, p. 126), and an aplite dike a mile to the southeast also contained some chalcopyrite. The source of the mineralization in the O K mine may very well be closely related to the aplitic dikes. (A fuller account of the O K mine is given by Butler, 1913).

DISSEMINATED DEPOSITS

The thinly alluviated southern flank of the mountains has been claimed in hopes that the quartz monzonite contains enough copper minerals to form a "porphyry copper" deposit. In many places the quartz monzonite has stainings of malachite and less commonly azurite which follows joints and small fractures. Whether the area contains enough copper to be profitably exploited is presently being explored by a large copper mining company.

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