Geology and Mineral Deposits of the Thomas and Dugway Ranges Juab and Tooele Counties Utah

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GEOLOGY AND MINERAL DEPOSITS OF THE THOMAS AND DUGWAY RANGES, JUAB AND TOOELE COUNTIES, UTAH

By Mortimer H. Staatz and Wilfred J. Carr

ABSTRACT

The area covered by this report includes nearly all the Thomas and Dugway Ranges, two small ranges in the eastern part of the Basin and Range province in western Juab and Tooele Counties, Utah. It includes all the Dugway Range quadrangle and the northern one-third of the Topaz Mountain quadrangle, an area of 306 square miles.

The units mapped may be grouped according to age and type into sedimentary rocks of Paleozoic age, volcanic rocks and associated sedimentary rocks of Tertiary age, and Lake Bonneville sediments and alluvium of Quaternary age.

Sedimentary rocks of Paleozoic age make up most of the Dugway Range, Spor Mountain, the eastern part of the Black Rock Hills, and the extreme southern end of the Thomas Range. Twenty-six formations ranging in age from Early Cambrian to Late Mississippian with a total thickness of more than 30,000 feet were mapped in this area. Ten of these formations are here described for the first time.

The rocks of Cambrian age are thicker than those of any other period, being at least 17,300 feet thick. At the base of the Cambrian section is the Prospect Mountain quartzite, which is at least 12,000 feet thick. The overlying Cambrian rocks, most of which are limestone and dolomite, consist of the following nine formations: the Cabin shale and the Busby quartzite of Early Cambrian age, the Shadscale formation, the Trailer limestone, and the Fandangle limestone of Middle Cambrian age, the Lamb dolomite of Middle(?) and Late Cambrian age, and the Straight Canyon formation, the Fera limestone, and the Dugway Ridge dolomite of Late Cambrian age.

Rocks of known Ordovician age consist of three formations: the Garden City formation, which is of Early Ordovician age in its lower and middle parts and of Middle Ordovician age in its upper part, the Swan Peak formation of Middle Ordovician age, and the Fish Haven dolomite of Late Ordovician age. The Swan Peak formation consists of a lower shaly unit and an upper massive quartzite unit; the other two Ordovician formations are mainly carbonate rocks.

Overlying the Fish Haven is the Floride dolomite, which is either Ordovician or Silurian in age. This formation is overlain by four Middle Siluran dolomites: the Bell Hill dolomite, the Harrisite dolomite, the Lost Sheep dolomite, and the Thursday dolomite.

Rocks of Devonian age, particularly Late Devonian, are much thicker in the Thomas and Dugway Ranges than in surrounding areas. Although 4,000 feet of Upper Devonian rocks is found in this area, not over 600 feet of rocks of this age has been described from anywhere else in western Utah. The following Devonian formations, which consist of dolomite, quartzite, and minor limestone, have been mapped in the Thomas and Dugway Ranges: the Sevy dolomite of Early(?) and Middle Devonian age; the Engelmann formation of Middle and Late Devonian age; and the Goshoot formation, the Gilson dolomite, and the Hanauer formation of Late Devonian age. In addition, in the Black Rock Hills some rocks whose position within the Late Devonian is not known have been mapped as Upper Devonian sedimentary rocks, undivided.

Rocks of Mississippian age are found only in the northern part of the Dugway Range and consist of the following three formations: the Madison limestone equivalent of Early Mississippian age, and the Woodman formation and Ochre Mountain limestone of Late Mississippian age.

A thick sequence of rhyodacitic and rhyolitic rocks of Tertiary age, probably Miocene and Pliocene, occupies the southern part of the Dugway Range, almost all of the main part of the Thomas Range, and the western part of the Black Rock Hills. In addition, dikes and small intrusive plugs are common on Spor Mountain and in parts of the Dugway Range.

The volcanic rocks are divided into an older group and a younger group, separated by an unconformity. The older group is poorly exposed, and relations between various rock units in this group are not well known. The older group contains the following 10 rock units: rhyodacite; rhyodacite breccia and associated tuffs; plagioclase crystal tuff; black glass-welded tuff; sanidine crystal tuff; quartz-sanidine crystal tuff; vitric tuff; red vitric tuff, conglomerate, and sandstone; porphyritic rhyolite; and intrusive breccia. The younger volcanic group consists of at least five overlapping rhyolitic subgroups, each made up from bottom to top of vitric tuff, breccia, and rhyolite; rhyolite makes up the great bulk of the rock. Cutting these three rock types is a green glass unit believed to represent rock formed in or adjacent to vents. Three small sandstone units of variable composition are interbedded at different horizons in the volcanics. The sandstone units were probably deposited in small lakes formed by the damming of streams by the volcanic rocks.

The volcanic rocks of the Thomas and Dugway Ranges are poorer in ferromagnesian minerals and more salic than the average volcanic rock, and have an alkali-lime index of 61.6, which is similar to that of the rock sequences from Crater Lake and Parícutin volcano. The rocks of the older volcanic group have an average uranium content of 0.001 percent and the rocks of the younger group have an average uranium content of 0.003 percent; the latter figure is three times that of the average rhyolitic rock in the western United States.

A unique assemblage of minerals including topaz, garnet, beryl, bixbyite, pseudobrookite, and specularite, occurs in the rhyolites of the younger group.

Lake Bonneville sediments, consisting chiefly of clay, marl, sand, and gravel, fill the basins on either side of the Thomas

and Dugway Ranges up to an elevation of 5,200 feet. Tufa and tufa-cemented conglomerate are found along some of the old shorelines. Gravel bars as much as 50 feet high were formed across the mouths of canyons and off points of land in old Lake Bonneville. Alluvium is found in some of the valleys and it overlies the Lake Bonneville sediments.

The Paleozoic sedimentary rocks and the older group of volcanic rocks have a dominant northerly strike and westerly dip that averages about 35°. The only large-scale fold in this sequence of rocks is the gentle Buckhorn syncline in the northeastern part of the Dugway Range. Most of the areas of Paleozoic rocks, however, are complexly faulted. The faults may be divided, in general, into three groups, according to age and type: First, and oldest, are four small thrusts on Spor Mountain and adjacent Eagle Rock Ridge, which offset the beds a maximum of 1,000 feet vertically, and one large thrust, the Buckhorn, in the northern part of the Dugway Range, which has a minimum stratigraphic displacement of 15,000 feet. Second is a group of diversely oriented normal and reverse faults with dip-slip movement of from a few inches to about 1,000 feet. These make up the great bulk of the faults. Third is a group of large north- or northwest-trending normal faults of the Basin and Range type. In general, these faults have a dip-slip movement of several thousand feet; they constitute the youngest group in the area and have elevated the ranges to their present height. Most of the movement on the first two groups of faults occurred prior to the emplacement of the volcanic rocks. The Basin and Range faults, however, cut rocks of the older volcanic group in places, but rarely those of the younger group. The volcanic rocks of the younger group are not tilted and are cut by only a few small faults with a maximum vertical displacement of about 100 feet.

Three types of ore deposits occur in the Thomas and Dugway Ranges: (1) uraniferous fluorspar, (2) uranium, and (3) lead-zinc-copper-silver.

The uraniferous fluorspar bodies have been found only on Spor Mountain, where they occur as pipes, veins, and disseminated deposits. The pipes are the only important deposits; more than 99 percent of the fluorspar produced has come from them. These pipes are generally circular or oval in plan and range from less than a foot in diameter to 155 feet long by 106 feet wide. They plunge vertically or steeply to the east. The pipes occur in the Ordovician and Silurian dolomites that overlie the quartzite of the Swan Peak formation. Most of the ore replaced shattered rock in zones along faults or adjacent to intrusive breccia bodies. The ore consists of 60 to 95 percent fluorite intermixed with montmorillonite, quartz, chalcedony, calcite, and dolomite. The ore contains from 0.003 to 0.33 percent uranium, which occurs chiefly in the fluorite, although a little carnotite is present near the surface in some deposits. The grade of the fluorite generally decreases with depth and as the gangue minerals, especially montmorillonite and chalcedony, increase. In some deposits uranium is secondarily enriched near the surface, the upper part of the ore body commonly containing twice as much uranium as the lower part. This enrichment probably took place by slow leaching and downward concentration of uranium from the uppermost part of the ore body as it was progressively exposed by erosion to weathering in an arid climate. The uranium was redeposited in dry underlying ore a few inches to 30 feet below the position from which it was leached.

The fluorspar deposits are believed to have been formed by the reaction of dolomite with fluorine-rich fluids containing uranium which were derived from the magma that formed the younger volcanic group.

The production of the Spor Mountain district from its beginning in 1944 through 1956 was 112,000 short tons of fluorspar containing 65 percent CaF_2. Over 75 percent of this production came from three properties: the Lost Sheep, the Fluorine Queen, and the Bell Hill.

The uranium deposits occur on the east and west flanks of the Thomas Range at the southern end of the main part of the range. They consist of two types: (1) veinlets in rhyolite and tuff and (2) disseminated minerals in tuffaceous sandstone and conglomerate. The first type consists of numerous veinlets made up chiefly of opal. The uranium content of these veinlets ranges from 0.009 to 0.026 percent; the small size and low grade of these deposits makes them of little economic importance. The second type of deposit, found only on the Good Will property, contains uranium in the rather rare mineral, weeksite, that replaces parts of limestone pebbles in a conglomerate, and in beta-uranophane that fills voids in a porous tuffaceous sandstone. A number of abnormally radioactive areas occur in the sandstone. The largest of these is at least 120 feet long by 65 feet wide. Nine samples from this zone ranged from 0.012 to 0.65 percent uranium.

The only ore shipped from any of the uranium deposits came from the Good Will property, and from 1954 through 1956 amounted to 129 short tons containing from 0.11 to 0.25 percent uranium.

The lead-zinc-copper-silver deposits are found in the Dugway district in the north end of the Dugway Range. These deposits are small; many ore bodies do not exceed 40 feet in length. About 60 percent of the production has come from the Four Metals mine, where the main vein is about 200 feet long and extends at least 300 feet down the dip. The deposits in this district are fissure veins in quartzite, and fissure veins and replacements in dolomite and limestone. Most are dominantly lead-zinc deposits that occur along minor faults; some of the deposits in the carbonate rocks adjacent to major northwest-trending faults, however, are dominantly of pyritic copper ore. The vein minerals consist chiefly of galena, sphalerite, pyrite, chalcopyrite, quartz, fluorite, and barite. In the upper parts of the veins the primary ore minerals have been largely oxidized, and on most properties this is the only ore that has been mined.

Although data are scarce for the period prior to 1934, the total production of the district through 1956 is estimated to be 12,000 short tons of ore containing on the average approximately 7.7 percent lead, 10.0 percent zinc, 0.07 percent copper, and 1.4 ounces per ton of silver.

INTRODUCTION

LOCATION, CULTURE, AND ACCESSIBILITY

The Thomas and Dugway Ranges are two small desert ranges in Juab and Tooele Counties, western Utah. The area mapped, the Dugway Range quadrangle and the northern third of the Topaz Mountain quadrangle, includes most of both ranges. This area is bounded by parallels 39°40′ and 40° and meridians 113° and 113°15′ (fig. 1). The western boundary of the area is about 43 miles east of the Utah-Nevada State line and the eastern boundary is about

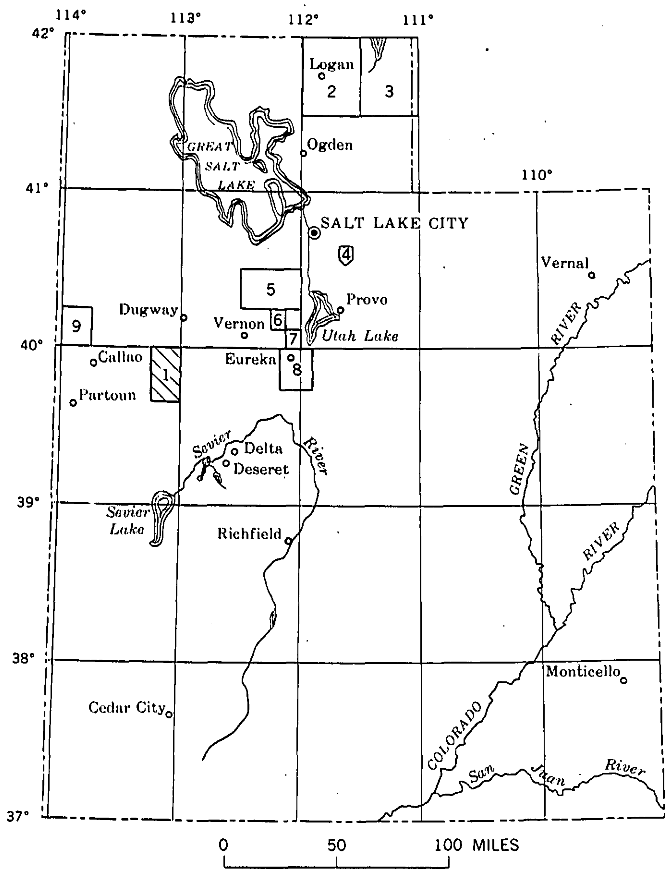

FIGURE 1.—Index map of Utah showing location of the Thomas-Dugway Ranges area and of other areas of interest covered by published reports. 1, Thomas-Dugway Ranges area; 2, Logan quadrangle; 3, Randolph quadrangle; 4, Cottonwood-American Fork area; 5, Stockton and Fairfield quadrangle; 6, Five Mile Pass quadrangle; 7, Allens Ranch quadrangle; 8, Tintic quadrangle; 9, Gold Hill quadrangle.

46 miles west of Eureka, Utah. Delta, Utah, the nearest town, is 31 miles from the southeastern corner of the mapped area.

No permanent residents live in the area, and the economy of the region is based on sheep-grazing between November and April and on mining. The Dugway mining district, a source of lead, silver, zinc, gold, and copper, is in the northern part of the Dugway Range; a new unnamed mining district, a producer of fluorspar, is on Spor Mountain in the western part of the Thomas Range; and several deposits containing uranium occur on the east and west sides of the Thomas Range near its southern end.

The Dugway Range and Topaz Mountain quadrangles are crossed from east to west by two good graded dirt roads (pl. 1). The northern one follows the old Pony Express route and connects Vernon, 49 miles east of the area, with Callao, Utah, 36 miles west. This route passes near the center of the Dugway Range quadrangle where it crosses Dugway Pass, the boundary between the Dugway and Thomas Ranges. The southern (Sand Pass) road follows approximately the southern border of the area mapped and connects Callao, 43 miles west of the area, with U.S. Highway 6 at Jericho, 51 miles to the east. At the southeast corner of the area the Jericho-Callao road is joined by a graded road to Delta.

The only other improved dirt road in the mapped area, the main haulage route to the fluorspar mines, branches off the Callao-Jericho road and goes north along the east side of Spor Mountain. A dirt road east of Topaz Mountain connects the Callao-Jericho road with the Callao-Vernon road; another on the east side of the Dugway Range leads north from the Callao-Vernon road to the Dugway mining district. Other roads, usually passable only to four-wheel-drive vehicles, follow along the west side of the Dugway Range and along the east and west sides of the Thomas Range.

The nearest railroad is the main line of the Union Pacific Railroad connecting Salt Lake City with Los Angeles. The nearest railheads are St. John's Station for the northern part of this area and Delta for the southern.

PHYSICAL FEATURES

The Thomas and Dugway Ranges are approximately 100 miles west of the eastern boundary of the Basin and Range province, which in northern Utah is defined by the western base of the Wasatch Range (Nolan, 1943, p. 142). Between the Thomas and Dugway Ranges and this boundary are the Keg, Simpson, Sheeprock, East Tintic, and Lake Ranges, and the intervening basins. The Thomas and Dugway Ranges form the central part of a long north-trending uplift, which consists from north to south of (1) Granite Mountain, (2) Dugway Range, (3) Thomas Range, and (4) Drum Mountains. Granite Mountain is separated from the Dugway Range by a flat about 3 miles wide. Dugway Range is arbitrarily divided from the Thomas Range at Dugway Pass, and the Thomas Range is arbitrarily divided from the Drum Mountains by the Jericho-Callao or Sand Pass road. West of the Dugway and Thomas Ranges lies Fish Springs Flat which separates these ranges from the north-trending Fish Springs Range. East of the Thomas and Dugway Ranges lies another flat, whose central part is occupied by Pismire Wash. This flat separates these ranges from the north-trending Keg Mountains. Both flats drain northward toward the Great Salt Lake Desert, which lies just north of the Dugway Range.

The Dugway Range trends generally northwest and is sigmoidal in shape, being widest in the central part and coming to a point at either end. The entire range is approximately 15 miles long and has a maximum width of 5 miles.

The Thomas Range consists of three topographically separate units. The main or eastern part trends north and is shaped like an hourglass. This part of the range is about 14 miles long and has a maximum width of 9 miles at its northern end. The western part, which is called Spor Mountain, is separated from the main part of the Thomas Range by The Dell, a valley 0.8 to 2 miles wide. Spor Mountain trends north-northwest and is oval shaped, being 5.5 miles long and as much as 2.5 miles wide. A northwestern extension of the Thomas Range, called Black Rock Hills, lies 2.5 miles west of the northern part of the main Thomas Range, and 3.5 miles northwest of Spor Mountain. The Black Rock Hills are circular and 4.5 miles in diameter.

The mountains of the Thomas and the Dugway Ranges exhibit two distinct types of topography (pl. 1). The main or eastern part of the Thomas Range, which is made up of flat-lying volcanic rocks, is a rolling upland from 6,400 to 6,800 feet in elevation that appears to represent in many places the slightly modified original top of the lava flows. It is bounded by steep escarpments and is cut by steep-sided canyons. Spor Mountain, the Black Rock Hills, and the Dugway Range, which are made up predominantly of northwest-dipping sedimentary rocks of Paleozoic age, are characterized by rugged topography, a steep eastern face, and a more gentle western slope.

The highest peak in the two ranges rises to 7,112 feet and lies near the east edge of the main part of the Thomas Range. This part of the Thomas Range is the highest of the four mountain blocks, having three main peaks over 7,000 feet high and 17 peaks over 6,500 feet. The highest peak in the Dugway Range has an elevation of 6,830 feet and is just west of the head of Fandangle Canyon in the central part of the range. Only six peaks in the Dugway Range are over 6,500 feet. Spor Mountain is lower than either the main part of the Thomas Range or the Dugway Range; its highest peak has an elevation of 6,584 feet. The highest peak in the Black Rock Hills has an elevation of only 5,712 feet, but because the surrounding flats in this region are low, the relief is more than 1,000 feet.

The valley flats surrounding these mountain blocks trend northwest in general and range in elevation from 4,320 to about 5,400 feet. The highest elevations occur southeast of Topaz Mountain, and the lowest in the northwest corner of the area.

Alluvial deposits slope away from the mountains. Some of this alluvium is in Recent fans, but much of it was deposited and reworked in Lake Bonneville. Many other topographic features found below an elevation of 5,200 feet were also formed by Lake Bonneville. The most conspicuous features are wave-cut benches from 5 to 100 feet wide cut into the mountain sides at several elevations. These are especially well exposed in the northwestern part of the Thomas Range, on the north end of the Dugway Range, and on a hill 2 miles south of Spor Mountain. Gravel bars formed in Lake Bonneville are also common along the sides of some mountains, across the mouths of small canyons, and as connecting links between a main mountain mass and a smaller outlier.

CLIMATE

The climate of the Dugway and Thomas Ranges, in common with much of the rest of the Basin and Range province, is arid.

There are no weather stations in these two ranges, but a comparison can be made with stations in similar terrain in the surrounding country. A compilation of records from weather stations at Deseret, 32 miles to the southeast; Dugway, 15 miles to the northeast; Eureka, 46 miles to the east; and Partoun, 40 miles to the west, is given in table 1.

Pronounced temperature differences between day and night are characteristic of this area. During July and August the daily temperature may range from more than 100°F to 60°F or less. The lowest temperature recorded in the region was −32°F at Deseret in 1932 and 1937; the highest was 106°F, at Delta in 1943.

Because the Thomas and Dugway Ranges have a higher elevation than any of the towns except Eureka, they probably receive more rain and snow. Precipitation is greatest along the ridges, which commonly receive moisture from small storms that do not reach the surrounding flats. Snow storms may occur from October to June, and are common from December through February. The snow from one storm usually melts and evaporates before the next snowstorm occurs. During the summer months widely scattered cloudbursts are common, and generally cover an area of from 1 to 10 square miles. The erosion resulting from these sudden storms is considerable. Several cloudbursts occurred on Spor Mountaain during July 1951. The runoff from one down a normally dry wash was more than 7 feet deep at a curve where the wash was 125 feet wide. The runoff from this same cloudburst widened a 4-foot-deep wash from 12 to 80 feet. Roads were washed out or covered with rock debris. Several boulders as large as 4 feet across

TABLE 1.—*Precipitation and temperature at Weather Bureau stations at Deseret, Dugway, Eureka, and Partoun, Utah*

[From U.S. Weather Bureau, 1935-54, Climatological data for the United States by section, Utah section]

Station	Altitude (feet)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Average monthly and annual precipitation, in inches														
Deseret [1]	4,541	0.47	0.37	0.70	0.85	0.78	0.50	0.51	0.50	0.35	0.76	0.42	0.61	6.93
Dugway [2]	4,359	.69	.17	.82	.83	.36	.37	.52	.24	.08	.37	.55	.57	5.44
Eureka [3]	6,530	1.53	1.38	1.80	1.32	1.21	.91	1.02	.96	.62	1.26	.86	1.58	14.43
Partoun [4]	4,537	.41	.33	.54	.51	.51	.35	.54	.41	.12	.52	.62	.42	5.93
Average monthly and annual temperatures, ° F														
Deseret [1]	4,541	26.4	32.3	39.4	48.9	56.9	64.7	74.3	72.3	63.4	51.3	37.0	29.9	49.9
Dugway [2]	4,359	32.4	34.7	38.5	50.8	59.5	67.7	78.9	76.5	67.5	53.9	39.9	29.4	52.2
Partoun [4]	4,537	30.8	33.2	38.0	50.4	57.2	65.3	75.5	72.5	64.0	53.5	41.6	28.1	50.3

[1] For 1935-1954, inclusive.
[2] For 1951-1954, inclusive.
[3] For 1935-1944, 1948-1954, inclusive.
[4] For 1950-1954, inclusive.

had to be removed from the road in the narrow valley between Spor Mountain and Eagle Rock Ridge.

High winds are common in the area from March to June and in November and December.

WATER SUPPLY

No permanent streams flow in either the Dugway or the Thomas Range. Water is found in the stream beds only after heavy rains or during warm periods following a snow storm. Most water for human usage is hauled from the nearest town. Water for sheep that graze in the area from November to April is obtained from snow, reservoirs, wells, and springs.

In favorable areas the U.S. Grazing Service has made low earth dams across the washes to pond the water from sudden rainfalls. Two such reservoirs, the Bittner Knoll Reservoir, which lies about 1½ miles east of Dugway Pass, and the East Topaz No. 2 Reservoir, which lies 3½ miles east of the central part of the Thomas Range, are in the area under study. A third reservoir is located beside the Jericho-Callao road about 2 miles east of the junction with the road to Delta.

Four wells have been drilled by the U.S. Bureau of Land Management on the flats along main routes of sheep travel. These wells are: (1) Fandangle well near the north end of the Dugway Range opposite the mouth of Fandangle Canyon, (2) Fera No. 38 well about 1¾ miles east of the central part of the Dugway Range, (3) Dugway-Topaz well on the south side of the Vernon-Callao road, 4.1 miles east of the top of Dugway Pass, and (4) Fera well No. 28 on Fish Springs Flat 1.2 miles north of the Vernon-Callao road.

Data on the depth and water level in these wells were compiled by C. T. Snyder of the U.S. Geological Survey and are given in table 2. All the wells are in unconsolidated Lake Bonneville sediments in which a number of gravel beds are present. The water level under the flats surrounding the Dugway Range is quite uniform (table 2); it varies only 24 feet in the four wells, whose surface elevations vary 131 feet.

The only analysis of well water available is from Fera well No. 28, which contains 5,022 ppm (parts per million) of dissolved material, of which 3,663 ppm correspond to NaCl. The water from all four wells is probably saline, however, because it has migrated through the Lake Bonneville sediments, which are high in evaporites.

TABLE 2.—*Depth of wells and position of water table in wells in the Thomas and Dugway Ranges area*

[Data from C. T. Snyder 1955, written communication]

Well	Depth (feet)	Depth from surface to water level (feet)	Elevation of water level in well (feet)
Fandangle	202	170	4,310
Fera No. 38	551	190	4,334
Dugway-Topaz	306	270	4,332
Fera No. 28	538	145	4,326

J. E. Palmer, range manager for the Bureau of Land Management (1955, oral communication), reported the water from the Dugway-Topaz Well to be warm, and estimated its temperature at about 120°F. Hot springs along the east foot of the Fish Springs Range, 18 miles to the west, have the same position relative to that mountain front as the Dugway-Topaz well has to the east face of the Dugway Range. The springs along the east side of the Fish Springs Range were cited by Bryan (1919, p. 533-535) as a classic example of fissure springs whose water is heated in the deeper and warmer parts of the earth. The warm water from the Dugway-Topaz well may be similar in nature; it represents water which has risen along a

TABLE 3.—*Analyses of spring waters from the Thomas Range*

[Analysts: J. P. McClure, W. D. Goss, I. C. Frost. Analyses in parts per million, except pH]

Spring	pH	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Chloride (Cl)	Floride (F)	Nitrate (NO_3)	Sulfate (SO_4)	Uranium (U)
Hangrock	8.1	73	19	103	7.9	13	230	185	0.5	0	37	0.020
Wildhorse	7.0	555	135	627	13	0	257	2,093	1.1	.5	332	.106

fissure and mixed with the surface water in the vicinity of the well.

Three springs are known in the area mapped: Hangrock, Wildhorse, and Straight Canyon Springs. Hangrock Spring is at an elevation of about 6,250 feet on the west side of Colored Pass (pl. 1) in the central part of the Thomas Range; it seeps out of a small fault (offset about 15 feet) in the rhyolite and has an estimated flow of 2 gallons per hour. The water is cold and has 668 ppm of dissolved substances, most of which are HCO_3, Cl, and Na (table 3). This water, although it contains a much lower amount of dissolved material compared to the water of this region that passes through Lake Bonneville sediments, is still high in dissolved material compared to other meteoric water. The spring is probably the result of slow downward seepage of ground water along fractures, and the dissolved salts are probably obtained from the enclosing rhyolite.

Wildhorse Spring is near the northern end of The Dell at the foot of a hill near the base of the prominent escarpment forming the west face of the main part of the Thomas Range (pl. 1); it issues out at an elevation of 5,200 feet, near the contact of a thick gray rhyolite with Lake Bonneville sediments. Its discharge measured on June 22, 1955, was 0.68 gallons per minute. The water is cold and has a brackish taste due to its high salt content (table 3). Dissolved substances total 4,014 ppm, most of which is Cl, Na, Ca, and SO_4. According to P. F. Fix (1955, oral communication), water of this nature is not uncommon in areas containing Lake Bonneville sediments, and represents water that has circulated through evaporites or other beds of high salinity, such as marl. The water at Wildhorse Spring is collected in a storage tank that is connected to a watering trough.

Straight Canyon Spring (pl. 1) lies 1¼ miles west-northwest of the canyon's mouth in a southwest-trending branch of the canyon; it is on the east side of the canyon about 20 feet above the bottom at an elevation of about 5,560 feet, and appears to be on a small fault zone. The water seeps out into a small pool about 8 feet across, and its rate of flow is difficult to estimate. Little or no runoff was observed from the pool when it was visited on September 8, 1956. The rate of flow is therefore probably not much larger than that of Hangrock Spring.

A fourth spring lies just west of the mapped area about midway between the Black Rock Hills and Dugway Range. It is called Salt Spring on the old Fish Springs quadrangle map. At present it consists of a shallow excavation into which water seeps out of the Lake Bonneville marls.

A potential source of water was discovered during exploration for uranium at the Good Will uranium property in The Dell. Diamond-drill holes reached water within 50 feet of the surface.

All the mines on Spor Mountain are dry, and only two of those examined in the Dugway district, the Four Metals and Bertha, contained any water. Water level in the Four Metals mines is just below the 270-foot level at an elevation of approximately 4,745 feet.

VEGETATION

The vegetation in this region is of two types: that of the flats and that of the mountains.

The flat lands and wide valleys are covered with a low sagebrush-type vegetation, which, owing to the lack of water, averages only about 1 foot in height, although along washes it may be 2 or 3 feet high. This flora includes several kinds of sagebrush (*Artemesia* sp.), Brigham's tea (*Epehdra nevadensis*), shadscale (*Atriplex confertifolia*), gray molly (*Kochia vestita*), and some bunch grasses. Rabbit brush (*Chrysothamnus* sp.) grows along some of the washes.

The mountains, in general, are characterized by somewhat larger plants. With the exception of rabbit brush, the plants of the flats are all present, though less abundant. In addition, juniper (*Juniperus utahensis*) and mountain mahogany (*Cercocarpus ledifolius*) are common throughout the region, and creosote bush (*Larrea* sp.) is common in the Dugway Range. The junipers range in height from a few to about 30 feet, and average about 8 feet. Owing to the rather limited range in elevations in these mountains, no distinct floral zones are apparent, though a few piñon pines (*Pinus edulis*) near the top of Topaz Mountain and on the upland in the northern part of the Thomas Range may represent a separate floral zone.

PREVIOUS WORK

The earliest reports on geology of the Thomas and Dugway Ranges are by Henry Engelmann, geologist for Captain J. H. Simpson's expedition across the Great Basin in 1859 (Simpson, 1876, p. 325–326), and by G. K. Gilbert (1875, p. 27, 119), attached to Lieutenant G. M. Wheeler's survey west of the 100th meridian. Engelmann briefly discussed the topaz from the Thomas Range; Gilbert, who went through Dugway Pass, mentioned the volcanic rocks and Paleozoic sedimentary rocks in the vicinity.

The Thomas Range has been a favorite mineral collector's locality since the topaz was first reported by Engelmann. Associated with the topaz in a few places are bixbyite, pink beryl, specularite, garnet, and pseudobrookite. These minerals have been the subject of numerous papers (Alling, 1887; Buranek, 1947; Cross, 1886; Hillebrand, 1905; Ives, 1947; Jones, 1895; Kunz, 1885, p. 738; 1893, p. 764; Montgomery, 1934, 1935; Pabst, 1938; Palache, 1934; Patton, 1908; and Penfield and Foote, 1897). Butler and Heikes briefly described the Dugway mining district of the northern part of the Dugway Range in a report on the ore deposits of Utah (Butler, Loughlin, Heikes, and others, 1920, p. 458–463). Ives (1946a, p. 839–844) has given a very brief description of the part of the Dugway mining district called Kellys Hole.

The discovery of fluorspar on Spor Mountain in 1936 eventually attracted considerable attention to that part of the Thomas Range. Between 1948 and 1950 the geology of this area was studied and some of the area mapped by W. P. Fuller for North Lily Mining Co., J. J. Beeson for Geneva Steel Co., and James Quigley for Chief Consolidated Mining Co. The first published report on this district is a brief description of some of the mines by Fitch, Quigley, and Barker (1949, p. 63–69).

In August and September 1950, Staatz, V. R. Wilmarth, and H. L. Bauer, Jr., who were investigating uranium resources in western Utah for the U.S. Geological Survey, mapped most of the fluorspar mining properties by planetable and telescopic alidade on scales of 1 inch to 40 feet and 1 inch to 50 feet. The results of this work were published in a report on fluorspar deposits of Utah (Thurston, Staatz, Cox, and others, 1954, p. 24–45). This preliminary study revealed many new problems on the stratigraphy and structure of the area and their relation to the ore deposits. To study these problems Staatz and F. W. Osterwald of the Survey started a two-year program in 1951 during which the geology of an area of 34 square miles surrounding and including Spor Mountain was mapped (Staatz and Osterwald, 1956, p. 131–136; 1959).

Bauer [1] mapped and described the mines and the areal geology of part of the northern end of Spor Mountain during the fall of 1951.

PRESENT WORK AND ACKNOWLEDGMENTS

The present work is a study of one and one-third 15-minute quadrangles, embracing an area of about 315 square miles. The map of 34 square miles previously made on Spor Mountain (Staatz and Osterwald, 1959, pl. 1) is incorporated in pl. 1. Fieldwork took 9½ months and was done at various times between October 1954 and October 1956. Mapping was done directly on topographic maps at a scale of 1:24,000 and later reduced to 1:31,680 for the final map. Detailed maps of the surface workings at a few of the smaller mining properties were made by tape and Brunton compass; other mines were mapped with planetable and telescopic alidade. Underground workings were mapped with tape and Brunton compass on scales of 1 inch to 20 feet or 1 inch to 40 feet. More than three hundred thin sections of the fine-grained volcanic rocks were studied.

A report of this type involves the help of many people who have given advice, suggested procedures, made analyses, and identified fossils. The writers wish to extend their appreciation to their colleagues in the U.S. Geological Survey for the help received. Among those who were particulrly helpful are M. D. Crittenden, R. K. Hose, T. S. Lovering, and H. T. Morris, who aided in the correlation of the stratigraphy with the surrounding areas, J. W. Adams for aid in mineralogic procedures, and C. W. Merriam for aid in the Devonian stratigraphy.

The writers want to acknowledge the whole-hearted cooperation of the miners and property owners in the Thomas Range fluorspar district. Particular thanks are due to Faye Spor, Ray Spor, George Spor, Al Willden, F. B. Chesley, C. D. Searle, and T. A. Claridge, all of Delta, Utah, and L. N. Rasmussen of Salt Lake City. We are also indebted to the following operators, owners, and geologists for history, production records, and assay figures on the Dugway mining district: G. W. Smith of Stockton, Utah; T. P. Costas of Park City, Utah; Dr. J. F. Cannon and L. K. Requa of Salt Lake City; S. R. Wilson of the U.S. Bureau of Mines, and W. P. Hewitt of the American Smelting and Refining Co.

[1] Bauer, H. L., Jr., 1952, Fluorspar deposits north end of Spor Mountain, Thomas Range, Juab County, Utah: Univ. Utah, Master's thesis.

This investigation was made on behalf of the Division of Raw Materials of the United States Atomic Energy Commission.

GENERAL GEOLOGY

The rocks in the Thomas and Dugway Ranges have an age spread of from Cambrian to Recent. About half the area within the two ranges is underlain by Tertiary volcanic rocks and about half by Paleozoic sedimentary rocks. The basins surrounding the ranges are filled chiefly with Lake Bonneville gravel and marl of Pleistocene age. The Paleozoic sedimentary rocks include 26 formations ranging in age from Early Cambrian to Late Mississippian, and have a total thickness of at least 30,000 feet. The Prospect Mountain quartzite, at the base of the section, makes up at least 12,000 feet; the rest of the Paleozoic rocks consist chiefly of limestone and dolomite with lesser amounts of quartzite, siltstone, and shale. A summary of these formations is given in table 4. In addition to the 26 formations some rocks in the Black Rock Hills are described under Upper Devonian sedimentary rocks, undivided (p. 61–64).

The Paleozoic rocks are overlain by Tertiary volcanics which are divided into two groups. The older group is exposed chiefly in low-lying hills adjacent to the main volcanic mass and as intrusive bodies in the Paleozoic sedimentary rocks. The following 10 units are distinguished in the older volcanic group: rhyodacite; rhyodacite breccia and associated tuffs; plagioclase crystal tuff; black glass welded tuff; sanidine crystal tuff; quartz-sanidine crystal tuff; vitric tuff; red vitric tuff, conglomerate, and sandstone; porphyritic rhyolite; and intrusive breccia. The younger volcanic group unconformably overlies the older and makes up the greater part of the volcanic rocks exposed. This group consists of at least five overlapping units each made up of a sequence of vitric tuff, breccia and rhyolite; the rhyolite makes up at least 95 percent of each unit. All three rocks are cut by green glass intrusives that probably formed in and near volcanic vents.

Three small sandstone units of varying composition are interbedded with the volcanic rocks and appear to be deposits formed in small lakes.

Quaternary rocks consist largely of thick deposits of sand, gravel, clay, and marl laid down in Lake Bonneville, but also include a thin local cover of Recent alluvium.

Rocks of Paleozoic age in the Thomas and Dugway Ranges in general strike north or northeast and dip at moderate angles to the west. The Paleozoic rocks are much faulted, particularly on Spor Mountain and

TABLE 4.—*Summary of the Paleozoic sedimentary rocks of the Thomas and Dugway Ranges*

Age	Formation	Thickness (feet)	General description
Upper Mississippian.	Ochre Mountain limestone.	470+	Medium-gray limestone with some interbeds of dark-gray dolomite.
	Woodman formation.	785	Upper half is thin-bedded light-gray silty limestone. Lower half is thin-bedded reddish-brown calcareous siltstone.
Lower Mississippian ———?———	Madison limestone equivalent.	315	Medium-gray limestone with some chert in upper part, and a few beds containing quartz sand in lower part in some places.
Upper Devonian	Hanauer formation.	480–730	Light- to dark-gray dolomite with a little light-gray limestone at the top, interbedded with brown-weathering gray to white dolomitic quartzite.
	Gilson dolomite	915–1,310	Light- to dark-gray dolomite with some beds containing numerous *Amphipora*.
	Goshoot formation.	390	Light- to dark-gray dolomite interbedded with brown-weathering dolomitic quartzite.
	Engelmann formation.	2,750+	Massive sandy-textured light-gray to black dolomite with some interbeds of light-gray to black limestone in lower half of the formation.
Middle Devonian ———?——— Lower(?) Devonian	Sevy dolomite	1,120	Fine-grained thin- to medium bedded mouse-gray laminated dolomite.
Middle Silurian	Thursday dolomite.	330	Thick-bedded light-gray sandy-textured medium-grained dolomite.
	Lost Sheep dolomite.	215–270	Upper part is gray dolomite containing numerous small parallel bands of gray or pink chert. Lower and middle parts are light-gray sandy-textured dolomite with some blue-gray mottled dolomite and one thin bed of black cherty dolomite.
	Harrisite dolomite.	110–175	Massive dark-gray sandy-textured dolomite containing numerous poorly preserved *Halysites*.
	Bell Hill dolomite.	340–430	Upper part is light-gray fine-grained dolomite. Lower part is massive dark-gray sandy-textured dolomite. Middle part on Spor Mountain is similar to lower part, but in the Dugway Range the middle part is interbedded with light-gray dolomite.
	Floride dolomite.	100–135	Thin-bedded, fine-grained, smooth-weathering gray dolomite and calcareous dolomite.
———?——— Upper Ordovician	Fish Haven dolomite.	225–310	Upper one-third is massive black mottled dolomite. Lower two-thirds is slope-forming thin- to medium-bedded smooth-weathering dolomite.
Middle Ordovician.	Swan Peak formation.	440–840	Upper one-half to two-thirds is thick-bedded white vitreous quartzite. Lower one-third to one-half is brownish-green shale interbedded with thin beds of hematitic red quartzite, limestone, and a little dolomite.
Lower Ordovician.	Garden City formation.	1,725	Upper one-quarter is gray thin-bedded nodular limestone and tan- to pink-weathering medium-bedded limestone with a few beds of green shale. Lower three-quarters is gray thin-bedded limestone with numerous thin beds of intraformational conglomerate.
Upper Cambrian.	Dugway Ridge dolomite.	885	Light- to dark-gray thick-bedded sandy-textured dolomite, which contains, in the eastern Dugway Range, a few beds of light-gray limestone near the top.

TABLE 4.—*Summary of the Paleozoic sedimentary rocks of the Thomas and Dugway Ranges*—Continued

Age	Formation	Thickness (feet)	General description
Upper Cambrian—Continued	Fera limestone	280–400	Upper one-fourth is thin-bedded gray limestone with silty partings. Lower three-quarters is a light-gray to pink, locally mottled limestone with minor dolomite.
	Straight Canyon formation.	360–390	Medium-gray thin- to medium-bedded limestone with massive gray medium-grained dolomite common, especially in the upper part.
	Lamb dolomite	865–1, 010	Upper one-fourth is reddish-weathering thin-bedded gray limestone with a thin-bedded red-brown calcareous quartzite at the top. Lower three-fourths is massive gray dolomite with a conspicuous zone of *Girvanella* at the base.
Middle Cambrian.	Fandangle limestone.	1, 670	Upper one-third is blue-gray thin-bedded to medium-bedded limestone interbedded with white-weathering light-gray laminated limestone with a few thin beds of intraformational conglomerate at the top. Lower two-thirds is blue-gray medium-bedded to massive limestone.
	Trailer limestone.	385	Upper two-thirds is dark blue-gray thin-bedded argillaceous limestone containing numerous worm trails. Lower one-third is a dark blue-gray massive limestone.
	Shadscale formation.	520	Upper three-fourths is a blue-gray fine-grained limestone interbedded with grayish-green shale. Lower one-fourth is brown-weathering grayish-green micaceous siltstone with orange-brown weathering cream-colored dolomite at the base.
Lower Cambrian.	Busby quartzite.	160	Brown-weathering greenish-gray quartzite overlain by a dark-brown-weathering green micaceous siltstone.
	Cabin shale	135–145	Brown-weathering green flaggy micaceous siltstone interbedded with brown-weathering white vitreous quartzite and minor greenish-brown shale.
	Prospect Mountain quartzite.	12, 000+	White to purple well-bedded quartzite with some quartz-pebble conglomerate beds. Parts of this formation contain beds of greenish shale, siltstone, and shaly quartzite interbedded with gray quartzite.

in the western part of the Dugway Range. Folding is unimportant, although there is one gentle syncline in the northeastern part of the Dugway Range. Three general groups of faults can be distinguished: (1) thrust faults, which are few in number and are the oldest, (2) normal and reverse faults of diverse trends, which are numerous and generally of small displacement, and (3) north- and northwest-trending Basin and Range faults, which are large and probably the youngest.

SUMMARY OF GEOLOGIC HISTORY

The geologic history of the sedimentation, volcanic activity, structure, and ore deposits of the Thomas and Dugway Ranges is discussed in greater detail in the sections on these subjects; only a brief summary of the major geologic events is given here.

The oldest rocks exposed in the area belong to the Prospect Mountain quartzite of Early Cambrian age, but rocks of Precambrian age may be included in this formation. The great thickness of this formation (12,000 feet) and the presence of ripple marks, raindrop prints, and crossbedding suggest that the sediments were deposited in a shallow but rapidly sinking basin. Sediments similar to those deposited throughout Prospect Mountain time formed the Cabin shale and Busby quartzite in late Early Cambrian time.

An abrupt change to a carbonate facies began in Middle Cambrian time and carbonate deposition continued virtually uninterrupted until Middle Ordovician time. During this interval a thick sequence of limestone and some dolomite layers were formed. Some of the beds were laid down in shallow water, as indicated by the intraformational limestone conglomerate beds in the Fandangle limestone and particularly in the Garden City formation.

During Middle Ordovician time, clay, silt, and sand were deposited to form the Swan Peak formation. Between the time the Swan Peak formation was laid down and the end of Middle Devonian, another thick sequence of carbonate rocks was deposited; these rocks are chiefly detrital dolomite and are commonly crossbedded. The dolomite is believed to have formed from limestone sand that was reworked in shallow water prior to consolidation.

The Upper Devonian rocks, which are mainly dolomite and dolomite interbedded with quartzite, are commonly crossbedded and many times thicker than rocks of similar age in adjoining regions. This suggests that the original sediments were deposited in a small, rapidly sinking basin.

During Mississippian time limestone, some siltstone, and some dolomite were deposited.

Uplift and erosion occurred after the deposition of these rocks. Regional compression probably in Cretaceous or early Tertiary time formed the small Buckhorn syncline and several thrust faults. There followed a period of uplift and tension, during which hundreds of diversely oriented normal faults were formed.

The older group of volcanic rocks was emplaced, probably in Miocene time beginning with intrusion of rhyodacite and followed by extrusion of porphyritic rhyolite and various kinds of welded tuffs. Basin and Range faulting may have begun during the later part of this volcanic episode.

In probable Pliocene time additional uplift and tilting were accompanied by Basin and Range faulting, which produced a number of large north- and northwest-trending faults. During this last major period of uplift and faulting, the ranges were raised to their present height.

After most of the faulting had ended, the rocks were eroded and then were partly covered by volcanic rocks of the younger group. Fluorspar and uranium deposits in the Thomas Range were formed probably late in this period of volcanism.

Half of the limestone in the Dugway Range was hydrothermally altered to dolomite. Following this alteration, lead-zinc-copper-silver deposits in the Dugway Range were formed, possibly at the same time as the fluorspar deposits, but there is little evidence of their exact age.

In postvolcanic time minor movement occurred along a few faults. Lake Bonneville covered the area between the ranges up to an elevation of about 5,200 feet in Pleistocene time. Gravel, sand, and marl were deposited in this lake, and wave-cut benches representing stillstands of the lake were cut at many places along its edge. Gradually the lake dried up, and in Recent time a thin layer of alluvium was deposited in most of the valleys.

ROCKS OF CAMBRIAN AGE

Cambrian sedimentary rocks are well exposed in the Dugway Range and were first mentioned by Gilbert (1875, p. 27), who crossed them at Dugway Pass. He found no fossils, but, because of stratigraphic similarities to rocks elsewhere in the Great Basin, believed these rocks to be Silurian. A brief description of part of the sequence in the Dugway mining district was given by B. S. Butler (Butler, Loughlin, Heikes, and others, 1920, p. 460). Although quartzite and carbonate rocks of Cambrian age are present in this complexly faulted mining district, the only fossils found by Butler were Mississippian in age. A reconnaissance map of west-central Utah compiled by the Intermountain Association of Petroleum Geologists (1951, pl. 2) indicates the Dugway Range to be made up of Ordovician and Silurian sedimentary rocks.

Cambrian rocks make up about 70 percent of the sedimentary sequence in the Dugway Range and form all of its steep east front. Cambrian rocks crop out also in large areas on the western side of Fandangle Canyon and along the main divide in the north-central part of the range. A small patch of Upper Cambrian rocks is exposed at the south end of the Thomas Range.

The Cambrian system has been divided into nine formations in the East Tintic Mountains (Morris and Lovering, 1961, p. 13–53) and the Gold Hill mining district (Nolan, 1935, p. 4–16) and into 11 formations in the House Range (Walcott, 1908, p. 173–185). All these areas have nearly complete Cambrian sections, yet different formation names were used in each. Sections have been described by Gilluly (1932, p. 7–20) in the Stockton and Fairfield quadrangles and Drewes and Palmer (1957, p. 104–120) in the southern Snake Range, and again, except for the basal quartzite and shale units, separate sets of names were used in each of these places also. In a few places such as the East Tintic Mountains and Stockton and Fairfield quadrangles, some of the same stratigraphic units are recognizable and the same names might have been used. Most areas, however, either are stratigraphically dissimilar or, where they appear similar, contain fossils that indicate the units are of different ages. In general, however, sequences of Cambrian rocks in the eastern Great Basin are all characterized by a basal quartzite unit overlain by a thick carbonate section with small shale interbeds.

In detail the Cambrian section differs from range to range, primarily because of differences in the distribution of shale and dolomite. Shale is most abundant in the section immediately above the basal Tintic or Prospect Mountain quartzite (figs. 2 and 3) and forms much of the Pioche, Cabin, and Ophir formations. Fossils indicate that the upper parts of these formations are of different ages. Above the lower shale unit only a few minor shale beds are found in the Gold Hill district, the East Tintic Mountains, and the Stockton and Fairfield quadrangles. Conspicuous shale-bearing units, however, are found stratigraphically higher in other areas: Chisholm shale (early Middle Cambrian) in the Pioche district (Westgate and Knopf, 1932, p. 11); the Wheeler formation (middle Middle Cambrian), and Orr formation (early Late Cambrian) in the House Range (Walcott, 1908, p. 176–177, 191); the Secret Canyon shale (late Middle Cambrian) and Dunderberg shale (Late Cambrian) in the Eureka district (Nolan, Merriam, and Williams, 1956, p. 16, 19); and the Lincoln Peak formation (Middle and early Late Cambrian) and Corset Springs shale (Late Cambrian) in the southern part of the Snake Range (Drewes and Palmer, 1957, p. 113–116) (figs. 2 and 3).

Dolomite units of Cambrian age are rather discontinuous and appear to be most common in the mining districts, where most of the early work was concentrated. H. T. Morris (1956, oral communication) pointed out that many of the units such as the

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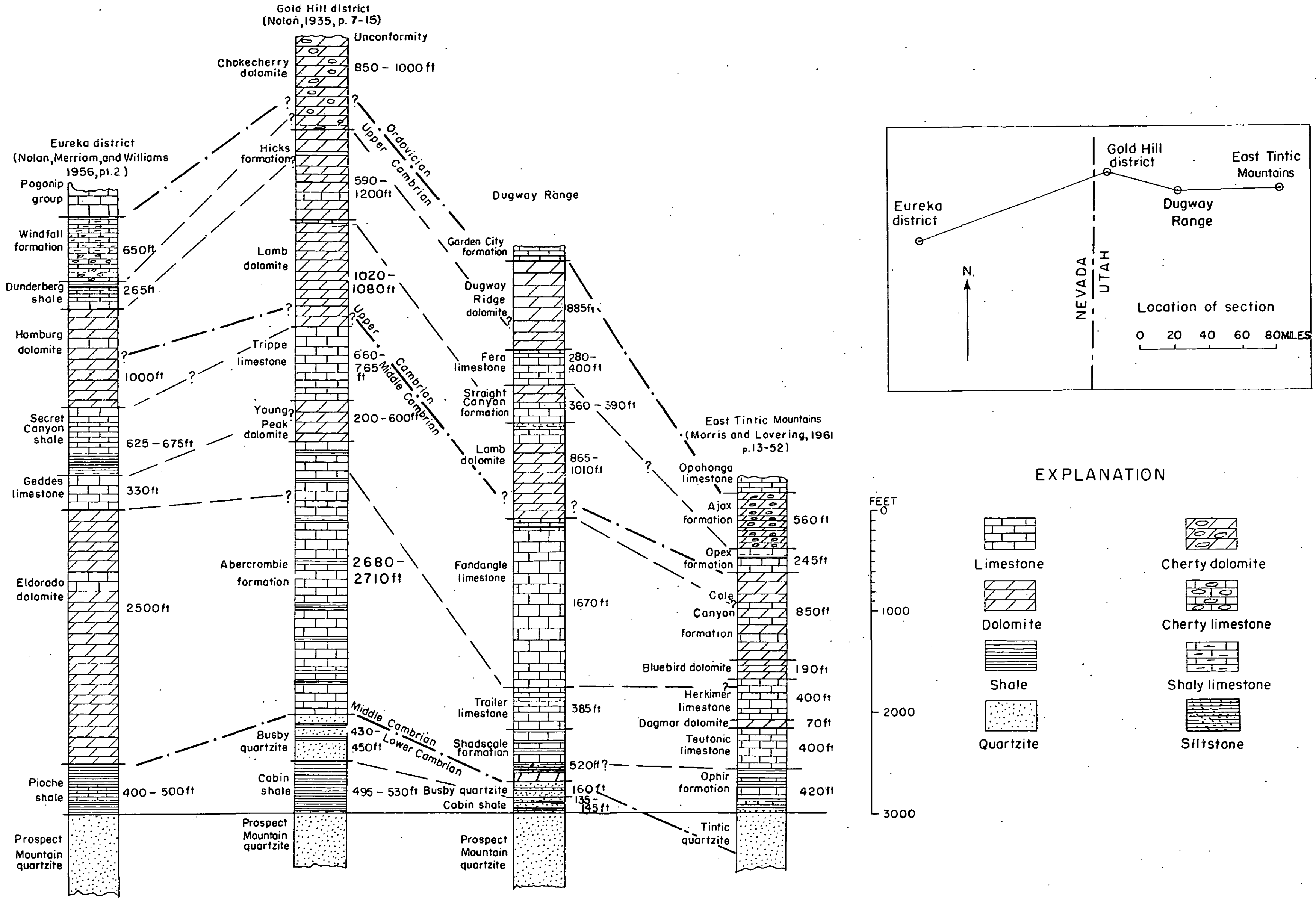


FIGURE 2.—Stratigraphic sections of Cambrian rocks of western Utah and eastern Nevada in a west-east direction through the Dugway Range.

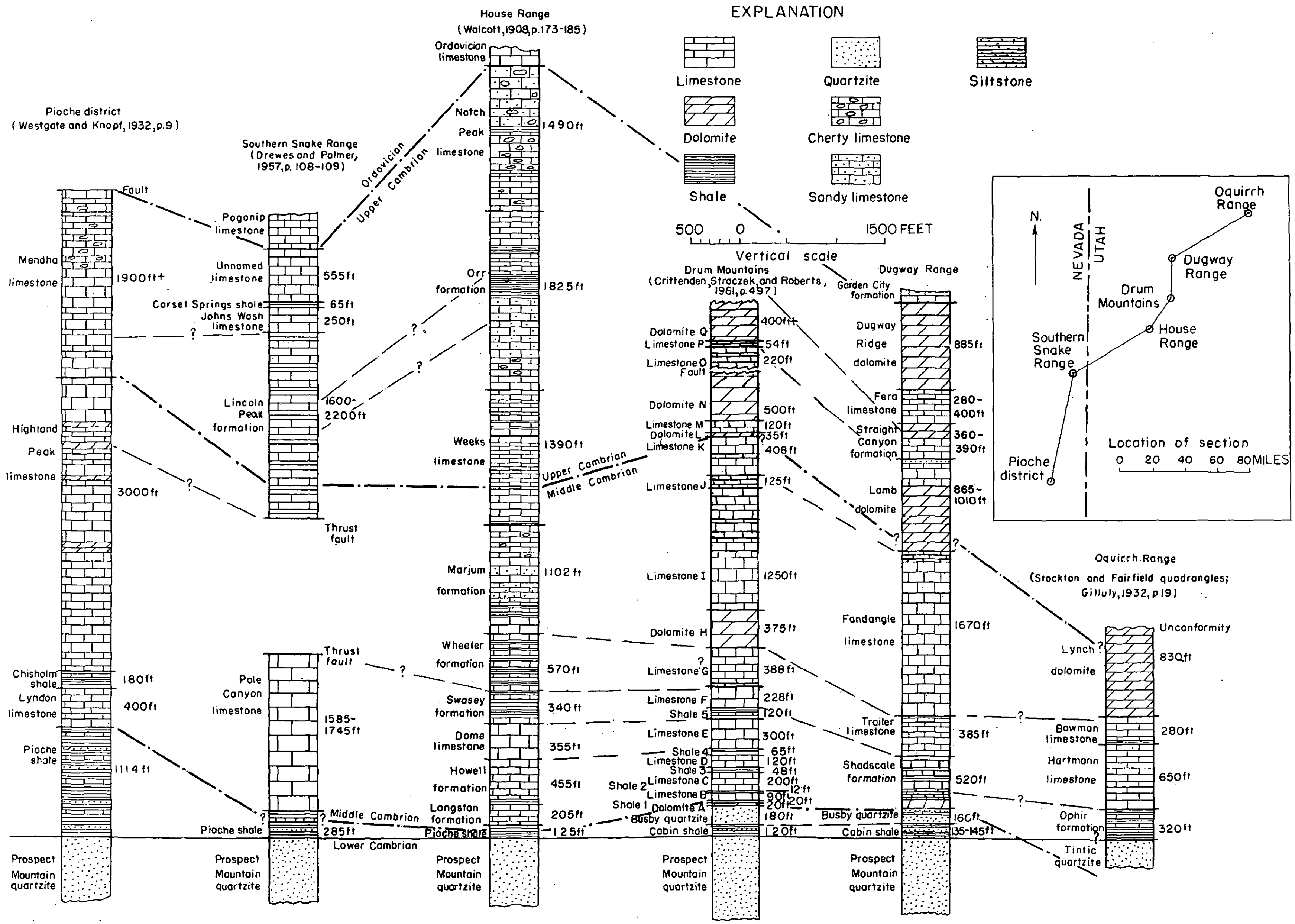


FIGURE 3.—Stratigraphic sections of Cambrian rocks of western Utah and eastern Nevada in a southwest-northeast direction through the Dugway Range.

Bluebird and the Cole Canyon mapped as dolomite in the Tintic and East Tintic mining districts are largely limestone in the outlying areas. The prominent dolomite H described by Crittenden, Straczek, and Roberts (1961, p. 501–502) in the Drum Mountains is represented in the Dugway Range by massive limestone. In the Dugway Range, much of the dolomite is clearly formed by hydrothermal alteration (see p. 71–72), and most, if not all, the dolomite units in surrounding areas also are probably formed by hydrothermal alteration. Because of regional changes in lithology, correlation of the various units rests largely on faunal evidence.

The Cambrian sedimentary rocks in the Dugway Range are here divided into 10 formations: the Prospect Mountain quartzite, the Cabin shale, the Busby quartzite, the Shadscale formation, the Trailer limestone, the Fandangle limestone, the Lamb dolomite, the Straight Canyon formation, the Fera limestone, and the Dugway Ridge dolomite. Six formational names, Shadscale, Trailer, Fandangle, Straight Canyon, Fera, and Dugway Ridge, are new. These new formations were set up because exact stratigraphic equivalents do not exist in other formations in the surrounding area. The rock units exposed in the Dugway Range correlate most closely with those in the Drum Mountains described by Crittenden, Straczek, and Roberts (1961, p. 496–503). Because their paper deals mainly with the manganese deposits, no formal names were given to their formations but the units were lettered and numbered. The Lower and Middle Cambrian series in the Dugway Range also correlates fairly well with the rocks in the Gold Hill district described by Nolan (1935, p. 4–15), and four of the formations in the Gold Hill district are recognized in the Dugway Range. Above the Lamb dolomite, however, the rocks of the Gold Hill district show little resemblance to those in the Dugway Range. The Young Peak dolomite in the lower part of the carbonate sequence at Gold Hill is not found in the Dugway Range. The base of the Young Peak dolomite is approximately equivalent to the contact of the Fandangle and Trailer formations, but the base of the Young Peak has a variable position in the Gold Hill district. It was mapped on the lowest dolomite bed in the southern part of its exposure and on a massive limestone unit in the northern part. As pointed out by Nolan (1935, p. 10), owing to the successive lensing out of lower dolomite beds, the base of the dolomite is represented by successively higher beds to the north and is, therefore, neither synchronous nor continuous.

Correlations of the Cambrian of the Dugway Range with Cambrian rocks of other districts in Utah and Nevada are shown diagrammatically in figures 2 and 3. The lowest stratigraphic unit in all these sections is a thick quartzite. A part of this unit is covered in all places except the East Tintic Mountains (Morris and Lovering, 1961, p. 10–13), and therefore the sections were constructed using the top of the quartzite as a base line. This base line probably is not a time line, inasmuch as the Chisholm shale in the Pioche district, which is approximately 1,500 feet above the basal quartzite, is equivalent in age to the Ophir formation in the East Tintic Mountains, which directly overlies the quartzite. The basal quartzite probably transgresses eastward with time, as suggested by Wheeler and Beesley (1948, p. 78–85). The sections, therefore, represent the Cambrian sequence laid down after the deposition of the basal quartzite.

Several regional relations are brought out by these sections. Figure 2, an east-west cross section, illustrates thinning of the sequence to the east of the Gold Hill district as the east edge of the Cambrian geosyncline is approached.

The Cambrian sequence also thins to the west of the Gold Hill district toward the center of the geosyncline near Eureka, Nev. The westward thinning is mainly in the Lower and Upper Cambrian rocks.

As shown in figure 3, a southwest-northeast cross section, the Middle Cambrian rocks are of fairly uniform thickness and the Lower Cambrian rocks thin moderately to the northeast. A much greater thinning is noted in the Upper Cambrian rocks, which are thickest in the House Range and which thin in both directions. Gilluly (1932, p. 18) suggested that the Cambrian geosyncline has a general north-northeast trend. This line of sections (fig. 3) cuts the trend of the geosyncline at a small angle, and hence the differences in thicknesses in the various sections may be due in part to local variations in sedimentation.

PROSPECT MOUNTAIN QUARTZITE (LOWER CAMBRIAN)

The Prospect Mountain quartzite of Early Cambrian age is the oldest formation exposed in the mapped area. It was named by Hague (1883, p. 254) from exposures on Prospect Peak in the Eureka district, Nevada. The Prospect Mountain quartzite is the most widespread Cambrian unit in this part of the Great Basin. It has also been described in the Pioche district, Nevada (Westgate and Knopf, 1932, p. 6–8); in the Chief district, Lincoln County, Nev. (Callaghan, 1936, p. 8–9); near Delamar, Nev. (Callaghan, 1937, p. 15–17); near Groom, Nev. (Wheeler, 1948, p. 20); in the southern Snake Range, Nevada

(Drewes and Palmer, 1957, p. 107–110); the Gold Hill district, Utah (Nolan, 1935, p. 4–60); in the Wah Wah Range, Utah (Walcott, 1908, p. 184); and in the Drum Mountains, Utah (Crittenden, Straczek, and Roberts, 1961, p. 496–498).

Most of the exposures of the Prospect Mountain quartzite in the mapped area are in the Dugway Range, where it forms steep-sided ridges as much as 1,200 feet high in the northwest part of the range (pl. 1 and fig. 48). Quartzite also crops out in an area of more than a mile square in the northeast corner of the Dugway Range, and small hills of quartzite occur along the east side of the Dugway Range between Shadscale Canyon and a point 1 mile north of Trailer Wash. Although the Prospect Mountain quartzite is not found in the Thomas Range, it crops out on several knolls to the northeast.

Lithology.—The Prospect Mountain quartzite is composed chiefly of white or tan massive quartzite, but it also contains purplish-red quartzite, quartz pebble conglomerate, shale, and siltstone.

The sequence of lithologic units, many of which are lenslike, varies from one fault block to another. No complete sequence exists within the mapped area, and the base of the formation is not exposed.

The part of the Prospect Mountain quartzite believed to be the oldest exposed in the area crops out on two mountains in the northeastern part of the Dugway Range just east of Fandangle Canyon (fig. 4). On the larger mountain to the north (block A), eight units were mapped. These are shown on figure 4. The lithology of the units is as follows, beginning with the oldest: (1) medium-bedded gray quartzite with interbedded greenish-brown quartzitic shales, (2) white to tan thick-bedded quartizte, (3) olive-green quartzitic micaceous shale and shaly quartzite interbedded with gray-green thick- to medium-bedded medium- to fine-grained quartzite, (4) massive white fine-grained quartzite, (5) olive-green fissile shale with 1- to 4-foot interbeds of dark brown-weathering quartzite, (6) massive light-gray to brownish-green quartz pebble conglomerate with spherical to ellipsoidal pebbles, which range from $\frac{1}{8}$ to $1\frac{1}{2}$ inches in diameter and make up from less than 1 to 75 percent of the rock, (7) slaty sericitic shale, which is olive-drab in the lower part and green in the upper part, capped by 10 to 20 feet of dark purplish-red thin-bedded sericitic siltstone, and (8) coarse-grained crossbedded violet hematitic quartzite with numerous lenses of conglomerate. Conglomeratic beds of unit 8 contain numerous quartz and red jasper pebbles.

On the smaller mountain (block B, fig. 4) to the south, three units were mapped: (1) 1- to 2-foot beds of hematitic brown and white fine- to medium-grained quartzite interlayered with about 25 percent drab olive-brown quartzitic shale in 1- to 6-inch beds, (2) vitreous white to light-gray and brown, massive fine- to coarse-grained quartzite, and (3) medium-bedded gray quartzite interbedded with greenish-brown quartzitic shales. Unit 3 in block B probably correlates with unit 1 in block A.

The largest area underlain by Prospect Mountain quartzite is in the northwestern Dugway Range (fig. 5). In this region near Cannon Canyon and northwest of it the formation consists mainly of 4,500 feet of thick- to massive-bedded, locally crossbedded, generally fine-grained white quartzite. In some places a few lenses of coarse quartz and jasper sand and small pebbles are present. Similar quartzite forms the two ridges northeast of Kellys Hole.

The irregular fault block in the southern part of the Kellys Hole area contains the following four units from oldest to youngest, as shown on figure 5: (1) olive-green and greenish-brown micaceous siltstone and minor shale interbedded with quartzite, (2) dark hematitic red medium- to coarse-grained quartzite that weathers very dark brown and contains a few beds of green siltstone, (3) dark-green micaceous siltstone like that in unit 1, which also contains a few beds of dark-red quartzite, and (4) brownish fine-grained micaceous quartzite.

Thickness.—Rough measurements from maps indicate that nearly 12,000 feet of Prospect Mountain quartzite is exposed in the Dugway Range, but the occurrence of various lithologic units in blocks isolated by faults makes any compilation of thickness somewhat tenuous.

The base of the Prospect Mountain quartzite was not recognized in the Dugway Range, but the top is exposed on the southeast side of the range and on a hill 2,000 feet southeast of the mouth of Cannon Canyon in the northwestern part of the range. In both areas only a few hundred feet of quartzite is exposed.

The thickness of the exposed Prospect Mountain quartzite was approximated by totaling the various units in the fault blocks. The thicknesses of the following general units or groups of units are given in their probable order from youngest to oldest: (1) 200+ feet of white, tan, and reddish brown quartzite (exposed beneath the Cabin shale in the southeast and northwest (pl. 1) corners of the Dugway Range), (2) 1,000+ feet of siltstone and red and brown quartzite (southern part of the Kellys Hole area, fig. 5);

(3) 4,500+ feet of white and tan quartzite (north and central parts of the area on the southwest side of Kelly Hole, fig. 5), (4) 1,600+ feet of violet quartzite (unit 8, block A, fig. 4), (5) 600 feet of shale and siltstone (unit 7, block A, fig. 4), (6) 2,400+ feet of shale, quartzitic and micaceous shale, and quarzite

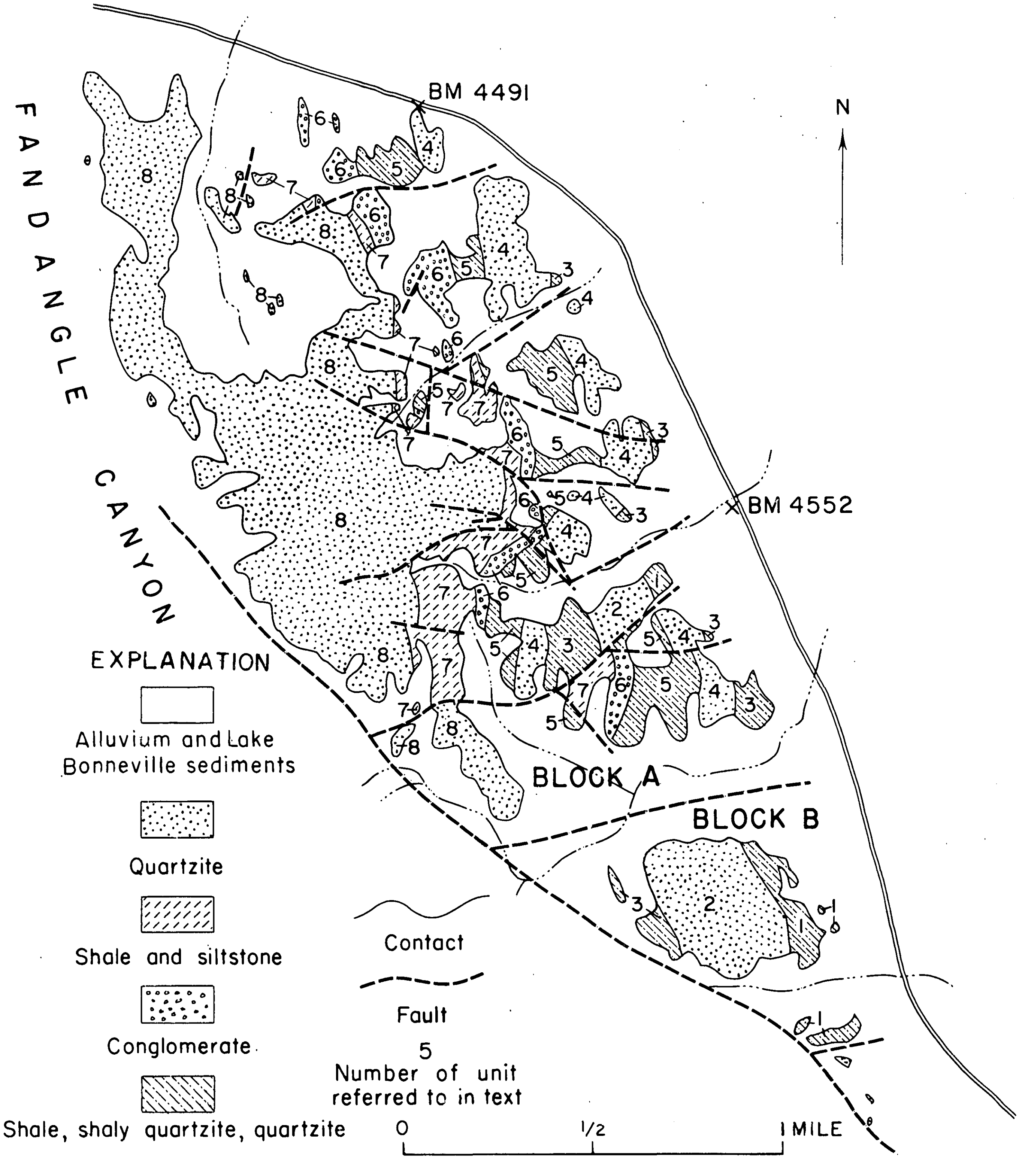


FIGURE 4.—Distribution of rock types in the Prospect Mountain quartzite in the northeast part of the Dugway Range.

and conglomerate (units 1 through 6, block A, fig. 4a), (7) 1,500 feet of gray quartzite (unit 2, block B, fig. 4), (8) 300 ± feet of quartzite and quartzitic shale (unit 1, block B, fig. 4).

Probably no significant repetition of beds is included in the estimates of thickness given above, but the possibility must be considered. It is possible, but unlikely, that unit 8, block A and the massive quartzite in the vicinity of Cannon Canyon on the southwest side of Kellys Hole are partly or wholly equivalent; it is also possible that units 1 to 4 in the southern part of the Kellys Hole area are duplicated in part by block B and units 1 through 7 of block A. Furthermore, the massive quartzite in the Cannon Canyon area may include some of the quartzite beds that underlie the Cabin shale at the southeast corner of the Dugway Range. If all such possible duplication is excluded, the exposed thickness of Prospect Mountain quartzite would be about 9,300 feet. (This estimate does not allow for undetected faulting in the massive white and purple quartzite beds). Actually it is more likely that the section is correct and that the exposed Prospect Mountain is nearly 12,000 feet thick.

Age and correlation.—No diagnostic fossils have been found in the Prospect Mountain quartzite in this area or elsewhere, but in western Utah and eastern Nevada it is overlain, apparently conformably, by shale units of Early Cambrian age (Nolan, 1935, p. 7; Nolan, Merriam, and Williams, 1956, p. 7; Westgate and Knopf, 1932, p. 10; Walcott, 1908, p. 184). The absence of any recognizable break in sedimentation and the widespread distribution of quartzite beneath these shale units have led to general agreement that at least the upper part of the Prospect Mountain quartzite is of Early Cambrian age. The great thickness, however, and the presence of thick shale units in the lower part have led others (Wheeler, 1948, p. 20) to conclude that the lower part may well be Precambrian.

The lower parts of the Prospect Mountain quartzite may be correlated with rocks of probable Precambrian age in western Utah on Fremont Island and Promontory Point (Eardley and Hatch, 1940, p. 795–843; Olson, 1956, p. 42–44), in the Cottonwood-American Fork area (Calkins and Butler, 1943, p. 7–9; Crittenden, 1955, oral communication), and in

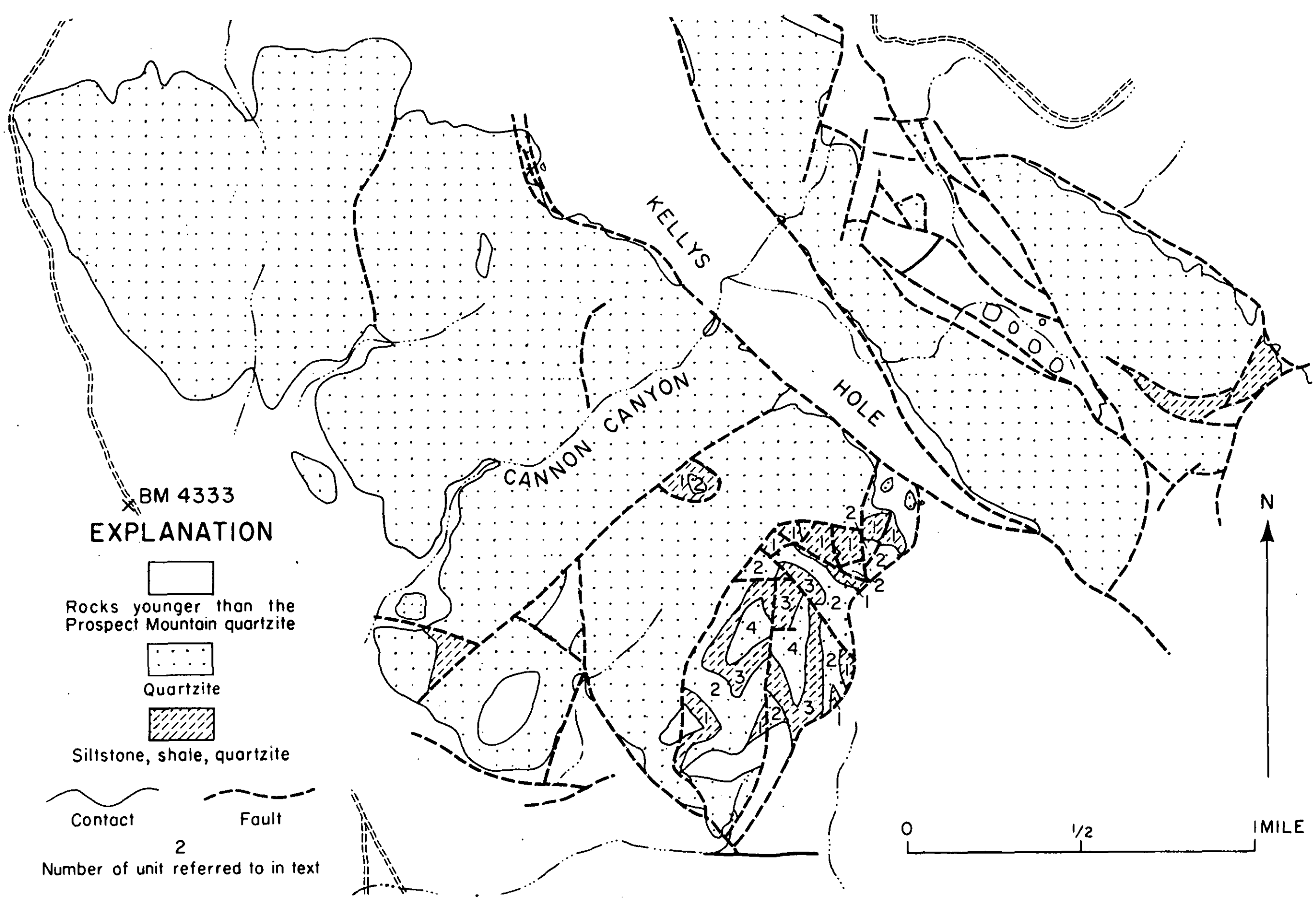


FIGURE 5.—Distribution of rock types in the Prospect Mountain quartzite in the northwest part of the Dugway Range.

the Sheeprock Range (Cohenour, 1958; Eardley and Hatch, 1940, p. 823–827).

In the East Tintic Mountains (Morris and Lovering, 1961, p. 12), Precambrian rocks are overlain disconformably by the Tintic quartzite, a stratigraphic and lithologic equivalent of the Prospect Mountain quartzite. The lower 300 feet or more of the Tintic quartzite is marked by purplish-red conglomerate containing pebbles of milky vein quartz. Quartz pebble conglomerate beds are found in the quartzite units of the Dugway Range, but most are thin and appear to be lenses of small areal extent. Furthermore, we cannot make a direct correlation of the rocks in the lower part of the Prospect Mountain quartzite in the Dugway Range with Precambrian rocks in other areas, although further work in the Sheeprock Range and in the eastern Drum Mountains to the south might make such a correlation possible. The writers conclude, therefore, that the greater part of the Prospect Mountain quartzite exposed in the Dugway Range is probably Early Cambrian in age.

CABIN SHALE (LOWER CAMBRIAN)

The Cabin shale of Early Cambrian age was originally described by Nolan (1935, p. 6–7) from its exposures in Cabin Gulch in the north end of the Deep Creek Mountains. Similar, but considerably thinner rocks in the Drum Mountains, have been described by Crittenden, Straczek, and Roberts (1961, p. 498), and the name is here applied to another similar greenish-gray shaly unit that overlies the Prospect Mountain quartzite along the east side of the Dugway Range.

The Cabin shale is exposed on Bittner Knoll, on the small hill 1.2 miles southeast of Bittner Knoll, along the east side of the Dugway Range in a series of low-lying hills between Shadscale Canyon and a point 0.9 of a mile north of Trailer Wash, and in a small outcrop on the west side of the Dugway Range west of the south end of Kellys Hole (pl. 1).

Lithology.—The Cabin shale in the Dugway Range consists of interbedded brown-weathering green siltstone, quartzite, and minor shale. The base of the formation is placed at the base of the lowest green siltstone above a massive red-weathering quartzite bed at the top of the Prospect Mountain quartzite. The top of the Cabin shale is placed at the base of a dark red-weathering quartzite that marks the bottom of the Busby quartzite.

The Cabin shale consists of (1) drab green flaggy siltstone and a little shale with a few beds of faintly laminated, gray-green dense feldspathic quartz siltstone or very fine grained sandstone and (2) prominent thin ledges of quartzite. The siltstone beds are commonly 1 to 5 inches thick and have partings marked by abundant fine flakes of muscovite. The siltstone generally weathers greenish brown. In two thin sections this rock was seen to consist of about 70 to 85 percent quartz, 15 percent feldspar, 3 to 15 percent muscovite and chlorite, a little clay, a few metamorphic rock grains, and trace amounts of spinel, magnetite, tourmaline, and zircon. The quartz and feldspar grains are very well sorted, subangular fragments that average about 0.08 mm in diameter. Much of the feldspar is microcline, but some orthoclase and plagioclase are present. Muscovite and chlorite occur in thin flakes parallel to the bedding; the slight concentrations of these mineral layers gives the rock faint megascopic laminations.

In some areas the quartzite beds are most numerous in the central part of the Cabin shale, but in others they are scattered throughout the entire formation. They are composed either of gray-green fine-grained, slightly calcareous quartzite containing a little muscovite and interbedded with subsidiary green micaceous siltstone or of brown fine-grained vitreous quartzite. A fairly typical section of the Cabin shale in one of its best exposed areas is given below.

Section in Cabin shale on small hill 1.2 miles southeast of Bittner Knoll

	Thickness (feet)
Busby quartzite: Quartzite, fine-grained, vitreous, brown; weathers reddish brown; beds ¾ to 1½ feet thick.	
Cabin shale:	
1. Siltstone, gray-green; partly covered	20
2. Quartzite, vitreous, fine-grained, light-brown; weathers dark-brown; forms distinct ledge	2
3. Siltstone, micaceous, gray-green; includes one 0.6-ft quartzite bed	35
4. Quartzite, vitreous, fine-grained, white; weathers brown	4
5. Covered; siltstone float	10
6. Quartzite, medium-grained, vitreous, brown	1
7. Siltstone and shale, greenish-brown, micaceous; in part fissile; partly covered	13
8. Quartzite, medium-grained, white; weathers brown	1
9. Siltstone and shale, like unit 7	28
10. Quartzite, fine-grained, light-brown to gray; weathers dark brown	2
11. Siltstone, micaceous, gray-green; weathers deep brown	12
12. Quartzite, coarse-grained, vitreous, white; weathers brown	2
13. Covered; siltstone float	5
Total thickness of Cabin shale	135
Prospect Mountain quartzite: Quartzite, vitreous, white; weathers rusty brown; forms prominent ledges.	

Thickness.—The Cabin shale is poorly exposed in most places, but because it is underlain by the resistant Prospect Mountain quartzite and overlain by the equally resistant Busby quartzite, the total thickness is readily measurable. The Cabin shale is 135 feet thick on the small hill southeast of Bittner Knoll, the southernmost exposure of the unit in this area, and 145 feet thick on a low ridge along the east flank of the Dugway Range 0.7 mile north of Trailer Wash and 4.2 miles north-northwest of the first locality. The Cabin shale is slightly thicker on the east flank of the Dugway Range than in the Drum Mountains to the south, where Crittenden, Straczek, and Roberts (1961, p. 497) found 120 feet of this unit; it is much thinner in both of these places than in its type section in the northern part of the Deep Creek Range where Nolan measured between 490 and 530 feet.

Age and correlation.—No fossils were found in the Cabin shale or in the underlying Prospect Mountain quartzite or overlying Busby quartzite in the Dugway Range. In the type section in the Gold Hill district, however, a single trilobite fragment was found by Edwin Kirk somewhat above the middle of the Cabin shale and was identified by C. E. Resser as an Early Cambrian specimen (Nolan, 1935, p. 6–7). The writers examined the Cambrian section along the north side of Dry Canyon in the Gold Hill district and found that, except for thickness, the Cambrian rocks up through the Abercrombie formation (fig. 2) closely resemble those in the Dugway Range. Even though the Cabin shale in the Gold Hill district is more than three times as thick as that in the Dugway Range, the similarity of the rock sequence strongly suggests that these rocks are stratigraphically continuous and that the Cabin shale in the Dugway Range may also be Early Cambrian in age.

The lowermost unit in the East Tintic Mountains that is predominantly shale is the Ophir formation, which contains lower Middle Cambrian fossils in its lower part and is, thus, partly the age equivalent of the Shadscale formation of the Dugway Range. The Cabin may be equivalent in age to some of the upper part of the Tintic quartzite of Early Cambrian age, which underlies the Ophir and which contains micaceous shales in the upper 500 feet. The Cabin shale in the Dugway Range appears equivalent to at least the lower part of the Pioche shale in the House Range, in the Eureka district, Nevada, and in the Pioche district.

BUSBY QUARTZITE (LOWER CAMBRIAN)

The Busby quartzite was named by Nolan (1935, p. 7–8) for its exposure in Busby Canyon on the east slope of Dutch Mountain in the Gold Hill mining district. Rocks of similar lithology in the Drum Mountains are referred to the Busby by Crittenden, Straczek, and Roberts (1961, p. 498). The name is here applied to quartzite beds that occupy a similar position on top of the Cabin shale in the Dugway Range. The quartzite beds are well exposed along the east edge of the Dugway Range in a series of low hills extending from Bittner Knoll to a little north of Trailer Wash, and on the west side of the Range southwest of Kellys Hole (pl. 1).

Lithology.—The Busby quartzite in the Dugway Range consists of a lower half made up chiefly of greenish-gray to white and red quartzite and an upper half of green micaceous siltstone. The lower contact is drawn at the bottom of brown- or red-weathering quartzite that conformably overlies siltstone of the Cabin shale; the upper contact is placed at the base of a distinctive orange-weathering dolomite that marks the base of the Shadscale formation.

The basal 35 feet of the Busby quartzite is medium- to fine-grained gray, white, green, or hematitic-red quartzite that weathers dark brown or red, particularly along bedding planes. This is overlain by about 30 feet of medium- to fine-grained pale to medium greenish-gray quartzite in beds generally ½ inch to 2 feet thick. Some of these quartzite beds are calcareous and micaceous; most have a semi-vitreous luster. The quartz grains are subangular to subround, closely packed, and well sorted.

Near the middle of the formation is a transitional zone about 12 feet thick of green-gray medium-grained quartzite interbedded with green siltstone. Above these beds the formation is almost entirely thin-bedded slabby dark-green chloritic to green-gray micaceous siltstone containing clay and abundant muscovite on the partings. This siltstone has irregular wavy bedding planes. Beds in this interval are 1/16 inch to 4 inches thick; little or no fissile material is exposed. A stratigraphic section of the Busby quartzite in the area of its most complete exposure is given below.

Section of Busby quartzite on the east side of the Dugway Range, on ridge 0.7 mile north of Trailer Wash

	Thickness (feet)
Shadscale formation: Limestone, medium-grained, gray with brown dolomitic mottlings.	
Busby quartzite:	
1. Covered	13
2. Siltstone, micaceous, dark-green; weathers dark brown; beds are 1/16 to 4 in. thick	28
3. Covered, siltstone float	12
4. Siltstone, micaceous, green; beds as much as 1 in. thick	12

Section of Busby quartzite on the east side of the Dugway Range, on ridge 0.7 mile north of Trailer Wash—Continued

Busby quartzite—Continued	Thickness (feet)
5. Siltstone, green-gray; weathers dark brown	21
6. Quartzite, medium-grained, green-gray; interbedded with a little green siltstone	12
7. Quartzite, medium-grained, somewhat limy, green-gray; weathers dark brown; beds are ½ in. to 2 ft thick	28
8. Quartzite, fine-grained, massive, greenish-white, weathers brown	13
9. Covered	9
10. Quartzite, medium-grained, massive, gray to very pale green; weathers hematitic red at the base to brown at the top	12
Total thickness of Busby quartzite	160

Cabin shale: Siltstone, micaceous, gray-green.

Thickness.—The only place where the upper and lower contacts of the Busby quartzite are exposed in a single section is on the low-lying ridge 0.7 mile north of Trailer Wash where the thickness of 160 feet was measured. (See preceding stratigraphic section.) This section approximates the 180 feet recorded by Crittenden, Straczek, and Roberts (1961, p. 497) in the Drum Mountains, but is much less than the 430 to 450 feet recorded by Nolan (1935, p. 8) in the type section in the northern part of the Deep Creek Range.

Age and correlation.—No fossils have been found in the Busby quartzite or in the underlying formations in the Dugway Range. A small trilobite cranidium, similar to that of *Onchocephalus depressus* Rasetti, was found 137 feet above the top of the Busby quartzite in the Shadscale formation. This fossil has been dated by A. R. Palmer as probably Middle Cambrian, although some similar forms occurred in Early Cambrian time.

The Busby quartzite in the Dugway Range is very similar lithologically to the section in the Gold Hill district (Nolan, 1935, p. 8) even though the latter is much thicker. Moreover, in both areas the lowermost unit of the overlying carbonate rocks is a thin cream-colored orange-weathering dolomite. No unconformities either above or below the Busby quartzite are noted in either region. Nolan (1935, p. 8) found no identifiable fossils in the Busby quartzite in the Gold Hill district, but, because this unit was deposited in a shallow water environment, he favored a Middle rather than an Early Cambrian age. In the Gold Hill area, A. R. Palmer (1956, written communication) more recently collected fragments of Olenellids, which indicate that at least part of the Busby quartzite is of Early Cambrian age. The close similarity in lithology and the position between similar rock units strongly suggest that the Busby quartzite exposed in the Dugway Range is also, at least in part, Early Cambrian in age.

The Busby quartzite is probably equivalent in age to the sandy beds in the Pioche shale in the House Range and to the lower or middle part of the Pioche shale in the Pioche district and the Eureka district, Nevada (figs. 2 and 3). To the east it is probably equivalent to the uppermost part of the Tintic quartzite in the East Tintic Mountains and the Stockton-Fairfield quadrangles; in these areas no conspicuous shale separates the Lower Cambrian quartzite into two formations as in the Gold Hill district and the Dugway Range, but thin shale beds occur throughout the upper 500 feet of the Tintic quartzite.

SHADSCALE FORMATION (MIDDLE CAMBRIAN)

The Shadscale formation is here named from exposures near Shadscale Canyon which is near the southern end of the Dugway Range. This formation crops out in only a few places, generally on low-lying ridges where the formation is incompletely exposed. The largest area of outcrop is a discontinuous band 1.3 miles long, extending northward from Shadscale Canyon along the east side of the Dugway Range (pl. 1). The type section was measured in this outcrop area along a low ridge, 0.6 mile north of Trailer Wash. The Shadscale formation crops out at four other localities: (1) in several small patches 1.2 miles east of Dugway Pass, (2) in a band along the west side of the south end of Fandangle Canyon, (3) along a ridge 1.4 miles south-southeast of the Four Metals mine, and (4) in several patches on the west side of the Dugway Range west of the south end of Kellys Hole.

Lithology.—The lower one-fourth of the Shadscale formation consists of about 60 feet of dolomite overlain by about 70 feet of siltstone; the upper three-fourths is gray limestone interbedded with green shale. The bottom of the formation is marked by a distinctive unit of orange-brown-weathering dolomite which overlies the dark-green siltstone of the Busby quartzite. The upper boundary of the formation is placed at the top of the highest shale bed. Most commonly this upper shale is covered, and the upper contact is placed at the base of the massive gray limestone that marks the bottom of the Trailer limestone.

The lowest beds of the Shadscale formation are cream-colored dolomite which weathers deep orange brown. These strata usually form a ledge between partly covered slopes. In places the dolomite contains layers of medium-grained massive gray limestone mottled with brown dolomite. Locally, the alga *Girvanella* is present. This dolomite is a very distinctive and persistent unit. A thin section shows a mosaic of subhedral to anhedral dolomite crystals ¼ to 1 mm in diameter; fine-grained calcite and traces of anhedral quartz and orthoclase occur in pockets. Many of the dolomite grains have a peripheral brown iron stain and are clouded with small opaque specks.

Above the brown-weathering dolomite is about 70 feet of olive-green to green-gray dolomitic to calcitic slabby micaceous siltstone which forms beds 1 to 3 inches thick. Most of the mica is muscovite, but some beds contain a little biotite.

The upper three-fourths of the formation consists of about 75 percent fine-grained blue-gray limestone interbedded with about 25 percent gray-green chloritic shale. The shale is generally poorly exposed. The limestone contains some oolitic and some *Girvanella*-bearing beds, and on a weathered surface some of it has a ribbed or streaked appearance. The limestone units are both thin- and thick-bedded, and dull brown sandy patches are common. The interbedded fissile shale and siltstone are light gray green; some intervals show small dark blue-green spots and streaks, probably chloritic. The shale beds are generally 1/16 to ¼ inch thick. Silt-sized flakes of sericite are visible in places. Commonly near the base of this limestone-shale unit is a gradational zone about 45 feet thick of gray limestone interbedded with thin layers and lenses of micaceous siltstone. A detailed stratigraphic section of the entire formation at its type area is given below.

Type section of Shadscale formation on east side of the Dugway Range, on ridge 0.6 mile north of Trailer Wash

[Fossils identified by A. R. Palmer]

	Thickness (feet)
Trailer limestone: Limestone, fine-grained, massive, blue-gray.	
Shadscale formation:	
1. Shale, green-gray; contains apparently undescribed ptychopariid trilobites common in the Middle Cambrian series elsewhere in the Great Basin	15
2. Covered; shale and limestone float	118
3. Limestone, fine-grained, blue-gray; contains dull sandy spots	44
4. Covered; shale float containing *Glossopleura* sp	12
5. Limestone, like unit 3	22
6. Limestone; like unit 3 except crisscrossed with numerous thin white calcite stringers	12
7. Covered; abundant green chloritic shale float	45
8. Limestone, fine- to medium-grained, blue-gray; upper part streaked; three beds in lower part containing *Girvanella* sp	28
9. Limestone, fine-grained, blue-gray; interbedded with irregular thin layers of brown micaceous siltstone	46
10. Covered	16
11. Limestone, fine-grained, medium-gray	18
12. Covered	13

Type section of Shadscale formation on east side of the Dugway Range, on ridge 0.6 mile north of Trailer Wash—Continued

	Thickness (feet)
Shadscale formation—Continued	
13. Siltstone, micaceous, gray to pale-green; weathers dark brown; beds are ½ to 2 in. thick	24
14. Covered	15
15. Siltstone, like unit 13	3
16. Covered	15
17. Siltstone, like unit 13	10
18. Dolomite, fine-grained, massive, cream-colored; weathers orange brown; contains poorly preserved *Girvanella* sp	24
19. Limestone, fine-grained, light-gray; mottled with orange-brown dolomite	7
20. Dolomite; same as unit 18, but without *Girvanella* sp	4
21. Covered	27
Total thickness of Shadscale formation	518
Busby quartzite: Siltstone, micaceous, green; beds are ½ to 2 in. thick.	

Thickness.—A continuous section of the Shadscale formation is found only on a small ridge along the east side of the Dugway Range, 0.6 mile north of Trailer Wash. At this locality it is 518 feet thick. Equivalent units in the Drum Mountains 22 miles to the south, which are 995 feet thick (Crittenden, Straczek, and Roberts, 1961, p. 497), indicate considerable thickening southward.

Age and correlation.—Fossils are not abundant in the Shadscale formation, and those found are generally poorly preserved. The lowest fossil was found 137 feet above the base of the section and was identified by A. R. Palmer as a small cranidium cf. *Onchocephalus depressus* Rasetti. Palmer (1955, written communication) stated that "this small trilobite resembles species described by Rasetti from earliest Middle Cambrian beds in the Canadian Rockies. *Onchocephalus* is also found in beds of Lower Cambrian age, but the specimen in this collection is more nearly like the Middle Cambrian species than any described Lower Cambrian forms." The trilobite *Glossopleura* sp. was found in a shale bed near the middle of the Shadscale formation at one locality. Concerning this fossil Palmer (1955, written communication) stated, "* * * this is a widespread trilobite in the Early Middle Cambrian beds of the Great Basin. *Glossopleura* has been found in the lower part of the Abercrombie formation in the Gold Hill district, in the lower part of the Ophir formation in the Tintic district, and in the Howell limestone in the House Range." Trilobites were also found in two places in the uppermost shale unit of the Shadscale formation, directly below the massive limestone that marks the base of the Trailer limestone. These were described by Palmer (1955, written communication) as "small, apparently undescribed ptychopariid trilobites." He further stated that "abundant small trilobites seem to be characteristic of several intervals in the early Middle Cambrian of the Great Basin. They are usually found in the first fossiliferous horizons above beds bearing *Glossopleura*. Similar fossiliferous horizons, although apparently with different species, are found in the lower part of the Abercrombie formation in the Gold Hill district, and in the lower part of the Swasey formation in the House Range." A Middle Cambrian age is thus indicated for most of this formation, although it is possible that the lowermost part may be late Early Cambrian in age.

The sequence of limestone and shales in the Shadscale formation corresponds closely with that of dolomite A, limestones B, C, D, and E, and shales 1, 2, 3, 4, and 5 in the Drum Mountains (Crittenden, Straczek, and Roberts, 1961, p. 499–501) (fig. 3), and there is little doubt that they are correlatives. *Glossopleura* is found in shale 4 in the Drum Mountains. The stratigraphy of the Shadscale also corresponds fairly closely with the lower two-thirds of the Abercrombie formation in the Gold Hill area (Nolan, 1935, p. 8–9) which also has a cream-colored orange-weathering dolomite bed at the base. The corresponding units of the Abercrombie formation are somewhat thicker than those of the Shadscale formation. The presence of *Glossopleura* in the Pole Canyon limestone in the Snake Range (Drewes and Palmer, 1957, p. 112) indicates that the Shadscale formation is equivalent in age to at least part of this formation. The Shadscale formation is also equivalent to all or part of the following formations: the Lyndon limestone and the Chisholm shale of the Pioche district (Westgate and Knopf, 1932, p. 10–11) and the Eldorado dolomite of the Eureka district (Nolan, Merriam, and Williams, 1956, p. 9–11) (figs. 2 and 3).

TRAILER LIMESTONE (MIDDLE CAMBRIAN)

The Trailer limestone is here named from exposures in Trailer Wash in the southeastern part of the Dugway Range. This formation is best exposed in a series of low-lying hills from Shadscale Canyon to a point approximately 1 mile north of Trailer Wash (pl. 1). Although the section is complete on both sides of Trailer Wash, the type section was measured along a narrow ridge 0.6 mile north of the wash because of better exposures. The Trailer limestone also crops out at five other places: (1) a few small knolls along the east side of the Dugway Range just north of Straight Canyon, (2) several knolls about 1 mile east of Dugway Pass, (3) in a band on the west side of the south end of Fandangle Canyon, (4) on a ridge at the south end of Bullion Canyon, and (5) along two hillsides 1.4 miles south-southeast of the Four Metals mine.

Lithology.—The Trailer limestone consists of blue-gray limestone and shaly limestone. The base of the Trailer limestone is marked by a massive gray limestone, which forms a small cliff rising above the covered slope underlain by shale at the top of the Shadscale formation. The upper boundary of the Trailer limestone is placed at the base of the massive cliff formed by the resistant gray limestone in the lower part of the Fandangle limestone.

The lower 150 feet of the Trailer limestone is a massive to thick-bedded dark blue-gray limestone with a few *Girvanella* near the base, and is locally cut by stringers of white calcite.

The upper part of the Trailer limestone is dark blue-gray, very fine grained limestone. The beds are ¼ to 2 inches thick and are separated by tan or yellow argillaceous partings. In weathered surfaces the rock is somewhat lighter gray than on fresh surfaces. As a rule the beds are poorly exposed. Cylindrical structural features, possibly worm-holes, ¼ to ½ inch in diameter and as much as 1½ inches deep are found in the middle part of this unit. In plan view, the cylindrical features consist of a central core or depression surrounded by one or more concentric rings which weather in relief. These features are commonly perpendicular to the bedding and are filled with a slightly coarser grained, dark-gray limestone.

Locally, the weathered surfaces of bedding planes in the upper part of the Trailer limestone have a crinkled appearance. Another feature of this thin-bedded limestone is the presence in some places of either single or clustered small dark-brown cubes of limonite, pseudomorphous after pyrite. These cubes were also noted by the authors in equivalent units in the House Range (Wheeler formation) and in the upper part of the Abercrombie formation in the Deep Creek Range. In the Dugway Range none of the cubes found in the Trailer exceeded ⅛ inch in width, but those in the House Range are as much as ¼ inch wide.

Insoluble residue analysis of thin-bedded limestone of the Trailer yielded 10.7 percent insoluble material, of which about 90 percent was clay-size and 10 percent sand-size. The clay-size material was very dark gray, owing to the presence of finely divided organic material.

The detailed stratigraphy of the Trailer limestone at the type section is given below.

Type section of Trailer limestone on east side of the Dugway Range on ridge 0.6 mile north of Trailer Wash

[Tribolite identified by A. R. Palmer]

	Thickness (feet)
Fandangle limestone: Limestone, fine-grained, massive, light to medium blue-gray; some dark-brown chert along fractures.	
Trailer limestone:	
1. Covered	19
2. Limestone, fine-grained, medium-gray; beds ¼ to 1 in. thick	42
3. Covered; limestone float	38
4. Limestone, similar to unit 2; contains worm tubes and a tribolite cf. *Elrathia kingii* (Meek)	88
5. Covered	45
6. Limestone, fine- to medium-grained, blue-gray; beds 1 to 3 ft thick	64
7. Limestone; like unit 6 except cut by numerous thin white calcite stringers	39
8. Limestone, fine-grained, massive, blue-gray; small bed containing *Girvanella* sp. near base	49
Total thickness of Trailer limestone	384
Shadscale formation: Shale, green-gray.	

Thickness.—Two sections of the Trailer limestone were measured on low ridges on the east side of the Dugway Range, 0.6 and 0.3 mile north of Trailer Wash. These measurements were 384 and 470 feet, respectively. The rather large difference between these two measurements, only 0.3 mile apart, suggests that one of the sections may be faulted. A rough map measurement (pl. 1) of the thickness of the Trailer limestone east of Dugway Pass suggests that in this vicinity it is almost 380 feet thick. Equivalent units in the Drum Mountains, 22 miles to the south, are over 600 feet thick (Crittenden, Straczek, and Roberts, 1961, p. 502).

Age and correlation.—A few fossils were found in the upper thin-bedded part of the Trailer limestone. These include numerous worm tubes(?) and scattered tribolite fragments. A. R. Palmer (1955, written communication) stated, "Trilobites from the four collections sent us are not well preserved; however, the tails and heads seem to conform to the characteristics of *Elrathia kingii* (Meek). This species is a characteristic form of the Middle Cambrian Wheeler formation in the House Range and has also been recorded from collections by Max Crittenden from the Drum Mountains." The position of the Trailer above the Middle Cambrian Shadscale formation and approximately 2,450 feet below the early Late Cambrian fossils in the upper part of the Lamb dolomite and the presence in its upper part of a trilobite which closely resembles *Elrathia kingii* point toward a Middle Cambrian age for the Trailer limestone.

The Wheeler formation in the House Range resembles the Trailer limestone in that it contains thin-bedded dark-gray limestone but differs in containing large amounts of shale. The Trailer limestone correlates with limestone F and most of limestone G of Crittenden, Straczek, and Roberts (1961, p. 502) in the Drum Mountains.

Similar strata consisting of both a lower massive limestone and an upper thin-bedded limestone occur in the upper part of the Abercrombie formation in the Gold Hill district, but these strata are two to three times as thick as the corresponding units in the Dugway Range. The thin-bedded limestone in the Gold Hill district also contains worm trails and the trilobite *Elrathia* sp. (Nolan, 1935, p. 10). Thus, the Trailer limestone can be correlated with the upper part of the Abercrombie formation with considerable confidence.

Correlatives of the Trailer limestone in other regions are more uncertain. The Trailer is believed equivalent in part to the Herkimer limestone of the Tintic district (see fig. 2), which is correlated by Morris and Lovering (1961, p. 35) with the upper part of the Abercrombie formation. Inasmuch as the Herkimer limestone lacks fossils, this correlation is based on its stratigraphic position and lithologic similarity (for example, presence of shale bed). Other tentative correlations of the Trailer limestone are made with the Geddes limestone in the Eureka district (fig. 2), the lower part of the Highland Peak limestone in the Pioche district, upper part of the Pole Canyon limestone in the southern Snake Range, the Bowman limestone in the Stockton and Fairfield quadrangles (fig. 3), and at least part of the Maxfield limestone of the Cottonwood-American Fork area (Calkins and Butler, 1943, p. 14–19).

FANDANGLE LIMESTONE (MIDDLE CAMBRIAN)

The Fandangle limestone is here named from outcrops near Fandangle Canyon in the north-central part of the Dugway Range, where it forms a wide band along the west side of this valley for approximately 3.5 miles. A second prominent outcrop extends for 7.2 miles along the east side of the Dugway Range from a point 0.3 mile south of Dugway Pass to the large canyon 1.5 miles north of Fera Canyon. The type section was measured just north of Straight Canyon in the latter area because the section in Fandangle Canyon is partially dolomitized and the upper and lower contacts are not exposed in the same fault block. A third exposure extends 2.6 miles southeastward from the head of Bullion Canyon.

Lithology.—The Fandangle limestone is characterized by massive beds, a medium blue-gray color, and in the upper part interbeds of distinctive laminated light-gray limestone that weathers white, pink, or yellow. The base of the formation is marked by a prominent cliff of massive gray limestone above partly covered slopes underlain by the thin-bedded Trailer limestone. At the top of the Fandangle limestone is a unit of thin-bedded gray limestone containing a few beds of intraformational conglomerate. Because this unit is commonly covered, the top of the formation is placed at the base of the massive cliff-forming *Girvanella*-bearing (fig. 6) limestone or dolomite that marks the base of the Lamb dolomite.

Approximately the lower two-thirds of the formation consists of rather uniform blue-gray fine-grained massive- to medium-bedded limestone which locally has silty partings or contains a little brown chert. Some beds are mottled light and dark, and some are oolitic. The massive beds form cliffs in most areas.

About 1,100 feet above the base of the formation occur interbeds and zones of light-gray fine-grained laminated limestone that weathers white to various shades of pink and tan. Similar beds are found at intervals nearly to the top of the formation.

At the top of the Fandangle limestone is a zone about 20 feet thick, commonly represented by a covered slope, of thin-bedded gray limestone with tube- or wormlike markings on some bedding planes and thin lenses of flat-pebble intraformational conglomerate. A few feet of an olive-green fissile shale was also noted near the top of the formation in the type section. Detailed stratigraphy of this formation at its type section is given below.

Type section of Fandangle limestone along ridge on north side of Straight Canyon, east side of the Dugway Range

	Thickness (feet)
Lamb dolomite: Dolomite, massive; contains numerous *Girvanella*.	
Fandangle limestone:	
1. Limestone, blue-gray, fine-grained, thin-bedded; lower half of unit is interbedded limestone and intraformational conglomerate	63
2. Shale, olive-green, fissile; partly covered	7
3. Limestone, blue-gray, fine-grained	3
4. Covered	21
5. Limestone, blue-gray, fine-grained; medium- to thick-bedded, with a few intraformational conglomerate beds	46
6. Limestone, blue-gray, with twiglike bodies of white calcite; interbedded with light-gray finely laminated limestone and limy dolomite that weathers orange, tan, or pink	41

Type section of Fandangle limestone along ridge on north side of Straight Canyon, east side of the Dugway Range—Continued

	Thickness (feet)
Fandangle limestone—Continued	
7. Limestone, blue-gray, fine-grained, and orange-yellow fine-grained dolomite	4
8. Limestone, blue-gray to light-gray, fine-grained; lower part weathers tan and has a little intraformational conglomerate; upper part has some silty partings	12
9. Limestone, blue-gray, fine-grained; thin-bedded to massive, with some brown to pink silty partings	226
10. Limestone, light-gray, fine-grained; weathers white	7
11. Limestone, blue-gray, fine-grained, thick-bedded; partly covered	63
12. Limestone and dolomite, light-gray, finely laminated, fine-grained; unit weathers tan; some beds of blue-gray fine-grained massive, locally mottled limestone; a few small covered intervals	75
13. Dolomite, medium-grained, blotchy; secondary	45
14. Limestone, blue-gray, fine-grained; massive, with twiglike bodies of white clacite	40
15. Dolomite, tan to gray, blotchy, coarse-grained; secondary	27
16. Limestone; like unit 14, but oolitic in part and containing twiglike bodies and irregular patches of white calcite; uppermost part is mottled brown owing to incipient dolomitization; one very thin bed of light-gray fine-grained, finely laminated limestone near top of unit	256
17. Mainly covered; one unit of blue-gray fine-grained oolitic limestone containing *Girvanella* exposed; float includes blue-gray oolitic limestone and intraformational conglomerate with pebbles as much as 2 in. long	108
18. Limestone, blue-gray, fine-grained, thin- to medium-bedded, with some oolitic silty partings, chiefly in upper part	161
19. Limestone, light-gray to gray, thin-bedded, very fine grained; some silty partings and worm trails and thin beds of intraformational conglomerate	41
20. Covered	20
21. Limestone, blue-gray, fine-grained, massive; contains some oolitic beds and some irregular dark patches, numerous twiglike bodies, and stringers of white calcite in upper part of unit; faint mottling near middle of unit	186
22. Limestone, blue-gray, oolitic, thin- to medium-bedded	35
23. Limestone, blue-gray, fine-grained, massive	18
24. Covered	21
25. Limestone, blue-gray, fine-grained; thin-bedded, with silty partings	54
26. Covered	89
Total thickness of Fandangle limestone	1, 669
Trailer limestone: Limestone, gray, fine-grained, thin-bedded.	

The lithology described above is typical of the formation along the southeast front of the Dugway Range. In that area dolomite is not prevalent in the Fandangle limestone, although small blotchy patches are present in some places. West of Fandangle Canyon, however, where the formation occurs in large fault blocks, dolomitization is widespread. The dolomite is fine- to medium-grained and tan to gray, but in places it has a blue-gray cast which helps to distinguish it from the dolomite of younger formations. The boundaries of the dolomite and the limestone are very irregular in form, are sharp to gradational, and in part are controlled by minor fractures. In many places dolomitization has obscured bedding and textural features, so that the identity of the rock is uncertain.

Thickness.—Although the Fandangle limestone is one of the most widespread units in the Dugway Range, its base is exposed only in a few places. Faulting makes accurate measurements impossible in most areas. Measurement of the type section showed the Fandangle limestone to be 1,670 feet thick. Equivalent units in the Drum Mountains 25 miles to the south are 1,750 feet thick (Crittenden, Straczek, and Roberts, 1961, p. 502).

Age and correlation.—Most of the Fandangle limestone is unfossiliferous, but a few poorly preserved trilobites were found just north of Straight Canyon. A. R. Palmer (written communication, 1956) stated that the best collection, (U.S.G.S. collection 2191) which came from 815 feet above the base, "contains cranidia of a form most like a species of *Modocia*, a late Middle Cambrian or early Late Cambrian genus." The Fandangle overlies the Middle Cambrian Trailer limestone and underlies the Lamb dolomite, which contains early Late Cambrian fossils 800 feet above its base.

The Middle-Upper Cambrian boundary in the Gold Hill district was placed by Nolan (1935, p. 13) at the base of the Lamb dolomite because of the lithologic similarity of the Lamb with the overlying Hicks formation and because of the sharp change in lithology at the base of the Lamb. In the Dugway Range, however, limestone rather than dolomite overlies the Lamb dolomite, and the change in lithology is as sharp at the top of the Lamb as it is at the base. In some places in the Dugway Range the base of the Lamb dolomite is limestone, not dolomite. The presence at the top of the Fandangle limestone of the intraformational conglomerate, indicative of a shallow-water environment, and the presence in the basal bed of the Lamb dolomite of numerous *Girvanella*, also probably indicative of a shallow-water environment (Richard Rezak, 1956, oral communication), suggest that there was little change in depositional environment during emplacement of the upper part of the Fandangle or the lower part of the Lamb. Hence, the boundary between Middle and Upper Cambrian could be anywhere from near the base of the Fandangle limestone to just below the early Late Cambrian fossils in the upper part of the Lamb dolomite. The presence of early Late Cambrian fossils in the upper part of the Lamb suggests that the base of the Upper Cambrian may be not far below, perhaps in the lower part of the Lamb dolomite. It seems likely, therefore, that the Fandangle limestone is all Middle Cambrian.

The Fandangle limestone resembles closely part of the sequence exposed in the Drum Mountains and correlates with dolomite H, limestone I, and limestone J of Crittenden, Straczek, and Roberts (1961, p. 502). The Fandangle limestone also correlates fairly well with the upper part of the Abercrombie formation, the Young Peak dolomite, and the Trippe limestone in the Gold Hill district (fig. 2). The Fandangle limestone tentatively correlates with the lower part of the Cole Canyon dolomite, the Bluebird dolomite, and possibly a little of the upper part of the Herkimer limestone in the East Tintic district (fig. 2); with the Marjum and Weeks limestone in the House Range (fig. 3); with the upper part of the Geddes limestone, the Secret Canyon shale, and the lower part of the Hamburg dolomite in the Eureka district, Nevada (fig. 2); and with the Highland Peak limestone in the Pioche district (fig. 3).

LAMB DOLOMITE (UPPER CAMBRIAN)

The Lamb dolomite was named by Nolan (1935, p. 12–13) from outcrops in Lamb Gulch on the north side of Dry Canyon in the northern part of the Deep Creek Mountains. Rocks of similar lithology and age in the Dugway Range are correlated with the Lamb dolomite of the Gold Hill district. The Lamb crops out in four areas: (1) along the steep east face of the Dugway Range between Dugway Pass and a large canyon 1.5 miles north of Fera Canyon, (2) at the south end of Fandangle Canyon, (3) about 1 mile west of Fandangle Canyon, and (4) in several patches, mainly along the ridge tops, 1 to 2 miles south of the south end of Bullion Canyon.

Lithology.—The Lamb dolomite may be divided into two parts: the lower three-fourths is chiefly gray massive dolomite with abundant pisolitelike algae, *Girvanella* (fig. 6), at the base; the upper fourth is pink- or red-weathering thin-bedded gray limestone having red-brown limy quartzite at the top.

The lowermost 250 feet of the formation is characterized by medium-grained massive dolomite, which generally weathers tan and has local banding and

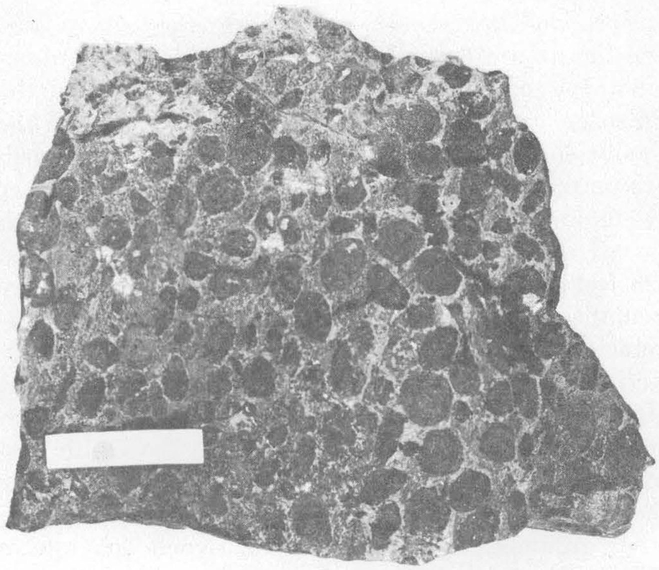


FIGURE 6.—*Girvanella*, a type of algae, from the Dugway Ridge dolomite. Similar types occur at the base of the Lamb dolomite and elsewhere in the Cambrian rocks. White bar is 1 inch long.

numerous beds containing *Girvanella* (fig. 6) ranging from 1/8 to 3/4 inch in diameter. These algae commonly show a concentric structure. In most places a cliff-forming unit of massive dark-gray limestone or dolomite as much as 40 feet thick, with abundant *Girvanella*, is present at the base of the formation. Locally this unit may be much thinner or even absent, and in some places is represented by tan dolomite; but in mapping, the *Girvanella* zone was found to be a rather reliable marker of the base of the formation. The thin-bedded limestone at the top of the underlying Fandangle limestone usually forms a covered slope beneath this massive unit.

A thin section of a specimen of gray tan-weathering dolomite in the *Girvanella* zone collected in the central part of the Dugway Range shows a rock made up almost entirely of a mosaic of anhedral to euhedral dolomite crystals averaging about .05 mm across. About 40 percent of the slide consists of nearly circular areas about 0.7 mm in diameter, each composed of a dolomite crystal surrounded by a thin ring of dusky fine-grained carbonate, possibly calcite. In hand specimen, small dark, closely spaced grains of dolomite surrounded by shallow pits in the lighter tan matrix give the weathered surface of the rock a "pepper and salt" texture. These grains, the circular areas seen in thin section, are probably small altered *Girvanella*.

Above the zone in which *Girvanella* are common, there is typically about 450 feet of massive light- to dark-gray sandy-textured dolomite with a few thin zones of thin-bedded fine-grained gray dolomite or limestone.

The upper 250 feet of the formation is commonly stained red and can be easily distinguished from a distance. In most places this zone is predominantly gray to pinkish-gray thin-bedded flaggy limestone containing local thin quartzite layers. Bedding planes commonly are stained reddish brown. A few beds, particularly toward the bottom of the zone, are of thin- and massive-bedded medium-grained pink or tan dolomite; in one place there are a few small intraformational conglomerate layers. In the upper part of the zone, quartz sand becomes more abundant, and at the top of the formation are two units 5 to 15 feet thick of thin-bedded red-brown calcareous quartzite separated by about 5 feet of gray, commonly brown-weathering thin-bedded limestone. The quartzite is micaceous in places and commonly has fucoidlike tubes on the bedding planes. In some places there are concentric reddish bands of iron-stain. A thin section of the quartzite contained about 65 percent of very fine to fine-grained angular well-sorted quartz sand in a calcareous cement, mostly calcite. Bent muscovite flakes between the quartz grains made up about 3 percent of the slide. An insoluble residue analysis of a similar specimen yielded 54 percent fine-grained quartz sand.

The Lamb dolomite varies considerably in lithology along strike because the rock is extensively dolomitized. Beds which in places are entirely tan dolomite may show an abrupt lateral change to almost unaltered gray limestone (fig. 16). The basal *Girvanella* zone is dolomite in one place, limestone in another. Dolomitization also extended irregularly across the upper part of the formation into the Straight Canyon formation. Like the dolomite in the Fandangle limestone, the dolomitized part of the Lamb exhibits few original textural features; its presence apparently is controlled in detail by bedding planes and minor fractures and is definitely related to faults. A relatively undolomitized section of the Lamb dolomite follows.

Section of Lamb dolomite on east side of the Dugway Range on ridge 1.2 miles northeast of Dugway Pass

[Fossils identified by A. R. Palmer]

	Thickness (feet)
Straight Canyon formation: Limestone, medium-grained, light to medium-gray; in part mottled.	
Lamb dolomite:	
1. Quartzite, fine-grained, limy, pinkish-gray; weathers red; beds are 1/4 to 2 in. thick and contain fucoids on undersides of some pieces	2
2. Limestone, medium-grained, massive, medium-gray	6
3. Quartzite, like unit 1	18
4. Limestone; like unit 2 except contains bands with quartz sand	7

Section of Lamb dolomite on east side of the Dugway Range on ridge 1.2 miles northeast of Dugway Pass—Continued

Lamb dolomite—Continued	Thickness (feet)
5. Quartzite, like unit 1	4
6. Limestone, medium-grained, massive, gray to pinkish-gray; has a little reddish-brown chert along bedding planes and fractures; contains *Hyolithes* sp., *Kinsabia* sp., and *Semicircularea* sp	54
7. Limestone, fine-grained, thin-bedded, gray to pinkish-gray; bedding planes are commonly stained red; quartz sand common in layers toward the bottom; several small intraformational conglomerate beds are present	130
8. Dolomite, medium-grained, sandy-textured, light- to medium-gray; calcite common along fractures	6
9. Covered	32
10. Limestone, fine-grained, dark-gray; thin irregular stringers of brown chert along fractures and bedding planes	34
11. Dolomite, medium-grained, sandy-textured, medium- to dark-gray; some layers faintly mottled; stringers of white calcite and dolomite common in some places	35
12. Limestone, fine-grained, dark-gray; some layers have irregular brown sandy-textured patches of dolomite	19
13. Dolomite, medium- to coarse-grained, sandy-textured, medium- to dark-gray; interbedded with some fine-grained light-gray dolomite near the bottom; contains numerous irregular stringers and in some places irregular masses of white and pink dolomite and white calcite	239
14. Covered	21
15. Dolomite, fine-grained, dark-gray; beds are 2 to 6 in. thick	13
16. Covered; gray limestone float	3
17. Dolomite, medium-grained, medium-gray; weathers tan; a few darker beds; some beds contain numerous *Girvanella* sp.; *Hyolithes*? sp. noted 90 feet from base	205
18. Dolomite, medium-grained, medium- to light-gray; all beds contain numerous *Girvanella* sp	38
Total thickness of Lamb dolomite	866
Fandangle limestone: Covered, fine-grained, blue-gray limestone float.	

Thickness.—The Lamb dolomite is completely exposed at numerous places along the entire east side of the Dugway Range and along part of the west side of Fandangle Canyon. It is 865 feet thick on a ridge 1.2 miles northeast of Dugway Pass, and 1,010 feet thick 3 miles north on a ridge 0.9 mile south of Straight Canyon. Equivalent units in the Drum Mountains are approximately 1,300 feet thick according to Crittenden, Straczek, and Roberts (1961, p. 502), although some repetition is possible. Nolan (1935, p. 13) gave similar thicknesses for the Lamb dolomite in the Deep Creek Mountains, where in three areas the unit is 1,080, 1,035, and 1,020 feet thick.

Age and correlation.—Although the algae *Girvanella* sp. are extremely common in the Lamb dolomite, the occurrence of this fossil throughout the Paleozoic section and its widespread occurrence in the Cambrian in the eastern part of the Great Basin province make it of little aid in specific dating. Other fossils are rare in the Lamb dolomite, but some with curved triangular-shaped cross sections were collected 128 feet above the base of the formation. These were examined by A. R. Palmer (1955, written communciation) who stated that they are "* * * cross-sections of objects that may be *Hyolithes*. Almost identical-appearing samples have been collected from near the top of the Lynch dolomite in the Ophir district; however, a correlation with the Lynch dolomite should only be suggested if it appears probable on other grounds." Inasmuch as the Lynch dolomite is Middle(?) and Late Cambrian and these *Hyolithes*(?) come from near its top, the lower part of the Lamb is probably of Late Cambrian age.

Fragmentary remains of other fossils were collected 800 feet above the base of the formation 6,100 feet northeast of Dugway Pass. These were identified by A. R. Palmer (1955, written communication) as *Hyolithes* sp., *Semicircularia* sp., and *Kinsabia* sp.

According to Palmer, these fossils are early Late Cambrian (Dresbach) in age. Fossils in the overlying Straight Canyon formation are also of early Late Cambrian age.

The upper part of the Lamb dolomite appears to correlate with the lower part of the Opex formation in the East Tintic Mountains, and it is quite probable that the lower part correlates with the upper part of the underlying Cole Canyon formation, which in turn is equivalent to part of the Lynch dolomite (Morris and Lovering, 1961, p. 43).

The resemblance of the Lamb dolomite in the Dugway Range to the type section of this formation in the north end of the Deep Creek Range (Nolan, 1935, p. 12–13) is remarkable. In both places, the base is marked by a conspicuous *Girvanella* zone; the bulk of the rock is massive drab sandy-textured dolomite; the upper part contains thin-bedded limestone, or dolomite, and the top is marked by reddish-weathering fine-grained calcareous quartzite or sandstone which contains some mica. The units that lie below the Lamb dolomite in the north end of the Deep Creek Range are similar lithologically to those occurring in the Dugway Range.

The Lamb dolomite corresponds lithologically in the Drum Mountains with units described by Crittenden, Straczek, and Roberts (1961, p. 502) as limestone K, dolomite L, limestone M, dolomite N, and limestones O and P.

Correlation with units in other areas is not so positive and is based primarily on the position of units relative to fossil-bearing horizons. Tentative correlation is made to part of the Weeks limestone in the House Range (fig. 3), part of the Mendha limestone in the Pioche district (fig. 3), and part of the Hamburg dolomite in the Eureka district (fig. 2).

STRAIGHT CANYON FORMATION (UPPER CAMBRIAN)

The Straight Canyon formation is here named from outcrops near Straight Canyon on the east-central side of the Dugway Range. The type section was measured along the ridge 1 mile south of Straight Canyon. This formation is well exposed along the east side of the Dugway Range from Dugway Pass to the large canyon 1.5 miles north of Fera Canyon. It is also exposed in a discontinuous band 1 to 2 miles west of the south end of Fandangle Canyon and on several knolls about 1 mile southeast of Dugway Pass.

Lithology.—The Straight Canyon formation consists chiefly of gray and pinkish-gray limestone and some tan-weathering gray dolomite. The lower contact of the formation is at the bottom of the first gray limestone or dolomite bed above the reddish-brown quartzite that marks the top of the Lamb dolomite. The upper contact is at the top of a zone of yellow or red limestone and dolomite and at the base of the first massive white limestone bed of the Fera limestone.

The lower two-thirds to three-fourths of the formation is medium-grained gray to dark-gray thin- to medium-bedded limestone that is locally mottled light and dark in streaks parallel to the bedding. Some of these beds are sandy textured or have reddish brown sandy patches on the bedding planes. Nodular irregular bedding is common in this interval.

The upper third to one-quarter of the formation consists of massive gray medium-grained dolomite that generally weathers tan, and black to gray fine-grained thin- to thick-bedded limestone locally stained red or light yellow on bedding planes. At the top of the formation is a 15- to 20-foot zone of yellow, pink, and reddish-brown fine-grained limestone and dolomite. Locally the uppermost bed is a distinctive purplish-gray or orange dolomite commonly with dark red-brown irregular mottles more or less parallel to bedding. The weathered surface of this rock is purplish tan with streaks of very fine quartz sand.

Like the underlying Lamb dolomite, the Straight Canyon formation has been subjected to all degrees of dolomitization. Commonly dolomite extends irregularly upward from the Lamb into the lower part of the Straight Canyon and in some places the formation is entirely dolomite. Where the rock has been altered to dolomite, primary structures, particularly bedding, are commonly obliterated. Dolomite occurs as irregular islands in limestone, and limestone as irregular islands in dolomite. Islands of dolomite in limestone are well exposed about 1 mile northeast of Dugway Pass (fig. 17). Apparently some of the mottling in limestone there and elsewhere represents an initial or incipient stage of dolomitization in which the gray limestone becomes tan and dolomitic in appearance, but still gives moderate effervescence with dilute hydrochloric acid. A stratigraphic section through one of the least dolomitized areas is given below.

Section of Straight Canyon formation on the east side of the Dugway Range on ridge 1 mile south of Straight Canyon

[Fossils identified by A. R. Palmer]

	Thickness (feet)
Fera limestone: Limestone, fine-grained, white; contains stylolites; beds are 1 to 5 ft thick.	
Straight Canyon formation:	
1. Dolomite, fine-grained, limy, orange	3
2. Limestone, fine-grained, finely laminated, pink; contains streaks of yellow dolomite	11
3. Limestone, fine-grained, medium-gray, thick-bedded	35
4. Limestone, fine-grained, medium-gray; beds are ¾ to 4 in. thick; bedding planes are commonly stained red; contains trilobite *Aphelaspis* sp. at base	24
5. Dolomite, medium-grained, massive, medium-gray; upper part weathers light tan	60
6. Limestone, medium-grained, sandy-textured, medium-gray, with darker gray mottlings	49
7. Limestone, fine-grained, medium-gray; contains trilobite *Crepicephalus* sp	36
8. Limestone, like unit 6	62
9. Limestone, fine-grained, medium-gray; beds ⅓ to ¾ in. thick; contains the trilobites *Crepicephalus* sp., *Llanoaspis* sp., and *Tricrepicephalus* sp	3
10. Limestone, like unit 6	24
11. Limestone, fine-grained, medium- to dark-gray; contains the trilobites *Crepicephalus* sp. and *Tricrepicephalus* sp	16
12. Limestone, like unit 6	30
13. Limestone, medium-grained, massive, medium-gray	16
Total thickness of Straight Canyon formation	369
Lamb dolomite: Quartzite, fine-grained, limy, gray; weathers red; beds are ¼ to 2 in. thick.	

Thickness.—The Straight Canyon formation was measured at three places along the east side of the Dugway Range. It is 390 feet thick on a ridge 1.3 miles north-northeast of Dugway Pass, 370 feet thick on a ridge 1 mile south of Straight Canyon, and 360 feet thick on the ridge north of Straight Canyon.

Age and correlation.—The Straight Canyon formation has been dolomitized or partially dolomitized in most places, and fossils are found only in those places where the limestone is unaltered. A. R. Palmer examined and identified the fossils collected from the formation and indicated that they are early Late Cambrian in age.

The gastropod *Semicircularea* sp. was found about 5 feet above the base of the formation at one place in the southern part of the Dugway Range. Trilobites are fairly common from this point to about 175 feet above the base of the formation, and the following types were identified:

Crepicephalus sp.
Llanoaspis sp.
Blountia sp.
Coosella sp.
Deiracephalus cf. *D. aster* (Walcott)
Meteoraspis sp.
Tricrepicephalus sp.
Coosina sp.

Palmer (1955, written communication) stated that "the trilobites in these collections are characteristic of the *Crepicephalus* zone of early Late Cambrian age, and fossils of similar age have been collected from the Opex formation in the Tintic district and the Weeks and lower Orr formations in the House Range."

The trilobite *Aphelaspis* sp. was found 300 feet above the base of the formation. Palmer (1955, written communication) stated that, "this trilobite is characteristic of the *Aphelaspis* zone at the top of the early Late Cambrian. It has been collected from the upper part of the Opex dolomite in the Tintic district, and from the middle of the Hicks formation in the Gold Hill district."

The Straight Canyon formation is thicker bedded, coarser grained, and darker colored than the Opex formation. The base of the Straight Canyon formation is probably younger than the lower 100 to 200 feet of the Opex in the East Tintic Mountains, and the top few feet of the Straight Canyon is probably younger than the top of the Opex.

The Straight Canyon formation resembles the Hicks formation of the Gold Hill district only in that both overlie the red quartzitic beds that mark the uppermost part of the Lamb dolomite. They differ in that the Hicks formation is approximately four times as thick, consists mainly of dolomite, and includes equivalents of part or all of the Fera limestone and perhaps part of the overlying Dugway Ridge dolomite. The Straight Canyon formation corresponds to dolomite Q in the Drum Mountains (Crittenden, Straczek, and Roberts, 1961, p. 502).

This formation is also equivalent, at least in part, to the Hamburg dolomite of the Eureka district (fig. 2), the Mendha limestone of the Pioche district (fig. 3), and the St. Charles limestone (Deiss, 1938, p. 1123–1124) of northern Utah.

FERA LIMESTONE (UPPER CAMBRIAN)

The Fera limestone, here named from its occurrence at Fera Canyon, crops out in a continuous band along the east side of the Dugway Range from a point 0.1 mile north of Dugway Pass to the valley 1.5 miles north of Fera Canyon. The type section is on the prominent ridge 1 mile south of Straight Canyon. The Fera limestone is also found (1) as prominent outcrops in a discontinuous band about 1.5 miles west of the southern part of Fandangle Canyon, (2) in a few small scattered outcrops a little over 1 mile southeast of Dugway Pass, and (3) in a narrow band trending northward from the north end of Green Grass Valley to the south end of Fandangle Canyon.

Lithology.—In general, the lower three-fourths of the Fera limestone consists of very light gray to pink locally mottled limestone and minor tan dolomite, and the upper one-fourth of thin-bedded banded gray limestone. The base of the formation is marked by 30 feet of massive white limestone; the top of the formation is the top of the highest banded limestone beneath massive Dugway Ridge dolomite.

At the base of the formation is about 120 feet of light-gray or pink to nearly white, fine- to medium-grained thick-bedded limestone that locally contains stylolites. Above these beds are about 90 to 140 feet of light-gray to gray and pink limestone and a few zones of tan dolomite. Near the center a few feet of a laminated fissile light-green shale commonly is present.

The upper part of the Fera limestone, about 100 feet thick, is thin- to medium-bedded fine-grained gray limestone with yellow, pink, and tan clayey partings. This unit contains numerous trilobites and brachiopods. Outcrops are distinguished by their slabby "flagstone" character and the "ribbon" appearance due to the light-colored partings. Locally the top 25 feet consists of gray fine-grained dolomite, but the thin beds serve to separate it from the overlying massive gray dolomite of the Dugway Ridge dolomite. The uppermost of these beds at places are finely laminated calcitic dolomite with some pink or purplish gray staining. The type section of the Fera limestone is given below.

Section of the Fera limestone on the east side of the Dugway Range, on a ridge 1 mile south of Straight Canyon

[Fossils identified by A. R. Palmer]

	Thickness (feet)
Dugway Ridge dolomite: Dolomite, medium-grained, dark-gray; weathers medium-gray.	
Fera limestone:	
1. Limestone, fine-grained, medium-gray; beds ½ to 2 ft thick; tan clay partings between beds	26
2. Limestone, fine-grained, medium-gray; beds are 1 to 5 in. thick; clayey partings along bedding planes are pink and yellow; unit contains conaspid trilobites and the brachiopods *Billingsella* sp. and *Eoorthis* sp	67
3. Limestone, coarse-grained, pinkish-gray; beds are ¼ to 3 ft thick; indeterminate trilobite fragments	107
4. Limestone, fine-grained, medium-gray	6
5. Covered; float shows green fissile shale is present	32
6. Limestone, like unit 4	9
7. Dolomite, fine-grained, massive, light-tan	4
8. Limestone, like unit 4	1
9. Dolomite, like unit 7	7
10. Limestone, fine-grained, light pinkish-gray; partly covered	18
11. Limestone, coarse-grained, medium-gray, tinged with pink; *Girvanella* sp., *Paterina* sp., and linguloid brachiopods near middle of unit	71
12. Limestone, fine-grained, massive, white	14
13. Limestone, fine-grained, pink; beds are 1 to 2 ft thick	9
14. Limestone; like unit 12 except beds are 1 to 5 ft thick	30
Total thickness of Fera limestone	401
Straight Canyon formation: Dolomite, fine-grained, limy, orange.	

Thickness.—The thickness of the Fera limestone was measured at three places along the east side of the Dugway Range, where the formation is best exposed. It is between 365 and 395 feet thick on a ridge 1.3 miles north-northeast of Dugway Pass, where the top of the Fera limestone is partly covered, 400 feet thick on a ridge 1 mile south of Straight Canyon, and 280 feet thick on the ridge that forms the north side of Straight Canyon. The thin northernmost section is only a mile from the thickest section; this may be explained by the presence of (1) a strike fault, (2) a regional unconformity, or (3) a facies change. The area north of Straight Canyon is well exposed and contains few faults, and no signs of an unconformity were noted; thus, the difference in thickness appears most likely to be due to a local facies change.

Age and correlation.—Fossils are abundant in some parts of the Fera limestone and indicate that its age ranges from early Late Cambrian to middle Late Cambrian. The lowest fossils found in the Fera limestone came from a coarse-grained medium-gray limestone bed, 84 feet above the base of the formation. These fossils were identified by A. R. Palmer (1955, written communication) as *Paterina* sp. and linguloid brachiopods. Palmer stated, "*Paterina* is a rather distinctive genus of phosphatic brachiopods that is not known at present to range above beds of late Dresbach (early Late Cambrian) age. However, the range of small phosphatic brachiopods such as these is still poorly known, and I would not like to exclude the possibility that this collection could be early Franconia (earliest medial Late Cambrian) in age." Some *Girvanella* sp. occur in a few places above the *Paterina* sp., but this alga is found throughout the Cambrian rocks in the Dugway Range. Fossils are most common in a fine-grained thin-bedded medium-gray limestone unit with grayish-yellow and pink silty partings, which occurs between 307 and 375 feet above the base of the formation. Fossils are generally so common in this unit throughout the Dugway Range that it is easily recognizable and highly useful as a marker bed. The following fossils were identified by Palmer from six collections from this unit in the upper part of the formation:

Conaspid trilobites
Brachiopods:
- *Billingsella* sp.
- *Eoorthis* sp.
- Conodonts

Palmer (1955, written communication) stated, "These six collections all seem to contain the same fauna. This is of medial Late Cambrian (Franconia) age. *Eoorthis* has been collected from beds that are 30 feet below the Emerald marker and about 60 feet from the base of the Ajax dolomite in the Tintic district." At the time Palmer examined these collections, no conodonts had been described from the Cambrian. Later, however, Muller (1956, p. 1336) examined the fossil material in these collections, as well as similar ones from other districts. He believed that they contain true conodonts.

Rocks of the same age as the Fera limestone occur between Red Pine Mountain and Lookout Pass in the Sheeprock Range, 40 miles east of the Dugway Range. These rocks are chiefly thin-bedded shaly limestone. Fossils collected from them by Robert Cohenour and identified by Palmer contain both the brachiopod *Billingsella* sp. and conodonts(?) similar to those found in the Dugway Range. Both *Billingsella* sp. and *Eoorthis* sp. have been reported from the St. Charles limestone in Blacksmith Fork in northern Utah (Walcott, 1908, p. 192–193); *Billingsella* sp. also has been noted in the unnamed limestone that overlies the Corset Springs shale in the southern Snake Range, Nevada (Drewes and Palmer, 1957, p. 116); *Eoorthis* sp. has been found in the Notch Peak limestone in the House Range (Walcott, 1908, p. 175). The Fera limestone is also equivalent in part to the Mendha limestone of the Pioche district (fig. 3) and to basal limestone of the Windfall formation of the Eureka district, Nevada (fig. 2).

DUGWAY RIDGE DOLOMITE (UPPER CAMBRIAN)

The Dugway Ridge dolomite is here named from exposures on Dugway Ridge, which forms the crest of the Dugway Range along its east side. The type section is along the south side of Straight Canyon, where this canyon cuts across Dugway Ridge. The Dugway Ridge dolomite crops out in a band that extends discontinuously from a point 0.8 mile north of Dugway Pass to the large canyon 1.5 miles north of Fera Canyon. Other outcrops are on the west side of the south end of Fandangle Canyon and in a wide northward-trending band lying to the west of Fandangle Canyon.

Lithology.—The base of the Dugway Ridge dolomite is placed at the top of the thin-bedded dark-gray limestone of the upper part of the Fera limestone, and its top is the top of the uppermost dolomite bed below the thin-bedded gray limestone of the Ordovician Garden City formation.

The Dugway Ridge dolomite is largely massive resistant medium- to coarse-grained sandy-textured dolomite, which is difficult to subdivide lithologically. In general, the lower half tends to be light gray and tan, the lower part of the upper half light and dark gray, and the upper part chiefly dark to medium gray. Some of the rock is color banded. Approximately 140 feet above the base and 135 feet below the top are zones containing conspicuous elliptical-shaped algae, *Girvanella* (fig. 6), in medium-grained gray sandy-textured dolomite. Dark-gray to black dolomite, some of which contains lenses and stringers of gray chert, is common in the upper part of this formation.

Along the east side of the Dugway Range an 11-foot thick fine-grained massive limestone bed with a little thin-bedded limestone at its base is found approximately 110 feet from the top of the formation. This unit, which was not found elsewhere, locally contains gray chert nodules. A thin section of the limestone shows that it consists of about 70 percent calcite grains, which are mostly less than 0.06 mm across, and about 25 percent clay-size material which occurs in layers that have a sharp contact on one side and that grade into the calcite on the other. Much of the calcite is fossil debris consisting of curved shell and trilobite fragments. Above the limestone is about 110 feet of gray and minor brown sandy, locally mottled dolomite. This dolomite commonly contains gray chert nodules and, near the top, a few chert layers less than an inch thick.

A detailed section of the Dugway Ridge dolomite at its well-exposed type section is given below.

Type section of the Dugway Ridge dolomite on south side of Straight Canyon, east side of Dugway Range

[Fossils identified by A. R. Palmer]

	Thickness (feet)
Garden City formation: Limestone, light-gray, fine-grained, contains some brown chert.	
Dugway Ridge dolomite:	
1. Dolomite, gray, medium-grained, sandy-textured, contains thin gray chert layers	20
2. Dolomite, gray to brown, medium-grained, sandy-textured	25
3. Dolomite, light-gray to gray, medium-grained, sandy-textured; patches have gray mottling	40
4. Dolomite, gray, medium-grained, sandy-textured, with irregular stringers of white dolomite; some beds weather light gray	23
5. Limestone, gray, fine-grained; beds 2 ft thick; fragments of Late Cambrian trilobites	10
6. Limestone, light-gray to gray, fine-grained, thin-bedded; intraformational conglomerate at base	1
7. Dolomite, light- to dark-gray, medium-grained, massive to thick-bedded, sandy-textured; zone with abundant *Girvanella* near middle of unit	33
8. Dolomite, gray, medium-grained, massive; weathers gray brown; some beds are oolitic, and some have gray chert lenses and stringers	157
9. Dolomite, dark-gray to black, medium-grained, massive, sandy-textured; lower 4 ft is banded	38
10. Dolomite, gray to light-gray, medium-grained; has irregular sandy-textured patches	18
11. Dolomite, white, coarse-grained, massive; weathers light tan	11
12. Dolomite, gray to dark-gray, medium-grained, sandy-textured; some white irregular markings	21
13. Dolomite, white to light-gray, coarse-grained, sandy-textured, massive; weathers light tan	295
14. Dolomite, gray, medium-grained, massive, mottled	22
15. Dolomite, white, coarse-grained, massive; weathers light tan	15
16. Dolomite, gray, limy, fine-grained, smooth-weathering	7
17. Dolomite, gray, medium-grained; contains *Girvanella* and worm tubes	7
18. Dolomite, light-gray; like unit 15	48
19. Dolomite, gray, medium-grained, massive, sandy textured; weathers drab gray; patches of finer grained dolomite in lower part	92
Total thickness of Dugway Ridge dolomite	883
Fera limestone: Dolomite, gray, thin-bedded, fine-grained.	

Thickness.—The Dugway Ridge dolomite is a resistant formation that caps ridges, and its upper contact is rather poorly exposed on the dip-slope side of the ridge. The formation is best exposed where it crosses Straight Canyon; on the ridge just south of this canyon the Dugway Ridge dolomite is approximately 885 feet thick.

Age and correlation.—The only fossils other than the alga *Girvanella* sp. occur in the 11-foot limestone bed 110 feet from the top of the Dugway Ridge dolomite. From this unit a number of poorly preserved fossil fragments were collected. They were examined by A. R. Palmer, who stated (1957, written communication) that two of the specimens "contain scraps of Late Cambrian trilobites. There is a piece of a *Eurekia* type cranidium in one and the tail in the other specimen has a spiny margin, which is most likely indicative of *Eurekia* and certainly has no known counterpart in the earliest Ordovician." The first fossils found in the Fera limestone occur just below the Dugway Ridge dolomite and are middle Late Cambrian in age. The first fossils noted in the Garden City formation occur 52 feet above the Dugway Ridge dolomite and are Early Ordovician in age. Thus, the greater part of, and quite possibly the entire, Dugway Ridge dolomite is Late Cambrian.

Lithologically the Dugway Ridge dolomite most closely resembles the Hicks formation of the Gold Hill district and probably correlates in part with it. Inasmuch as the Dugway Ridge dolomite is the youngest Cambrian formation in the Dugway Range, it probably is also partly equivalent to the lower part of the Chokecherry dolomite of the Gold Hill district (fig. 2). Owing to the scarcity of fossils in the Dugway Ridge dolomite, correlations with other areas are difficult.

ROCKS OF ORDOVICIAN AGE

Throughout most of western Utah and eastern Nevada, Ordovician sedimentary rocks show much less variance in lithology than those of Cambrian age. The Ordovician section consists in general of three units, a thick lower gray limestone, a middle quartzite, and an upper dolomite.

Two sets of names have been widely used for Lower and Middle Ordovician sedimentary rocks in the eastern part of the Great Basin. These rocks in southeastern Idaho, northeastern Utah and parts of western Utah have been called the Garden City and the Swan Peak formations (Richardson, 1913; Williams, 1948; Ross, 1951; Mansfield, 1920, 1927, 1929); in eastern Nevada and parts of western Utah they are called the Pogonip group and the Eureka quartzite (Hintze, 1952; Webb, 1956; Nolan and others, 1956). The two sets of names are not interchangeable, for the Pogonip group is equivalent to the Garden City formation and the lower part of the Swan Peak formation; hence, either one set of names or the other must be used for any one area.

Other names are used locally for Lower and Middle Ordovician rocks. In the East Tintic Mountains, the limestone of Early Ordovician age, which has considerable resemblance to the Garden City formation is called the Opohonga limestone (Lindgren and Loughlin, 1919, p. 32–34; Morris and Lovering, 1961, p. 55–56), a dark-gray cherty dolomite in the Gold Hill district that contains fossils of both Cambrian and Ordovician age is called the Chokecherry dolomite (Nolan, 1935, p. 15–16).

The Upper Ordovician dolomite in Utah and southeastern Idaho is called the Fish Haven; the names Hanson Creek formation and Ely Springs dolomite are commonly used for these rocks in eastern Nevada.

Part or all of the Ordovician sedimentary rocks are missing in several areas in western Utah. Their position is marked by an unconformity in such localities as the central Wasatch (Calkins and Butler, 1943, p. 18–19), the Stockton and Fairfield quadrangles (Gilluly, 1932, p. 18–20), the East Tintic Mountains (Morris and Lovering, 1961, p. 57–58), and the Gold Hill mining district (Nolan, 1935, p. 16).

The sedimentary rocks of Ordovician age in the Thomas and Dugway Ranges (fig. 7) have been divided into three formations: (1) Garden City formation, (2) Swan Peak formation, and (3) Fish Haven dolomite. These rocks lithologically resemble the Ordovician rocks of northeastern Utah and are of the same age. They also resemble in some aspects the Ordovician rocks of eastern Nevada, but the lithology is considerably different, especially in rocks of late Early Ordovician and Late Ordovician age.

GARDEN CITY FORMATION (LOWER AND MIDDLE ORDOVICIAN)

The Garden City formation, named for its exposure in Garden City Canyon, in the Randolph quadrangle of northern Utah, was originally described by Richardson (1913, p. 408–409) as consisting of approximately 1,000 feet of light-gray thick- and thin-bedded Ordovician limestone. Williams (1948, p. 1135–36) in the adjoining Logan quadrangle measured 1,400 feet of Garden City formation, which he described as "essentially dark-neutral gray, thin-bedded, shaly limestone that weathers olive-buff." The boundary between the Garden City and the underly-

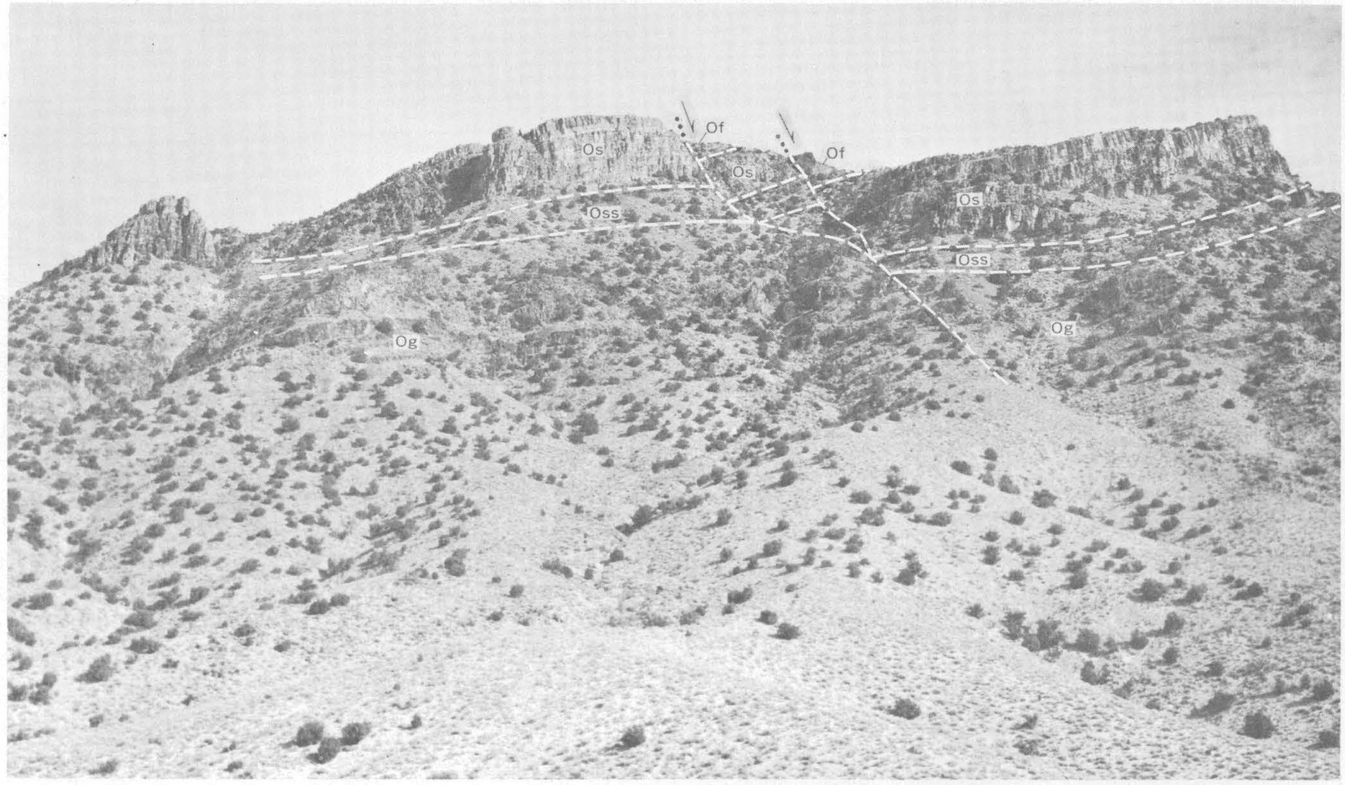


FIGURE 7.—Ordovician rocks in the Dugway Range. View of Castle Mountain from the west showing faulted capping of quartzite of the Swan Peak formation (Os) underlain by the shale unit (Oss) and overlain by Fish Haven dolomite (Of). The lower slopes of the mountain are Garden City formation (Og).

ing St. Charles formations was not defined by Richardson, but Williams noted that thick dark-gray dolomite beds occur as prominent stratigraphic markers at the top of the St. Charles; Williams placed the base of the Garden City formation at the base of the lowest limestone beds above the thick gray dolomite (Williams, 1948, p. 1135). This boundary was followed by Ross (1951, p. 6) in his study of the stratigraphy of the Garden City formation in northeastern Utah.

The Garden City formation is exposed in three areas in the Thomas Range and in five areas in the Dugway Range: (1) low hills at the extreme south end of the Thomas Range, south of Topaz Mountain, (2) hills 1.2 miles south of the south end of Spor Mountain, (3) a small area on the east side of Spor Mountain just west of the south end of Eagle Rock Ridge, (4) for 5 miles along the east sides of Green Grass Valley and Fandangle Canyon, (5) several patches at the southwest extremity of Fandangle Canyon, (6) in the canyon just south of peak 6830 in the center part of the Dugway Range, (7) a large area that surrounds Castle Mountain on the west side of the Dugway Range, and (8) a large area just south of Kellys Hole on the west side of the Dugway Range. The Garden City formation is also found in several neighboring ranges, being present in the northern part of the Drum Mountains and Fish Springs Range.

Lithology.—The base of the Garden City formation is placed at the top of the highest dolomite in the underlying Dugway Ridge dolomite. The top of the Garden City is at the base of the brown calcareous shale and interbedded hematitic red limestone of the shale member of the Swan Peak formation. The limestone below this contact is gray.

The Garden City formation is quite distinctive and is made up largely of gray fine-grained limestone that characteristically weathers to very light shades of purple, green, and pink. This colored limestone is not found in any other formation in the area, except in a thin interval in the Cambrian Fera limestone. The Fera, however, does not contain the numerous intraformational conglomerates characteristic of the Garden City.

Subsidiary lithologic features make it possible, for the purposes of discussion, to divide the Garden City formation into two parts. Approximately the lower three-fourths of the formation is thin-bedded gray limestone characterized by numerous beds of intraformational conglomerate. The upper one-fourth is thin-bedded nodular gray limestone and tan- and pink-weathering thin- to medium-bedded gray limestone containing a few thin beds of brown to green shale or shale partings.

The lower part of the Garden City formation is very fine grained medium- to light-gray thin-bedded limestone. In places these beds weather pinkish gray or have a greenish cast. Much of this unit is made up of intraformational conglomerate beds (fig. 8)

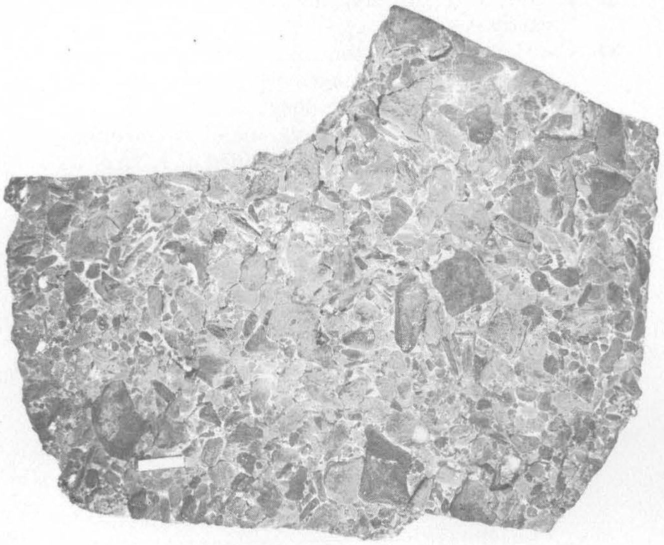


FIGURE 8.—Informational conglomerate typical of the middle part of the Garden City formation. Pebbles and matrix are both gray limestone. White bar is 1 inch long.

1 inch to 1 foot thick, in which the pebbles are gray limestone like the matrix. The flattened pebbles and cobbles are as much as 6 inches long, but average about ½ inch thick by 2 inches long. Some of the beds in this part of the formation are locally channeled on a small scale.

The upper part of the Garden City formation is characterized by abundant fossils, by a greater proportion of brownish-gray limestone, and by thin shale beds. Conglomerate beds are scarce. The lower part of this upper unit is medium- to coarse-grained gray limestone with some shaly beds and numerous trilobite fragments. Many of the trilobites and other fossils are silicified and may be recovered by dissolving the limestone in acid. In the middle of the unit is a zone about 130 feet thick of thin-bedded brownish-gray to gray limestone with irregular bedding planes, abundant fossils, and some interbeds of dark-brown fissile shale. The uppermost part of the formation is fine-grained thin- to thick-bedded light-gray limestone which weathers red brown to pinkish gray.

The preceding description is typical of the Garden City in the east-central Dugway Range. The lithology in the Thomas Range is like that in the Dugway Range, except that more chert and greenish-gray shale beds are present.

The Garden City formation is dolomitized on the west side of the Dugway Range south of Kellys Hole. In this area much of the limestone is converted to a sandy-textured dark-gray dolomite, which, except for the presence of scattered patches of typical Garden City limestone, is difficult, if not impossible, to distinguish from the Dugway Ridge dolomite.

Two samples of limestone from the middle and upper parts of the Garden City formation south of Spor Mountain contained 96 and 95 percent calcite in the carbonate fractions (table 5).

TABLE 5.—*Lime and magnesia contents of limestone and dolomite from the Thomas Range*

[Analyses made in Denver Laboratory of the U.S. Geological Survey. CaO and MgO analyses: a, L. M. Kehl; b, L. M. Tarrant]

Formation	Location	CaO (percent)	MgO (percent)	Dolomite in carbonate fraction (percent)	Remarks
Garden City	Southwest edge of mapped area.	38.13a	0.63a	4	Massive beds.
		42.41a	0.88a	5.2	Lumpy bed.
Fish Haven	Near Floride mine	29.81a	19.69a	95	Lower part of formation.
	Northeast of Fluorine Queen mine.	30.59a	21.11a	98	Upper black mottled part of formation.
Floride	Northeast of Dell No. 5 mine.	33.64a	17.01a	81	
Bell Hill	Near Lost Sheep mine	30.59a	21.52a	98	
Harrisite	do	30.69a	21.27a	98	
Lost Sheep	Near Blowout mine	29.25a	19.43a	95	Mottled gray beds.
		14.11a	9.59a	96	Cherty part.
Thursday	800 ft northeast of Lost Sheep mine.	29.74a	20.80a	98	
Sevy	Northwest of Spor Mtn.	30.29a	20.41a	96	
Engelmann	do	35.90b	16.20b	75	
		55.08b	0.31b	1.4	
Upper Devonian, undivided.	Near base of hill 0.3 mile south of Goshoot Canyon, Black Rock Hills.	53.02b	0.48b	2.3	
Gilson	North side of Goshoot Canyon, Black Rock Hills.	30.93b	21.13b	98	

Section of the Garden City formation, one-half mile south of the head of Straight Canyon, east-central Dugway Range

[Fossils identified by R. J. Ross, Jr.]

	Thickness (feet)
Swan Peak formation: Shale, brown, limy, and brown thin-bedded limestone; unit contains numerous brachiopods.	
Garden City formation:	
1. Covered	9
2. Limestone, light-gray, fine-grained; weathers reddish or tan brown to pinkish gray; thin- to medium-bedded	145
3. Covered	22
4. Limestone, light-gray to gray, fine-grained, thin-bedded; abundant brachiopods; *Pseudomera* sp.; *Orthambonites*? cf. *O. buttsi* (Schuchert and Cooper) or *O. blountensis* Cooper	20

Section of the Garden City formation, one-half mile south of the head of Straight Canyon, east-central Dugway Range—Continued

	Thickness (feet)
Garden City formation—Continued	
5. Limestone, brownish-gray, thin- and nodular-bedded; interbeds of crumbly dark-brown shale, and yellow silty partings; numerous fossil fragments; many covered intervals	143
6. Limestone, light-gray, fine-grained; yellow shaly partings; fossil debris; *Phyllograptus* cf. *P. anna* Hall; *Paranileus* sp. cf. *P. ibexensis* Hintze, *Diparelasma*? sp	7
7. Limestone; similar to unit 6 except medium to coarse grained; a few beds of intraformational conglomerate at top of unit; fossil fragments; *Kirkella* sp., *Lachnostoma* sp., *Carolinites* sp	27
8. Limestone, light-gray, fine-grained, thin-bedded; stained pink and yellow on bedding planes; one bed of intraformational conglomerate; float of thin shale interbeds; abundant fossil fragments; *Goniotelina brighti* (Hintze), *Pseudomera* sp., *Cybelopsis*? aff. *C. speciosa* Poulsen, *Syntrophopsis*? sp., *Hesperonomia*? sp	16
9. Covered	14
10. Limestone, gray, medium-grained; largely unidentifiable fossil debris	12
11. Covered, except for a small bed of gray fine-grained limestone with shaly partings	29
12. Limestone, gray, medium-, to coarse-grained; *Dimeropygiella* sp., *Paranileus*? sp., trilobite, aff. *Jeffersonia peltabella* Ross	30
13. Covered, except for a few beds like unit 12	63
14. Limestone, like unit 12; trilobite fragments	52
15. Conglomerate, limestone, intraformational gray, medium-bedded	14
16. Limestone, gray to light-gray, fine- to medium-grained, a few beds of intraformational conglomerate	22
17. Limestone, gray to light-gray, fine-grained	16
18. Conglomerate, limestone, intraformational, numerous trilobite fragments; *Psalikilus* cf. *P. typicum* Ross, *Protopliomerops contractus* Ross, *Paranileus*? sp	27
19. Limestone, gray; interbedded with intraformational conglomerate	169
20. Conglomerate, limestone, intraformational	9
21. Conglomerate, like unit 20; interbedded with limestone; light-gray to gray, fine-grained, thin-bedded; weathers pinkish gray; *Asaphellus*? sp	113
22. Conglomerate, like unit 20, but with a few beds of limestone; gray, fine-grained	28
23. Covered	17
24. Conglomerate, like unit 20; partly covered	97
25. Mostly covered, but a few beds of intraformational conglomerate beds exposed	57
26. Limestone, light-gray to gray, fine-grained; weathers reddish gray; numerous intraformational conglomerate beds; partly covered	46
27. Covered	18
28. Limestone, gray to brownish-gray, fine- to medium-grained, thin- to medium-bedded; several 1- to 2-ft beds of intraformational conglomerate	24
29. Limestone, gray to light-gray, fine-grained, medium-bedded; bed of intraformational conglomerate at base	33
30. Limestone, gray, fine-grained, thin-bedded	14
31. Limestone, gray, fine-grained, massive; some brownish-gray intraformational conglomerate	24
32. Limestone, light-gray, fine-grained, thin-bedded; partly covered	35
33. Conglomerate, limestone, intraformational, gray; pebbles are mostly flattened and are as much as 3 in. wide and 6 in. long	19
34. Limestone, brownish-gray, fine- to medium-grained, thin- to medium-bedded	35
35. Limestone, gray to light-gray, fine-grained, thick-bedded; one 1-ft intraformational conglomerate bed; gastropods including *Ophileta*? sp	62
36. Conglomerate, like unit 33; many covered intervals	73
37. Covered, except for one 3-ft bed of purplish-gray intraformational conglomerate	33
38. Limestone, gray to light-gray, thin- to thick-bedded, fine-grained; weathers pinkish- to reddish-gray; contains a little gray chert and several thin intraformational conglomerate beds; *Symphysurina* cf. *S. woosteri* Ulrich, *Bellefontia*? sp	136
39. Limestone, gray, very fine grained, contains some brown chert	14
Total thickness of Garden City formation	1, 724
Dugway Ridge dolomite: Dolomite, gray, medium-grained, sandy-textured; contains thin gray chert beds.	

Thickness.—The Garden City formation is one of the thickest but most poorly exposed formations in the Dugway and Thomas Ranges. This formation generally underlies partially covered low hills and dip slopes of the steeper ridges. In spite of its widespread occurrences, the entire formation is well exposed only at the head of Straight Canyon, where it forms the steep divide between Straight Canyon and Fandangle Canyon. Along the ridge on the south side of Straight Canyon, the Garden City formation is 1725 feet thick.

Age and correlation.—Numerous fossils are found in the Garden City formation. Fossils collected at five localities in the Dugway Range, four localities in the southern Thomas Range, and one locality in the northeasternmost Drum Mountains were identified by R. J. Ross, Jr., of the U.S. Geological Survey and are given in table 6. The collections from most of the localities represent relatively small stratigraphic intervals, but the collection from locality 1 represents most of the stratigraphic section of the Garden City formation just south of Straight Canyon, and the collection from locality 6 represents half of the section 1½ miles

Table 6.—*Fossils collected at various localities in the Garden City formation*

[Fossils identified by R. J. Ross, Jr.]

Fossil	Locality									
	1	2	3	4	5	6	7	8	9	10
Arthropoda:										
Trilobites:										
Symphysurina cf. *S. woosteri* Ulrich	×	----	----	----	----	----	----	----	----	×
Bellefontia? sp	×	----	----	----	----	----	----	----	----	----
Asaphellus? sp	×	----	----	----	----	----	----	----	----	----
Psalikilus cf. P. *typicum* Ross	×	----	----	----	----	----	----	----	----	----
Protopliomerops contractus Ross	×	----	----	----	----	----	----	----	----	----
Paranileus sp	×	----	----	×	×	----	----	----	----	----
sp. cf. *P. ibexensis* Hintze	×	----	----	----	----	----	----	----	----	----
Dimeropygiella sp	×	----	----	----	----	----	----	----	----	----
Trilobite aff. *Jeffersonia peltabella* Ross	×	----	----	----	----	----	----	----	----	----
Cybelopsis? aff. *C. speciosa* Poulsen	×	----	----	----	----	×	----	----	----	----
Pseudomera sp	×	×	----	----	----	----	----	----	----	----
Goniotelina brighti (Hintze)	×	----	----	----	----	----	----	----	----	----
Lachnostoma sp	×	----	----	----	----	----	----	----	----	----
latucelsum Ross	----	----	----	----	----	×	----	----	----	----
Kirkella sp	×	----	----	----	----	----	----	----	----	----
declevita Ross	----	----	----	----	----	----	----	----	×	----
cf. *K. declevita* Ross	----	----	----	----	----	×	----	----	----	----
cf. *K. vigilans* (Whittington)	----	----	----	----	×	----	----	----	----	----
Carolinites sp	×	×	----	----	----	----	----	----	----	----
Pseudocybele nasuta Ross	----	----	----	×	----	×	----	----	×	----
Strigigenalis sp	----	----	----	----	----	----	×	----	----	----
Xenostegium sp	----	----	----	----	----	----	----	----	----	×
Ostracode:										
Macronotella sp	----	----	----	----	----	×	----	----	----	----
Brachiopoda:										
Hesperonomia sp	×	----	----	----	----	×	----	----	----	----
Syntrophopsis? sp	×	----	----	----	----	----	----	----	----	----
Diparelasma? sp	×	----	----	----	----	----	----	----	----	----
Orthambonites subalata (Ulrich and Cooper)	----	----	×	----	----	----	----	----	----	----
cf. *O. subalata* (Ulrich and Cooper)	----	----	----	×	----	----	----	----	----	----
? cf. *O. buttsi* (Schuchert and Cooper) or cf. *O. blountensis* Cooper	×	----	----	----	----	----	----	----	----	----
sp	----	×	----	----	----	----	----	----	----	----
Orthidiella sp	----	×	----	----	----	----	----	----	----	----
Hesperonomiella cf. *H. minor* (Walcott)	----	×	----	----	----	×	----	----	----	----
Apheoorthis sp	----	----	----	----	----	----	----	×	----	----
Anomalorthis sp	----	----	----	----	----	×	----	----	----	----
Mollusca:										
Unidentified gastropods	×	----	----	×	×	×	----	----	×	----
Ophileta? sp	×	----	----	----	----	----	----	----	----	----
Unidentified cephalopod	----	----	----	×	×	----	----	----	----	----
Porifera:										
Archaeoscyphia sp	----	----	----	----	×	----	----	----	----	----
Protochordata:										
Graptolites:										
Phyllograptus sp	----	----	----	----	×	----	----	----	----	----
cf. *P. anna* Hall	×	----	----	----	----	----	----	----	----	----
Didymograptus sp	----	----	----	----	×	----	----	----	----	----
Tetragraptus cf. *T. taraxacum* Ruedemann	----	----	----	----	----	×	----	----	----	----
cf. *T. decipiens* T. S. Hall	----	----	----	----	----	×	----	----	----	----

Localities

1. Ridge south of Straight Canyon in Dugway Range from bottom to top of formation. See preceding stratigraphic section. U.S. Geol. Survey collections D317aЄO, D317bЄO, D317cЄO, D317dЄO, D317eЄO, D317fЄO, D317gЄO, D317hЄO, D317iЄO, and D317kЄO.
2. Green Grass Valley, Dugway Range, 2,400 ft north of marker 5841. U.S. Geol. Survey collection D303ЄO.
3. Green Grass Valley, Dugway Range, 4,200 ft north of marker 5841. U.S. Geol. Survey collection D317l.
4. Valley on west side of Dugway Range, 3,000 ft due south of peak 6830.
5. Ridge west side of Dugway Range, 4,600 ft. S. 4° E. of Castle Mountain. U.S. Geol. Survey collection D317jЄO.
6. Hill 1½ miles south of Spor Mountain in section in NW¼ sec. 26 and NE¼ sec. 27, T. 13 S., R. 12 W.
7. Shallow wash in south end of Thomas Range 2,600 ft southwest of the mouth of Topaz Canyon in the SW¼ sec. 16, T. 13 S., R. 11 W. U.S. Geol. Survey collection D168ЄO.
8. Low hill in south end of Thomas Range, 3,200 ft southwest of the mouth of Topaz Canyon in the NW¼ sec. 21, T. 13 S., R. 11 W. U.S. Geol. Survey collection D170ЄO.
9. Low hill in south end of Thomas Range, 4,200 ft due west of the mouth of Topaz Canyon in the SE¼ sec. 17, T. 13 S., R. 11 W. U.S. Geol. Survey collection D167ЄO.
10. Ridge top in extreme northern end of Drum Mountains in the SE¼ sec. 28, T. 13 S., R. 11 W. U.S. Geol. Survey collection D169ЄO.

south of Spor Mountain. The stratigraphic position of the fossils collected at locality 1 is given on pages 33–34 of this report, and of the fossils collected at locality 6 on pages 10 and 11 of the report on the Thomas Range fluorspar district (Staatz and Osterwald, 1959).

The great bulk of the Garden City formation is Early Ordovician in age; the Lower Ordovician-Middle Ordovician boundary is in the upper part of the formation. The entire sequence is conformable.

Ross (1951) studied the Garden City in its type area in the Randolph quadrangle in northeastern Utah; he distinguished 12 faunal zones there, which he labeled A to L. In collections from the Dugway and Thomas Ranges, Ross recognized faunal sequences belonging to the B, C, G, H, J, K, and L zones. He (1951, p. 31–32) pointed out that the Lower Ordovician-Middle Ordovician boundary falls somewhere between the K and L zones, or below the lowest occurrence of the brachiopod *Anomalorthis* and probably above the highest occurrence of the brachiopod *Hesperonomia*. In the Dugway Range this boundary is somewhere in the interval between 180 and 340 feet below the top of the formation.

The lowest clearly identifiable fossils, (*Symphysurina* cf. *S. woosteri* Ulrich and *Bellefontia*? sp.), are found 52 feet above the base of the Garden City formation; they are Early Ordovician in age and belong to faunal zone B of Ross. Late Cambrian trilobite fragments are found 114 feet below the Garden City formation in the Dugway Ridge formation. It is possible, therefore, that some of the lower 52 feet of the Garden City formation is Late Cambrian in age or that some of the top 114 feet of the Dugway Ridge formation is Early Ordovician.

The Garden City formation correlates closely with the lower and middle parts of the Pogonip group of eastern Nevada and western Millard County, Utah. Hintze (1951, 1952) made a faunal study of this group in western Utah and eastern Nevada. He found 15 faunal zones and labeled them so as to correspond as nearly as possible with Ross' faunal zones. Ross' zone A was not recognized, and in addition to Ross' zones B through L, Hintze recognized faunal zones M, N, and O in the Pogonip group. Zone M is present in the lower part of the Swan Peak formation; the two higher faunal zones (N and O) have not been recognized in northeastern Utah. Because numerous fossils mark Ross' faunal zones A through L and Hintze's zones B through L, the different parts of the Garden City can be correlated with comparable parts of the Pogonip group with considerable certainty. The lithology of both formations is similar in that both consist principally of fine-grained light-gray limestone. The Garden City formation also resembles the Pogonip group in the southern part of the Confusion Range (Ibex area) of western Millard County, Utah, in that both are almost entirely thin bedded and contain numerous intraformational conglomerate beds (Hintze, 1951, p. 30-63). Farther west, however, in the Eureka district, Nevada, only the central part (Ninemile formation) of the Pogonip group is dominantly thin bedded, and no intraformational conglomerate beds are mentioned (Nolan, Merriam, and Williams, 1956, p. 23–29).

The writers have used the name Garden City rather than Pogonip in the Thomas and Dugway Ranges for the following reasons: (1) The upper part of the Pogonip group, which correlates with the lower part of the Swan Peak formation, is dominantly thick-bedded gray limestone (Nolan, Merriam, and Williams, 1956, p. 28–29) in the Eureka district, 30 miles northwest of the type section, but equivalent beds in the Thomas and Dugway Ranges are mainly shale. (2) Hintze (1951, p. 11–20) was able to divide the Pogonip group into six formations in the Confusion Range, and Nolan, Merriam, and Williams (1956, p. 23–24) divided the group into three formations in the Eureka district; except for Hintze's Kanosh shale, which is equivalent to the lower part of the Swan Peak formation, none of these formations is mappable in the Thomas and Dugway Ranges. In the Thomas and Dugway Ranges the difficulty in recognizing equivalents to the subdivisions of the Pogonip may be due in part to poor exposures, but mostly it is due to the similarity of the lithology throughout this area. (3) R. J. Ross, Jr., who examined the Lower Ordovician sedimentary rocks in the Thomas Range, stated (1952, oral communication) that they are lithologically almost identical to the Garden City formation in its type area in northeast Utah.

The Garden City formation in the Thomas and Dugway Ranges can be correlated to the east with the Opohonga limestone in the East Tintic Mountains, where Morris and Lovering (1961, p. 55–56) reported fossil collections equivalent to faunal zones from B through J in the Garden City formation. Inasmuch as an unconformity separates the Opohonga limestone from the overlying Fish Haven dolomite, the Opohonga as originally laid down may have been equivalent to the entire Garden City formation.

Nolan (1935, p. 15) has called the Chokecherry dolomite to the west in the Gold Hill district Lower Ordovician on the basis of the gastropod *Scaevogyra*? sp. collected near the base of the formation. A. R. Palmer (1956, oral communication) believed this fossil to be Late Cambrian in age. Later Kenneth F. Bick in a letter to R. J. Ross, Jr., dated October 22, 1956, reported collecting the Lower Ordovician graptolite *Phyllograptus typus* Hall from the upper part of the Chokecherry dolomite in the Deep Creek Mountains. Hence, the upper part of the Chokecherry correlates with at least part of the Garden City.

The Garden City formation probably also correlates with the Yellow Hill limestone and the lower part of the Tank Hill limestone in the Pioche district (Westgate and Knopf, 1932, p. 14–15) and with part of the Grampian limestone in the San Francisco district (Butler, 1913, p. 28–31).

SWAN PEAK FORMATION (MIDDLE ORDOVICIAN)

The Swan Peak formation, originally called the Swan Peak quartzite, was named by Richardson (1913, p. 409) from its occurrence on Swan Peak in northern Utah. Williams (1948, p. 1136), who studied the Logan quadrangle, pointed out that the Swan Peak contained not only the massive quartzite described by Richardson, but also underlying beds of shale interbedded with quartzite and limestone. Ross (1951, p. 10) stated that "the appearance of the type section is misleading and the lower half is masked by rusty-colored silty, sandy, and badly weathered quartzite rubble." He (1951, p. 10, 13) noted that 3 miles west-northwest of the type section a good exposure on the side of a small gorge shows massive quartzite overlying shale interbedded with quartzite and limestone. Thus, the Swan Peak formation at its type section actually consists of an upper massive quartzite member and a lower shaly member containing interbeds of quartzite in its upper part and limestone in its lower part.

The Swan Peak formation is exposed at the following places in the area mapped: (1) in the low hills 1.2 miles south of the south end of Spor Mountain, (2) in a number of bands along the east side of Spor Mountain, (3) in a north-trending band from the north end of Green Grass Valley into Fandangle Canyon, (4) in several areas on and to the west of Castle Mountain, and (5) in several areas on the west side of the Dugway Range about 1½ miles southeast of Kellys Hole. The Swan Peak formation is also exposed 10 miles west of the area mapped in the northern part of the Fish Springs Range.

Lithology.—The Swan Peak formation is composed of two distinct units: a lower third to one-half of brownish-green shale interbedded with thin beds of limestone, quartzite, and a little dolomite, and an upper part of thick- to massive-bedded white quartzite. The lithology of the shaly unit varies considerably from place to place, and much of this interval is commonly covered by slope wash. The overlying quartzite, however, is quite uniform and resistant and is generally well exposed in steep cliffs (fig. 7). The base of the Swan Peak formation is marked by the first shale bed above the limestone of the Garden City formation, and the top is the contact between the quartzite and the lowest dolomite bed of the Fish Haven dolomite.

The lower beds of the Swan Peak formation are brownish green to green, somewhat lumpy fissile shale that is commonly stained hematitic red on fractures and bedding planes. Locally they contain some small pieces of chert. Interbedded at irregular intervals are units from less than 1 inch to 5 feet thick of thin-bedded coarse-grained gray to brownish-gray limestone. Several of these beds consist almost entirely of brachiopods. Dolomite or dolomitic limestone beds are common near the middle of the shaly member of the Swan Peak formation. These beds are generally red, hematitic, and from 0.1 to about 2.5 feet thick. Toward the top of the middle part of the shale unit they contain some quartz sand. Above this dolomitic zone only quartzite beds are found interbedded with the shale. The quartzite is generally fine grained and brick red to brown or gray, and occurs in beds ½ inch to 3 feet thick. This rock commonly has fucoids on the undersides of its bedding planes.

A 6-inch banded bed of brown quartzitic phosphorite was noted just below the top of the shaly unit at one locality in the upper part of Fandangle Canyon. Black carbonaceous or phosphatic material was observed in this interval at a few other localities, and other phosphate beds may be present but concealed. A thin section of the phosphorite showed it to be composed of medium- to coarse-grained quartz sand (about 45 percent) cemented by wavy, banded, and streaked colloform collophane (about 50 percent), and brown limonite (about 4 percent).

The upper part of the Swan Peak formation is composed entirely of fine- to medium-grained quartzite in beds which range from 1 to 10 feet thick, but are generally 2 to 4 feet thick. The quartzite is predominantly white, but locally it may be pink. On fracture surfaces it commonly weathers brown, and crossbedding is common locally. The quartz sand is generally well sorted and subangular to subround. Minor orthoclase and biotite have been noted at some localities, and traces of heavy minerals such as tourmaline and zircon are present. The quartzite is highly resistant and generally forms steep cliffs.

In the Dugway Range the contact between quartzite of the Swan Peak formation and dolomite of the Fish Haven dolomite is locally transitional through a zone 1 to 10 feet thick, apparently as a result of secondary silicification or dolomitization. The transitional rock is tan arenaceous dolomite or dolomitic quartzite, which may grade laterally within a few feet into gray dolomite on the one hand and pure vitreous quartzite on the other. One thin section of the transitional rock showed what appeared to be minor replacement of some of the quartz sand grains by dolomite. The weathered surface of this rock is covered in places by a thin coating of brown chert.

Thickness.—The entire Swan Peak formation is exposed in only a few places and the whole formation was measured only on the southeast side of Castle Mountain where it is 470 feet thick. The lower and upper members of the formation were measured separately in a number of places. The lower shaly member was measured: (1) just west of the south end of Eagle Rock Ridge on the east side of Spor Mountain, (2) at the southwest corner of the area mapped in sec. 23, T. 13 S., R. 12 W., (3) on the ridge forming the divide between Straight Canyon and Fandangle Canyon, and (4) on the southeast slope of Castle Mountain. The thickness of the shale member at these four localities is 250, 390, 290, and 265 feet, respectively. At the last locality the upper contact between the shale member and the overlying quartzite member is covered and the shale member may be a little thinner than the thickness given. Variations in the thickness of this member may be due to differences in local sedimentation. Individual beds within the shale unit also vary in thickness; quartzite and carbonate beds cannot be correlated in sections only a mile apart.

The upper massive quartzite member was measured: (1) 800 feet northeast of the Floride mine on Spor Mountain, (2) on the southeast slope of Castle Mountain, and (3) along the west side of the valley 2.1 miles southeast of the southern end of Kellys Hole. The thickness of the quartzite member at these three localities is 590, 205, and 175 feet, respectively. A thinning of at least 385 feet occurs between the central part of Spor Mountain and the central part of the Dugway Range, 15½ miles to the north. A similar northward thinning was noted in the northern Fish Springs Range, where in 1½ miles the quartzite member of the Swan Peak formation thinned from 115 to 60 feet. The comparative thicknesses of the quartzite in the Thomas and Dugway Ranges and in the Fish Springs Range also indicates westward thinning of this unit.

Age and correlation.—No fossils have been found in the upper quartzite member of the Swan Peak formation. In the underlying shale member, however, some beds are composed almost completely of brachiopods. Although fossils are abundant, especially in the lower and middle parts of the shaly unit, they consist chiefly of two genera of brachiopods and less commonly of several genera of trilobites in the lower part of the unit. *Receptaculites* and a few unidentified bryozoans and ostracodes have also been found at some localities. All our fossils from this formation were identified by R. J. Ross, Jr. In the lowest bed of the Swan Peak formation, 1½ miles south of Spor Mountain the following suite of fossils was found:

Orthambonites cf. *O. subalata* (Ulrich and Cooper)
Anomalorthis sp.
Trilobite cf. *Pseudomera barrandi* (Billings)

Ross stated (1952, written communication) that this collection is probably of early Chazyan age (early Middle Ordovician) and the fauna is the same as that in the uppermost beds of the Garden City formation.

Fossils were collected above this lowest bed at a number of localities on both Spor Mountain and the Dugway Range. The most complete collection (U.S. Geol. Survey colln. D358€O) came from the south side of Castle Mountain, 25 to 50 feet above the base of the formation, and contained the following fossils:

Orthambonites michaelis (Clark)
Anomalorthis utahensis Ulrich and Cooper
    cf. *A. lonensis* Ulrich and Cooper
Eleutherocentrus petersoni Clark
Bathyurellus pogonipensis Hintze
Numerous small ostracodes

A complete list of the identified fossils from the Swan Peak formation in the mapped area was compiled from U.S. Geol. Survey collections D358€O, D355€O, D356€O, D357€O, D317m, D317n, D317o, D317p and is given below:

Orthambonites sp.
    michaelis (Clark)
    cf. *O. michaelis* (Clark)
    cf. *O. occidentalis* Cooper
    cf. *O. sublata* (Ulrich and Cooper)
    cf. *O. eucharis* (Ulrich and Cooper)
    swanensis (Ulrich and Cooper)
Anomalorthis sp.
    utahensis Ulrich and Cooper
    cf. *A. utahensis* Ulrich and Cooper
    aff. *A. lonensis* (Walcott)
    cf. *A. lonensis* (Walcott)
Pseudomera sp.
Eleutherocentrus petersoni Clark
Bathyurellus pogonipensis Hintze
Receptaculites sp.
Bryozoa, undet.
Small ostracodes, undet.

These fossils all indicate an early Middle Ordovician age for the lower part of the Swan Peak formation.

The quartzite and shale members of this formation correlate stratigraphically, and the shale member paleontologically, with the Swan Peak formation at its type locality in northeastern Utah. Ross (1952, oral communication), after visiting Spor Mountain, stated that the Middle Ordovician rocks in that area are similar in lithology to those of the Swan Peak formation he had studied in the type area. Ross (1951, p. 27) found both *Orthambonites michaelis* (Clark) and *Anomalorthis* sp. in the lower part of the Swan Peak formation in the Logan quadrangle in northeastern Utah.

The lower part of the Swan Peak formation correlates closely with part of the upper part of the Pogonip group in the Ibex area of the Confusion Range (Hintze, 1951, p. 30–68). Hintze divided the Pogonip group in this region into six formations: House limestone, Fillmore limestone, Wahwah limestone, Juab limestone, Kanosh shale, and Lehman formation. The first four correlate with the Garden City formation and the Kanosh shale with the lower part of the Swan Peak formation; the Lehman formation apparently has no recognized equivalent in this part of Utah. Lithologically Hintze's Kanosh shale in the Confusion Range resembles the lower part of the Swan Peak formation; both contain the same suite of fossils. Overlying the Lehman in the Confusion Range is an interbedded series containing sandstone, limestone, dolomite, and shale which Hintze (1951, p. 20–21) and Webb (1956, p. 11–12) believed to be Swan Peak quartzite. On top of this is a dolomite called the Crystal Peak dolomite by Webb (1956, p. 12–13), which in turn is overlain by the Eureka quartzite. The Crystal Peak dolomite of Webb has been reported 12 miles to the west in the Fish Springs Range but does not occur in either the Thomas or the Dugway Range. No fossils are known from the upper part of the Swan Peak formation, and the fossils from the three units overlying Hintze's Kanosh shale are all Middle Ordovician in age. The stratigraphy of the "Swan Peak quartzite" of Hintze (1951, p. 20–21) and of Webb (1956, p. 11–12) in the Confusion Range does not resemble the quartzite of the Swan Peak formation in other parts of western Utah. Furthermore, the stratigraphy of the "Swan Peak" of Hintze and Webb shows considerable variation in lithology between sections in western Millard County measured by Hintze (1951, p. 67, 69, 74–75, 82–83). Inasmuch as this unit stratigraphically resembles neither the quartzite of the Swan Peak formation nor the Eureka quartzite and occurs only in the area of thickest deposition during the Middle Ordovician, we believe this unit to be only local in extent. Thus, the massive quartzite of the upper part of the Swan Peak formation may correlate with the similar-appearing Eureka quartzite of eastern Nevada, and apparently no units equivalent to Hintze's Lehman formation and Swan Peak(?) quartzite and Webb's Crystal Peak dolomite exist in the Thomas and Dugway Ranges. On the other hand, the upper vitreous-appearing quartzite of the Swan Peak in the Thomas and Dugway Ranges may possibly be a separate lens at a stratigraphic horizon different from that of the Eureka quartzite.

To the east in the East Tintic Mountains (Morris and Lovering, 1961, p. 57–58) and in the Stockton and Fairfield quadrangles (Gilluly, 1932, p. 10–20) and to the west in the Gold Hill district (Nolan, 1935, p. 16), this period of sedimentation is represented by an unconformity. The Swan Peak formation, according to Ross (1956, written communication), has similar fossils and is equivalent in at least part to the Antelope Valley formation of central Nevada.

FISH HAVEN DOLOMITE (UPPER ORDOVICIAN)

The Fish Haven dolomite was named by Richardson (1913, p. 409–410) from its exposure near the head of Fish Haven Creek in southern Idaho. In his discussion of the overlying Silurian Laketown dolomite, Richardson (1913, p. 410) did not appear certain of the exact position of the lower contact, but he proposed to restrict the Laketown dolomite to beds of Silurian age. Thus, the Fish Haven dolomite in its type area includes all the Ordovician sedimentary rocks above the quartzite of the Swan Peak formation.

The name Fish Haven dolomite has been widely used for Upper Ordovician dolomites in Utah and Idaho. Fish Haven dolomite has been described from the Fort Hall Indian Reservation, Idaho (Mansfield, 1920, p. 33–34); the Portneuf quadrangle, Idaho (Mansfield, 1929, p. 20); the southeast corner of Idaho (Mansfield, 1927, p. 58); the Randolph quadrangle, Utah (Richardson, 1941, p. 17–18); the Logan quadrangle, Utah (Williams, 1948, p. 1137); the East Tintic Mountains, Utah (Morris and Lovering, 1961, p. 58–63); the Gold Hill district, Utah (Nolan, 1935, p. 16–17); the Sheeprock Mountains, Utah (Cohenour, 1959, p. 78–79); and the Promontory Range, Utah (Olson, 1956, p. 52–53).

In the Thomas and Dugway Ranges the Fish Haven dolomite is found in the following areas: (1) a series of faulted blocks along the east side of Spor Mountain, (2) several patches at the south end of Fandangle Canyon, (3) small fault blocks southwest of peak 6830 in the Dugway Range, (4) the top of Castle Mountain, (5) a number of fault blocks 1 to 2 miles southeast of Kellys Hole, and (6) on the west edge of the Dugway Range south of Kellys Hole.

Lithology.—The Fish Haven dolomite is composed of two distinct members: The lower two-thirds of the formation consists of slope-forming thin- to medium-bedded gray to black smooth-weathering dolomite and limestone, the upper one-third of massive ledge-forming black dolomite with dark-gray mottling. The lower contact of the Fish Haven is placed at the top of the massive quartzite of the Swan Peak formation, and the upper boundary is at the top of the massive black mottled dolomite and at the base of a unit of thin- and lumpy-bedded gray dolomite of the Floride dolomite.

The basal 30 to 50 feet is light- to dark-gray fine-grained dolomite containing quartz sand in places, locally a little chert, and a few thin beds of pinkish white to brown medium-grained quartzite. These beds are from ½ to 2 feet thick. A thin section of a quartzitic dolomite from this part of the Fish Haven in the Dugway Range contained about 45 percent rounded to subangular quartz grains concentrated in small streaks and patches. The quartz grains average about 0.25 mm in diameter and are moderately well sorted. The matrix of this rock is composed of rather uniform dolomite anhedra 0.1 to 0.2 mm in diameter. In outcrops of this type of rock, fractures and weathered surfaces may have a thin coating of brown silica, or the entire rock may be so silicified that it resembles the underlying Swan Peak quartzite. Such silicified beds can be traced laterally into sandy dolomite.

The lower member above the zone containing quartz sand consists of 100 to 150 feet of thin-bedded light- to dark-gray fine-grained smooth-weathering dolomite, limy dolomite, and locally limestone. Limestone is more prevalent on Spor Mountain than in the Dugway Range. In this interval a few beds commonly contain numerous small holes as much as 1 mm in diameter that in some places are filled with white calcite. Lumpy-bedded limy dolomite is also present locally.

The upper member of the Fish Haven, about 100 feet thick, is a fairly uniform black to gray sandy-textured medium-grained massive dolomite which weathers a slightly lighter gray. It is persistently mottled with small gray patches, and locally contains poorly preserved cup corals and crinoid stems.

Stratigraphic sections representative of the Fish Haven dolomite on Spor Mountain and the Dugway Range are given below.

Section of the Fish Haven dolomite, 2,000 feet north of the Floride mine, Spor Mountain in NE¼ NE¼ sec. 3, T. 13 S., R. 12 W.

[Fossils identified by Jean M. Berdan and Helen Duncan]

	Thickness (feet)
Floride dolomite: Dolomite, light-gray to pinkish-gray, limy, thin-bedded, nodular.	
Fish Haven dolomite:	
1. Dolomite, dark-gray with gray mottles, particularly in lower part; limy in places; contains numerous crinoid stems and a coral, *Palaeophyllum*? sp., near top of unit	91
2. Limestone, light- to dark-gray, banded, dolomitic smooth-weathering, lithographic; contains some limy dolomite; partly covered	50
3. Limestone, black, fine-grained	4
4. Dolomite, gray, limy; contains numerous crinoid stems	2
5. Limestone, like unit 3; contains *Catazyga*? sp., *Hesperorthis* sp., *Favosites* sp., high-spired gastropod, horn coral, and bryozoans	4
6. Dolomite, gray, mottled light-gray	1
7. Limestone, light- to dark-gray; sandy at top, banded and flaggy at base	8
8. Dolomite, light-gray, limy, banded; contains numerous small holes as much as 1 mm across	32
9. Dolomite, light- to dark-gray, limy, medium-grained, smooth-weathering	74
10. Dolomite, light-gray to black, banded; a little chert along fractures; quartz sand in some layers	16
11. Quartzite, gray to pinkish white, medium-grained	2
12. Dolomite, gray to black, limy, fine-grained; quartz sand in some layers	19
Total thickness of Fish Haven dolomite	303
Swan Peak formation: Quartzite, white, massive.	

Section of the Fish Haven dolomite, 3,000 feet southwest of peak 6,755, south-central Dugway Range

[Fossil identified by Jean M. Berdan]

	Thickness (feet)
Floride dolomite: Dolomite, light-gray, limy, fine-grained, smooth-weathering, lumpy-bedded.	
Fish Haven dolomite:	
1. Dolomite, black, massive, medium-grained, sandy-textured; some dark-gray mottles; silty fragments and coral, *Palaeophyllum* sp	8
2. Dolomite; like unit 1, but weathers gray and mottling not evident	30
3. Dolomite, like unit 1	57
4. Covered	23
5. Dolomite, black, massive- fine-grained, smooth-weathering	6
6. Dolomite; like unit 5, but gray; weathers to light gray	21
7. Dolomite; like unit 5, but beds are 8 in. to 1.5 ft. thick	5
8. Dolomite, gray, fine-grained, smooth-weathering; weathers light gray; beds 1 in to 1 ft thick	41
9. Dolomite, interbedded gray and dark gray; fine-grained; beds ¾ in. to 1.5 ft thick	35
Total thickness of Fish Haven dolomite	226
Swan Peak formation: Quartzite, white, massive, fine-grained, vitreous.	

Thickness.—The Fish Haven dolomite was measured in the following four places: (1) 2,000 feet north of the Floride mine on Spor Mountain in the NE¼NE¼ sec. 3, T. 13 S., R. 12 W., (2) 1 mile S. 63° E. of the Lost Sheep mine on Spor Mountain, (3) 5,000 feet S. 30° W. from peak, 6,830, in the Dugway Range, and (4) 7,400 feet N. 74° W. from the top of Castle Mountain in the Dugway Range. The thickness in the four sections is 305, 280, 225, and 310 feet, respectively. The average thickness of the Fish Haven is about 290 feet.

Age and correlation.—Fossils are not common in the Fish Haven dolomite in either the Thomas or the Dugway Range. Poorly preserved unidentifiable cup corals have been noted in a number of widely scattered areas. The best preserved fossils were found in a 20-foot limestone bed that is locally present near the top of the lower member in the southern part of Spor Mountain. Collections were made from this unit along a canyon bottom 2,100 feet due north of the Floride mine and on a small ridge 3,100 feet S. 5° E. of the Floride mine. The two collections were almost identical. The following fossils were identified by Helen Duncan and Jean M. Berdan:

Catazyga? sp.
Hesperorthis sp.
Favosites sp.
Fardenia sp.
Horn coral, undet.
Bryozoans, undeter.
High-spired gastropod, undet.
Stromatoporoids

A collection of fossils was also made from a dolomite at approximately the same stratigraphic horizon in the northern end of the Fish Springs Range 10 miles to the west of the area mapped. R. J. Ross, Jr. (1952, written communication) examined some of the fossils from this collection and reported gastropods of the "*Hormotoma*-type" and brachiopods that may belong to *Catazyga* cf. *C. anticostiensis* (Billings). Jean M. Berdan (1955, written communication) examined other fossils from the collection and reported that it "contains two multiserial *Halysites*-like corals referable to the recently described genus *Manipora*. * * * Corals of this type occur in the Montoya limestone in Teaxs and the Selkirk member of the Red River formation in Canada, and are known only from Upper Ordovician rocks."

Fossils in the upper black mottled dolomite member are rare and generally poorly preserved. They consist chiefly of a colonial coral and a cup coral found near the top of the formation. The cup coral is too poorly preserved to be identified. Several specimens of the colonial coral collected both on Spor Mountain and in the Dugway Range were reported by Berdan to be *Palaeophyllum*? sp. with a halysitoid growth form. Berdan stated (1952, written communication) that "the cateniform growth habit of this species is similar to that of *Palaeophyllum halysitoides* Troedsson, but * * * the corallites of the Utah specimens are much smaller."

The Fish Haven dolomite in the mapped area was examined by R. J. Ross, Jr., who stated (1952, oral communication) that it is almost identical lithologically with the type Fish Haven dolomite. This dolomite, on the basis of its Late Ordovician age, its stratigraphic position above the Swan Peak formation, and its lithology, is correlated with the Fish Haven dolomite of northeastern Utah. It is also correlated with units of the same name in the East Tintic Mountains (Morris and Lovering, 1961, p. 58–63), the Gold Hill mining district (Nolan, 1935, p. 16–17), and the Confusion Range (R. K. Hosé, 1955, written communication). The Fish Haven dolomite is probably equivalent at least in part to the Hanson Creek formation in the vicinity of Eureka, Nev. (Nolan, Merriam, and Williams, 1956, p. 32–34) and the Ely Springs dolomite in the Pioche district (Westgate and Knopf, 1932, p. 15–16).

ROCKS OF ORDOVICIAN OR SILURIAN AGE

In many areas in western Utah and eastern Nevada the Ordovician-Silurian boundary is difficult to locate exactly. In the Thomas and Dugway Ranges a practically unfossiliferous formation, the Floride dolomite, lies between the Ordovician Fish Haven dolomite and rocks of known Silurian age. This formation may be wholly Ordovician, wholly Silurian, or of both ages.

FLORIDE DOLOMITE (UPPER ORDOVICIAN OR SILURIAN)

The Floride dolomite was originally named by Staatz and Osterwald (1959, p. 21–22) in their report on the Thomas Range fluorspar district. It was named from exposures at the Floride mine on the east side of the central part of Spor Mountain.

The Floride dolomite is most common on Spor Mountain, where it occurs mainly along the east side of the mountain. In the Dugway Range it is found mainly in three areas: (1) on the east side of the southern part of Fandangle Canyon, (2) north, west, and south of peak 6,830, and (3) west of Castle Mountain on the west side of the Dugway Range.

Lithology.—In general the Floride dolomite consists of thin-bedded fine-grained gray smooth-weathering dolomite and limy dolomite. These partly-covered rocks commonly form a slope between the massive dark dolomite ledges at the top of the Fish Haven dolomite and the base of the overlying Bell Hill dolomite.

The lower 40 to 60 feet of the Floride dolomite is light-gray, pinkish-gray, or dark gray fine-grained smooth-weathering limy dolomite, which is thin and nodular. On Spor Mountain the next higher beds contain numerous small spherical holes, 1 to 2 mm across, but in the Dugway Range these beds were not observed. The upper part of the formation is light- to dark-gray fine- to medium-grained dolomite, which on Spor Mountain is locally limy and cherty. In places these beds have a sandy texture and are faintly banded or mottled a lighter gray.

A sample of the limy dolomite was found by analysis to contain 81 percent dolomite in its carbonate fraction (table 5).

The stratigraphic section given below illustrates the lithology of the formation at its type section.

Type section of the Floride dolomite, measured about 2,600 feet north of the Floride mine, Spor Mountain

	Thickness (feet)
Bell Hill dolomite: Dolomite, dark-gray, medium-grained, banded; contains silty fragments and cup corals.	
Floride dolomite:	
1. Dolomite, gray, fine-grained; weathers smooth; contains poorly preserved horn corals	13
2. Dolomite, gray to light-gray; some beds mottled	50
3. Dolomite, dark-gray, fine-grained, banded	5
4. Dolomite, gray, fine-grained, banded; contains numerous small holes 1 to 2 mm across	8
5. Dolomite, dark- to light-gray, very fine grained; several covered intervals	20
6. Dolomite, light- to pinkish-gray, limy, fine-grained; lumpy 1-in. layers	39
Total thickness of Floride dolomite	135
Fish Haven dolomite: Dolomite, gray to dark-gray, mottled; limy in places; medium-grained.	

Thickness.—Although the Floride dolomite is generally poorly exposed, its total thickness can be measured with considerable accuracy; it lies between the resistant dolomites in the overlying and underlying formations. The Floride was measured at three places on Spor Mountain and at two in the central part of the Dugway Range. From south to north these localities are: (1) 2,600 feet north of the Floride mine in NE¼ sec. 3, T. 13 S., R. 12 W., (2) 5,800 feet S. 45° E. of the Lost Sheep mine, (3) 3,400 feet S. 16° W. of the Blowout mine, (4) 5,000 feet S. 30° W. from peak 6,830 in the Dugway Range, and (5) 7,400 feet N. 74° W. of the top of Castle Mountain. The thickness of the Floride dolomite at these five localities is 135, 120, 100, 100, and 100 feet, respectively. These figures indicate that the formation thins from the south end to the north end of Spor Mountain, but from there to the Dugway Range the thickness remains constant.

Age and correlation.—Fossils are extremely rare in the Floride dolomite; the only ones noted were poorly preserved unidentifiable cup corals found about half a mile north of the Floride mine on Spor Mountain. Near the top of the underlying Fish Haven the Late Ordovician coral *Palaeophyllum* has been found, and in the lowest beds of the overlying Bell Hill dolomite a collection of seven Silurian corals has been made. Thus, the age of the Floride may be Late Ordovician, Silurian, or both.

ROCKS OF SILURIAN AGE

In the area mapped, Silurian sedimentary rocks make up most of Spor Mountain; they are also found in the Dugway Range near the head of Fandangle Canyon, northwest and south of peak 6,830, and on the mountain 4,000 feet west of Castle Mountain. In all these areas, the rocks of Silurian age are highly faulted; the most complete sections are found on Spor Mountain.

The Thomas and Dugway Ranges lie in the eastern part of the Silurian geosyncline. The eastern border of this geosyncline lies from 2 to 20 miles east of the East Tintic Mountains and trends roughly north to Great Salt Lake and then turns to the east. In the East Tintic Mountains (Morris and Lovering, 1961, p. 64), the Silurian section is less than 300 feet thick and is entirely within the Bluebell dolomite, which also contains rocks of Late Ordovician and Devonian age. The Silurian section thickens westward towards the central part of the geosyncline, and on Spor Mountain in the Thomas Range it is about 1,200 feet thick. The section within the deeper part of the original geosyncline shows some local variation for at Gold Hill (Nolan, 1935, p. 17) it is only 970 feet thick. Elsewhere the thickness remains fairly constant westward to the western part of White Pine County, Nev. West of this area the section thickens again, and 4,100 feet of Silurian sedimentary rocks has been reported in the Roberts Mountains (Nolan, Merriam, and Williams, 1956, pl. 2).

Silurian sedimentary rocks in most areas in Utah have been called the Laketown dolomite and correlated with the type section in the Randolph quadrangle in northeastern Utah (Richardson, 1941, p. 18). In two areas other names have been used. One of these is the East Tintic Mountains where the sedimentary rocks were deposited on the sloping shelf of the geosyncline; these sedimentary rocks are much thinner and lithologically are quite different from the Laketown of other areas. The other area is in western Millard County, where Rush (1956, p. 20–25) correlated the lower part of the Silurian sequence with the Roberts Mountains formation of eastern Nevada and named two new formations the Jack Valley formation and the Decathon dolomite. We examined some of these rocks in the southern part of the Confusion Range and found that they resemble rocks mapped as Laketown in other areas.

On Spor Mountain in the Thomas Range and in the Dugway Range, we mapped four new Silurian formations (the Bell Hill dolomite, the Harrisite dolomite, the Lost Sheep dolomite, and the Thursday dolomite) in addition to the previously described Floride dolomite, which is tentatively assigned to the Ordovician and Silurian systems. These five units are fairly widespread and were recognized by us also in the northern part of the Fish Springs Range and the southern part of the Confusion Range.

Among the fossils collected from the four dolomites of Silurian age in the Thomas and Dugway Ranges, types such as *Favosites* sp., *Halysites* sp., *Heliolites* sp., and *Virgiana* sp., are similar to those in the Laketown dolomite in the Logan quadrangle of northeastern Utah (Williams, 1948, p. 1138), the Randolph quadrangle of northern Utah and western Wyoming (Richardson, 1941, p. 18), and the Gold Hill mining district in western Utah (Nolan, 1935, p. 18). Gardner [2] also reported Laketown dolomite in the West Tintic Range. According to Jean Berdan and Helen Duncan (1953, written communication), who examined the fossils from our area, some of the collections contain elements not observed in the Laketown. Although the Silurian rocks of the Thomas and Dugway Ranges appear to correlate, at least in part, with the Laketown of northeastern Utah, uncertainty of the exact age range of the type Laketown prevents precise correlation.

BELL HILL DOLOMITE (MIDDLE SILURIAN)

The Bell Hill dolomite was originally described by Staatz and Osterwald (1959, p. 23–25) in their report on the Thomas Range fluorspar district. The formation was named from outcrops at the Bell Hill mine on the southern end of Spor Mountain.

The Bell Hill dolomite is found in five general areas: (1) fault blocks scattered throughout the cen-

[2] Gardner, W. C., 1954, Geology of the West Tintic mining district and vicinity, Juab County, Utah: Univ. Utah, Master's thesis.

tral and southern parts of Spor Mountain, (2) fault blocks along the east side of the southern end of Fandangle Canyon, (3) fault blocks north, west, and south of peak 6,830 in the Dugway Range, (4) a small patch 6,000 feet southwest of Castle Mountain on the west side of the Dugway Range, and (5) a number of adjacent fault blocks on the west side of the Dugway Range west of Castle Mountain.

Lithology.—In the Dugway Range the Bell Hill dolomite consists of alternating gray and dark-gray dolomite, with a massive dark-gray dolomite unit at the base and a light-gray, partly limy dolomite unit at the top. On Spor Mountain, the formation is dark-gray coarse-grained dolomite except for the light-gray, partly limy dolomite at the top. The formation shows minor local variations in both areas.

The bottom of the Bell Hill dolomite is placed at the base of a ledge of black dolomite that overlies the slope-forming light-gray Floride dolomite. The top of the formation is placed at the bottom of a massive ledge of black dolomite that forms the base of the Harrisite formation.

The lowest unit of the Bell Hill dolomite is a conspicuous ledge of massive coarse- to medium-grained dark-gray to black dolomite, characterized by sand-size dolomite grains, color banding, and local cross-bedding. A marker bed 3 to about 20 feet thick near the base of this unit contains angular lenslike pieces of a lighter gray dolomite in the darker matrix. Cup corals are common in this marker. A banded zone composed of dolomite and brown chert stringers and lenses is found locally near the base of the unit in the Dugway Range. The lower dark dolomite unit is much thicker in the Thomas Range than in the Dugway Range, and locally it becomes lighter gray.

In the Dugway Range the middle part of the formation is made up of alternating light- and dark-gray beds which are 6 inches to 2 feet thick and consist of fine-grained sandy-textured, locally laminated dolomite. The color of individual beds commonly lightens or darkens along strike. The lighter colored beds in this interval, some of which weather tan, are typically pock-marked with numerous cavities or oval-shaped areas of darker dolomite as much as 1 mm across. Some of these cavities may be remains of algae. A thin section of this rock contained about 75 percent dusky, very fine grained anhedra of dolomite, 20 percent oval areas of darker very fine grained dolomite with concentric structure, and 5 percent cavities. Most of the cavities are lined with a coarser grained carbonate, probably calcite. No quartz was present in the slide.

The upper part of the formation in both the Thomas and Dugway Ranges is commonly a banded fine-grained smooth-weathering light-gray dolomite, which is locally limy. It is less resistant to weathering than the overlying and underlying dolomite, and is generally covered.

A detailed stratigraphic section of this formation made on Spor Mountain is given in Staatz and Osterwald (1959, p. 19), and another section measured in the west-central part of the Dugway Range is given below.

Section of the Bell Hill dolomite, 3,000 feet S. 52° W. of peak 6,830, west-central Dugway Range

	Thickness (feet)
Harrisite dolomite: Dolomite, black, medium-grained, massive, sandy-textured.	
Bell Hill dolomite:	
1. Dolomite, light-gray, fine-grained, smooth-weathering, partly limy	45
2. Dolomite, like unit 1; interbedded with dolomite; dark gray, fine grained	24
3. Dolomite, dark-gray, fine-grained, banded	45
4. Covered	25
5. Dolomite, light-gray, fine-grained, interbedded with fine-grained dark-gray dolomite	11
6. Dolomite, like unit 3; sandy textured; beds 8 in. to 2 ft thick	20
7. Dolomite, light-gray, fine-grained; beds 6 in. to 1 ft thick	7
8. Dolomite, like unit 6	24
9. Dolomite, light- and dark-gray; like unit 5	5
10. Dolomite, dark-gray, medium-grained, sandy-textured; beds 1 to 2 ft thick	22
11. Dolomite; like unit 5, but medium-grained	52
12. Covered	10
13. Dolomite, gray, medium-grained, drab-weathering, sandy-textured; contains lenslike pieces of lighter gray finer grained dolomite; cup corals common, *Halysites* present	50
Total thickness of Bell Hill dolomite	340
Floride dolomite: Dolomite, gray, medium-grained.	

The carbonate fraction of a sample from the lower part of the Bell Hill dolomite from Spor Mountain contained 98 percent dolomite (table 5).

Thickness.—The Bell Hill dolomite was measured at three places on Spor Mountain and one in the central part of the Dugway Range. These localities from south to north are: (1) 2,600 feet north of the Floride mine in NE¼ sec. 3, T. 13 S., R. 12 W., (2) 5,800 feet S. 45° E. of the Lost Sheep mine, (3) 3,400 feet S. 16° W. of the Blowout mine, and (4) 3,800 feet S. 52° W. of peak 6,830 in the central Dugway Range. The Bell Hill dolomite is 410, 430, 395, and 340 feet thick, respectively, at these four localities. At the second locality minor faulting may have repeated part of the section. These sections show, in general, northward thinning of the formation.

Age and correlation.—The Bell Hill dolomite is the most fossiliferous of all the formations of Silurian age in the area mapped. Fossils are most abundant in the lower part of the formation, rare in the upper part. The most conspicuous fossil-bearing bed, which is a detrital dolomite containing thin lighter gray dolomitic lenses, is 4 to 20 feet above the base of the formation. This unit contains chiefly cup corals, and is apparently continuous throughout Spor Mountain and the Dugway Range. It also was noted in the northern part of the Fish Springs Range.

Fossils collected from three places in this horizon were identified by Jean M. Berdan and Helen Duncan. Two of the collections were made near the Bell Hill mine in the southern part of Spor Mountain. The first collection came from the top of a low ridge 350 feet S. 4° E. of the main ore body and contained:

Halysites (*Catenipora*?) sp.
Pycnactis? sp. and other horn corals
Cephalopods, undet.
Crinoid columnals

The second collection came from a small draw 200 feet S. 40° W. of the main ore body and contained:

Circophyllum sp.
Heliolites sp.
Favosites sp. (small corallites)
Halysites (*Cystihalysites*) sp.
(*Catenipora*?) sp.
Pycnactis? sp. and other horn corals
Entelophyllum? sp.
Stromatoporoids
Branching favositid corals
Fragments of pentameroid brachiopods
Cephalapod, undet.

The third collection came from the northeastern part of Spor Mountain, 5,000 feet S. 52° E. of the Lost Sheep mine and contained:

Favosites sp.
Halysites (*Catenipora*?) sp.
Pycnactis? and other horn corals

Horn corals were collected from several other localities at this horizon, but were unidentifiable.

Fossils are scattered throughout the overlying 100 to 150 feet of strata, but no persistent fossiliferous horizons are evident. Berdan and Duncan identified the following fossils from these beds:

Favosites sp. A (small corallites)
sp. B (large corallites)
(*palaeofavosites*?) cf. *F. asper* Orbigny
Halysites sp. (large corallites)
Horn corals, undet.
Platyceratid gastropod
Virgiana cf. *V. decussata* (Whiteaves)

The assemblage is considered to be of Middle Silurian age.

A unit equivalent in age and lithology to the Bell Hill dolomite was noted by us in the northern part of the Fish Springs Range and the southern part of the Confusion Range. The Bell Hill is tentatively correlated with a part of the Bluebell dolomite in the East Tintic Mountains (Morris and Lovering, 1961, p. 63–70) and with a part of the Roberts Mountains formation in the Eureka mining district, Nevada (Nolan, Merriam, and Williams, 1956, p. 36–37).

HARRISITE DOLOMITE (MIDDLE SILURIAN)

The Harrisite dolomite was named by Staatz and Osterwald (1959, p. 25–26) from exposures at the Harrisite mine on the south end of Spor Mountain.

The Harrisite dolomite is found in five general areas: (1) numerous northeast-trending fault blocks throughout Spor Mountain, (2) a small patch in the southern end of Fandangle Canyon, (3) fault blocks on the north, west, and south sides of peak 6,830 in the Dugway Range, (4) several patches 5,000 feet southwest of Castle Mountain on the west side of the Dugway Range, and (5) several fault blocks west of Castle Mountain on the west side of the Dugway Range.

Lithology.—The Harrisite dolomite is relatively uniform in its lithology throughout the Thomas and Dugway Ranges, where it consists entirely of massive medium-grained dark-gray to black sandy-textured dolomite. The formation overlies the slope-forming light-gray dolomite of the Bell Hill dolomite and underlies dark- to light-gray limy cherty dolomite of the Lost Sheep dolomite.

In addition to the persistent black to dark-gray color and the sandy texture, the Harrisite dolomite is characterized by numerous faint wormlike markings of white dolomite. The white markings in some places can be shown to be the remains of the chain coral *Halysites*. These markings are locally scarce in the lower 10 to 30 feet of the formation but become more numerous upwards.

The basal 10 or 15 feet of the formation is faintly mottled, somewhat limy, and color banded, and locally exhibits a brownish cast. Blebs, layers, and fracture fillings of black and brown chert make up 5 to 20 percent of the rock at some localities, particularly on Spor Mountain. Three stratigraphic sections made on Spor Mountain have previously been published (Staatz and Osterwald, 1959, fig. 2). A detailed section of this formation from the west-central part of the Dugway Range is given below.

Section of the Harrisite dolomite, 5,000 feet S. 53° W. of peak 6830, west-central Dugway Range

	Thickness (feet)
Lost Sheep dolomite: Dolomite, gray to black, medium-grained, sandy-textured; minor brown chert.	
Harrisite dolomite:	
1. Dolomite, black, medium-grained, massive, sandy-textured; numerous wormlike markings of white dolomite, probably the remains of *Halysites*, and traces of gray chert	106
2. Dolomite, gray, sandy-textured; interbedded with dark-gray sandy-textured dolomite; beds 1 to 6 in. thick	7
3. Dolomite, black, medium-grained, massive, sandy-textured; banded in places; contains a little quartz sand and traces of chert	34
Total thickness of Harrisite dolomite	147
Bell Hill dolomite: Dolomite, light-gray, fine-grained, smooth-weathering.	

The carbonate fraction of a sample of Harrisite dolomite from the northern part of Spor Mountain contained 98 percent dolomite (table 5).

Thickness.—The Harrisite dolomite is well exposed; it was measured in three places on Spor Mountain and two places in the central part of the Dugway Range. These localities from south to north are: (1) the type section, 2,000 feet N. 28° W. of the Bell Hill mine in sec. 10, T. 13 S., R. 12 W., (2) 5,000 feet S. 46° E. of the Lost Sheep mine, (3) 2,750 feet southwest of the Blowout mine, (4) 5,000 feet S. 53° W. of peak 6,830 in the central part of the Dugway Range, and (5) 9,200 feet S. 75° W. of Castle Mountain. The Harrisite dolomite is 175, 110, 120, 145, and 140 feet thick, respectively, at these localities. This formation shows a greater variation in thickness on Spor Mountain than it does between Spor Mountain and the central part of the Dugway Range. This variation suggests that the differences in thickness are due mainly to local changes in sedimentation. The average thickness of the Harrisite dolomite in this area appears to be about 140 feet.

Age and correlation.—The Harrisite dolomite contains considerable fossil debris. *Halysites* sp. and crinoid stems are commonly present but in general are poorly preserved. Easily identifiable fossils are rare. The best preserved fossils found were silicified remains collected on a hill just east of the Harrisite mine. These were studied by P. E. Cloud, Jr., of the U.S. Geological Survey, who identified: *Halysites* sp., pentamerid brachiopod, undetermined gastropod, crinoid stem. Cloud (1952, written communication) stated, "Although *Halysites*, in the broad sense, is itself an equivocal dating element in the Great Basin region, being about as common or more common in the Upper Ordovician Bighorn dolomite (as the subgenus or closely related genus (*Catenipora*) as in the Silurian, the presence of a large pentamerid brachiopod, even though not determinable as to genus, is presumptive evidence of Silurian age. The horizon is probably equivalent to some part of the Bluebell dolomite of the East Tintic Mountains." The Silurian age of these rocks can also be verified by their stratigraphic position above the Bell Hill dolomite and below the Thursday dolomite, both of which contain fossils of Middle Silurian age.

A unit equivalent to the Harrisite dolomite was also noted by us in the north end of the Fish Springs Range and in the Confusion Range. The Harrisite dolomite is tentatively correlated with a part of the Roberts Mountains formation of the Eureka district, Nevada (Nolan, Merriam, and Williams, 1956, p. 36–37).

LOST SHEEP DOLOMITE (MIDDLE SILURIAN)

The Lost Sheep dolomite was originally described by Staatz and Osterwald (1959, p. 26–28) in their report on the Thomas Range fluorspar district. It was named from outcrops of this formation at the Lost Sheep mine in the northern part of Spor Mountain.

The Lost Sheep dolomite is most common on Spor Mountain and on the neighboring Eagle Rock Ridge where it is found in northeast-trending fault blocks. This formation is less extensive in the Dugway Range, where it occurs in three areas: (1) the southern part of Fandangle Canyon, (2) north, west, and south of peak 6,830, and (3) west and southwest of Castle Mountain on the west side of the range.

Lithology.—The lower and middle parts of the Lost Sheep dolomite consist chiefly of light-gray and some dark-gray sandy-textured dolomite with a little chert; the upper part is gray dolomite containing numerous parallel chert bands. The lower contact of the formation is placed at the base of the lowest light-gray dolomite bed, and the top of the formation is the top of the highest bed containing chert bands.

The basal beds of the Lost Sheep dolomite are coarse grained, sandy textured, and limy. This unit varies in color, and on Spor Mountain it is chiefly a light-gray saccharoidal dolomite that closely resembles the overlying Thursday dolomite, but at many places in the Dugway Range it is a dark gray weathering to a medium gray that is similar to the color of the underlying Harrisite dolomite. The absence of *Halysites*, however, serves in most places to distinguish the dark facies of the Lost Sheep dolomite from the dark dolomite of the Harrisite.

The next higher unit is a dark-gray to black medium- to fine-grained, locally banded dolomite with 1 to 20 percent gray to black chert in bands and lenses 1 to 5 inches thick. Overlying this cherty zone is bluish-gray medium-grained mottled dolomite, which is limy in places. This mottled dolomite, together with the underlying dark cherty dolomite, forms a good marker zone.

The middle part of the formation is composed of a light-gray to white, slightly limy medium- to coarse-grained saccharoidal dolomite, which on Spor Mountain resembles the basal part of the Lost Sheep dolomite. Locally parts of this unit are darker gray and contain a little chert.

The top part of the formation, which averages about 70 feet thick, is a ledge-forming medium- to fine-grained gray to dark-gray dolomite. This unit generally contains from 15 to 75 percent pink or gray chert, mostly in 1- to 5-inch discontinuous bands parallel to the bedding. In the northern part of Spor Mountain the chert is generally pink or white, but elsewhere is predominantly gray. In a few places chert may constitute as much as 95 percent of the rock, while in other places it may be absent from some of the beds within this unit. This cherty unit is a persistent and excellent marker zone.

Two complete sections and the lower part of a third section found on Spor Mountain have been published previously (Staatz and Osterwald, 1959, fig. 2). A detailed stratigraphic section in the west-central part of the Dugway Range is given below.

Section of the Lost Sheep dolomite, west side of Dugway Range, 1.9 miles west-southwest of Castle Mountain

	Thickness (feet)
Thursday dolomite: Dolomite, white, medium-grained, sandy-textured.	
Lost Sheep dolomite:	
1. Dolomite, white to gray, fine- to medium-grained, sandy-textured; layers and lenses of white to gray chert. Chert layers are as much as 6 in. thick and comprise 30 to 75 percent of the rock	66
2. Dolomite, dark-gray, medium-grained, with a little brown chert mainly along fractures; partly covered	75
3. Dolomite, white, coarse-grained, saccharoidal; interbedded with light-gray medium-grained saccharoidal dolomite; unit contains white chert stringers	36
4. Dolomite, gray, medium-grained, mottled; weathers blue gray	20

Section of the Lost Sheep dolomite, west side of Dugway Range, 1.9 miles west-southwest of Castle Mountain—Continued

Lost Sheep dolomite—Continued	Thickness (feet)
5. Dolomite, dark-gray to black, fine-grained; lower part contains as much as 10 percent gray chert and has poorly preserved cup corals and brachiopods	32
6. Dolomite, dark-gray, medium grained, sandy textured; weathers medium gray; contains poorly preserved crinoid stems and brachiopods	43
Total thickness of Lost Sheep dolomite	272
Harrisite dolomite: Dolomite, black, medium-grained, massive, sandy-textured; numerous white wormlike markings, probably *Halysites*.	

Analysis of the carbonate fraction of two samples from the lower and upper parts of the formation yielded 95 and 96 percent dolomite, respectively (table 5).

Thickness.—Although good exposures of the full thickness of the Lost Sheep dolomite are fairly common in the northern part of Spor Mountain, they are rare in the central Dugway Range, where we were able to measure a complete section at only one place. Two sections of the entire formation were measured in the northern part of Spor Mountain. These three localities from north to south are: (1) 9,300 feet S. 75° W. of Castle Mountain, (2) 2,750 feet S. 21° W. of the Blowout mine, and (3) 3,000 feet S. 61° E. of the Thursday mine. The thickness of the Lost Sheep is 270, 215, and 245 feet, respectively. The lower member of this formation makes up from 150 to 205 feet of these sections, the upper member from 65 to 90 feet. The lower member of the Lost Sheep was also measured 2,500 feet N. 30° W. of the Bell Hill mine where it is 160 feet thick.

Age and correlation.—The Lost Sheep dolomite is in general poorly fossiliferous, fossils being most common in the black chert-bearing dolomite in the lower member. Although fossil fragments are common in the lower member, they are so poorly preserved that they are difficult to identify. Several collections made from this unit on Spor Mountain were examined by Jean Berdan and Helen Duncan. The following types were noted: crinoid stems, smooth pentameroid brachiopod, ribbed brachiopod, and gastropod. In addition, a coral was collected from the upper member near the Harrisite mine in the southern part of Spor Mountain. Berdan and Duncan identified this fossil as *Halysites* (*Cystihalysites*) sp. The presence of *Halysites* (*Cystihalysites*) sp. and a pentameroid brachiopod indicates a Silurian age for these rocks. Confirmatory evidence is the stratigraphic position of the Lost Sheep dolomite above the Bell Hill dolomite and below the Thursday dolomite, both of which contain fossils of Middle Silurian age.

A unit equivalent to the Lost Sheep dolomite was noted by us in the north end of the Fish Springs Range and in the southern part of the Confusion Range. The Lost Sheep dolomite is correlated with a part of the central part of the Laketown dolomite and tentatively correlated with a part of the Roberts Mountains formation in the Eureka district (Nolan, Merriam, and Williams, 1956, p. 36–37).

THURSDAY DOLOMITE (MIDDLE SILURIAN)

The Thursday dolomite was named by Staatz and Osterwald (1959, p. 28–29) for exposures at the Thursday mine in the northern part of Spor Mountain.

The Thursday dolomite crops out in numerous northeast-trending fault blocks on Spor Mountain. It is most common in the northern part of Spor Mountain, but is also common in the southern part, along the west side, and on Eagle Rock Ridge. The Thursday dolomite is less common in the Dugway Range where it is found mainly in three areas: (1) outcrops on the east side of Fandangle Canyon, (2) fault blocks north, west, and southwest of peak 6,830, and (3) fault blocks southwest of Castle Mountain on the western side of the Dugway Range.

Lithology.—The Thursday dolomite is a rather uniform light-gray medium-grained saccharoidal, somewhat friable rock which is generally a slope maker. The lower contact is the top of the highest cherty beds of the Lost Sheep dolomite; the upper contact is at the base of the fine-grained dense light-gray dolomite of the Sevy dolomite.

A medium-grained gray dolomite approximately 15 feet thick with 1- to 4-inch bands of pink chert parallel to the bedding occurs about 135 feet above the base of the formation in the northern part of Spor Mountain. Lithologically his unit is indistinguishable from the cherty member at the top of the Lost Sheep dolomite. Brown chert occurs as a fretwork along fractures in many places in the Thursday dolomite, particularly in the upper third of the formation.

Insoluble residues of the dolomite show that it contains minor amounts of clear quartz grains and white chert. Uniform-sized subhedral dolomite crystals averaging about 0.4 mm across make up almost all of a thin section examined. A few cavities are lined with dolomite and minute amounts of subhedral quartz grains. The carbonate fraction of a sample of Thursday dolomite contained 98 percent dolomite (table 5).

Thickness.—Although the Thursday dolomite is quite common on Spor Mountain, and is exposed in a few places in the western part of the Dugway Range as well, its thickness is difficult to measure. In the Dugway Range the Thursday dolomite is not found in contact with the overlying Sevy dolomite, and on Spor Mountain no complete section is found owing to the numerous faults. The thickness was estimated by combining two partial sections. The lower part of this formation from the base to a bed containing a network of thin chert was measured 100 feet west of the Blowout mine, and the thickness from the bottom of this bed to the overlying Sevy dolomite was measured 1,400 feet to the southeast. The composite thickness, thus obtained, is 330 feet.

Age and correlation.—The Thursday dolomite is poorly fossiliferous, and even traces of fossil debris are rare. Identifiable fossils were found only at two localities where they had been replaced by chert. Jean Berdan and Helen Duncan examined these collections. The species of *Halysites* was identified by E. J. Buehler. The best collection came from the north end of Spor Mountain, 5,000 feet N. 41° W. of the Lost Sheep mine, and contains the following:

Zelophyllum aff. *Z. intermedium* Wedekind
Halysites magnitubus Buehler
Favosites? sp. (small corallites)
Alveolites sp.
Stromatoporoids

The other collection came from the west side of the Dugway Range, 6,700 feet S. 50° W. of peak 6,830, and contains the following:

Halysites sp.
Heliolites? sp.
Beak of pentameroid brachiopod

According to Berdan and Duncan (1952 and 1955, written communications) both collections are Middle Silurian in age.

A unit lithologically similar and in the same relative position in the section as the Thursday dolomite was noted by us in the northern part of the Fish Springs Range and the southern part of the Confusion Range. The Lost Sheep is correlated with the upper part of the Laketown dolomite of western and northern Utah, probably with part of the Bluebell dolomite of the East Tintic Mountains (Morris and Lovering, 1961, p. 63–70), and with the upper part of the Roberts Mountains formation of the Eureka district, Nevada (Nolan, Merriam, and Williams, 1956, p. 36–37).

ROCKS OF DEVONIAN AGE

Sedimentary rocks of Devonian age in the Thomas and Dugway Ranges, with the exception of those belonging to the Lower and Middle(?) Devonian Sevy dolomite, differ considerably in lithology and thickness from known rocks of Devonian age in surrounding areas. The Devonian sedimentary rocks are about 6,000 feet thick in the northern part of the Dugway Range, and may be more than 7,000 feet thick in the Black Rock Hills. The greater thickness of the Devonian section in the area mapped is for the most part in the Upper Devonian, where the sedimentary rocks are approximately 4,000 feet thick and represent one of the greatest thicknesses of Upper Devonian rocks known in the western United States.

Upper Devonian rocks in nearby parts of the Great Basin are much thinner. The Devonian rocks in the Gold Hill district, reported by Nolan (1935, p. 18–21) to be of Early and Middle Devonian age, have been shown by further work (C. W. Merriam, 1955, written communication) to contain some beds of Late Devonian age. According to Merriam, approximately 200 feet of the Guilmette formation, the beds including *Platyschisma*? cf. *P. mccoyi* Walcott and above, is probably of Late Devonian age. In the Confusion Range, Hose (1955, written communication) measured 2,650 feet of Guilmette formation, of which 75 to 400 feet is Late Devonian; in the East Tintic Mountains, Morris and Lovering (1961, p. 63–78) measured 300 to 600 feet of sedimentary rocks of Late Devonian age; at Newark Mountains in the Eureka, Nevada, region Nolan, Merriam, and Williams (1956, p. 48–52) found that the upper member of the Devils Gate formation is 790 feet thick. The Middle-Late Devonian boundary lies in the upper half of this member. Thus, on three sides of the Thomas and Dugway Ranges the sedimentary rocks of Late Devonian age do not exceed 600 feet in thickness; this thickness contrasts markedly with the approximately 4,000 feet of Upper Devonian rocks found in the mapped area.

The great local thickness of Upper Devonian rocks, together with the apparent shallow-water deposition of most of the rocks, suggests that during Late Devonian time the Thomas and Dugway Ranges were near the center of a rapidly sinking basin. Considerable differences in lithology do not permit exact correlations of these sedimentary rocks with formations in surrounding regions.

The sedimentary rocks of Devonian age in the Thomas and Dugway Ranges are divided into five formations, four of them new, and a local sequence of Upper Devonian rocks whose stratigraphic position is not certain. This last unit is mapped as Upper Devonian, undivided.

The lowermost Devonian formation in the area mapped is the Sevy dolomite, which has also been reported in the Gold Hill region (Nolan, 1935, p. 18–19), Confusion Range (Hose, 1955, oral communication), and numerous places in eastern Nevada (Osmond, 1954, p. 1914–1931). Overlying the Sevy is the Engelmann formation of Middle to Late Devonian age followed by the Goshoot formation, Gilson dolomite, and Hanauer formation, all of Late Devonian age. Except for the lower 800 feet of the Sevy dolomite, the Devonian rocks form an unbroken sequence in the northeastern part of the Dugway Range.

Sedimentary rocks of Late Devonian age in the Black Rock Hills are found in three separate areas or blocks containing rocks with similar lithology and fossils, but differing in their lithologic sequence. These blocks along with the various types of lithology exposed are shown in plate 3. The first block (A) in the northern half of the eastern part of the Black Rock Hills contains an unbroken sequence starting with the upper 1,000 feet of the Engelmann formation and including the Goshoot formation, the Gilson dolomite, and most of the Hanauer formation. This block is separated from the second block (B) in the southern half of the eastern part of the hills by a fault with a minimum displacement of 3,100 feet. The sedimentary rocks in block B are chiefly limestone and some quartzite and a little dolomite. The third block (C) is a group of low hills approximately 4,000 feet southeast of block B. The sedimentary rocks in block C are dolomite, limestone, and quartzite.

The sedimentary rocks in all three blocks are similar in some places, but the detailed stratigraphy indicates that the sequence is not repeated. The bottoms of the sections in all three blocks begin at the upper margin of Lake Bonneville sediments, and the tops of the sections are covered either by Lake Bonneville sediments or Tertiary rocks.

The paradoxical situation arises that a complete stratigraphic section of Late Devonian rocks in the northeastern part of the Dugway Range correlates well with the sedimentary rocks of block A in the Black Rock Hills, but has no apparent equivalents with the Upper Devonian sections in blocks B and C. Possibly sedimentation during one part of the Late Devonian was greatest in the area of the Black Rock Hills, and during this relatively short time the sequences found in blocks B and C were deposited in this one area but not in the northeastern part of the Dugway Range, 12 miles to the northeast.

The position of the sedimentary rocks in blocks B and C within the Late Devonian sequence may be suggested in accordance with this hypothesis: Block A, which lies across Goshoot Canyon from block B, has only the upper part of the Hanauer and the lower part of the Engelmann formations missing. Inasmuch as it is very unlikely that such a large change in sedimentation could occur in the short distance across Goshoot Canyon, sediments in blocks B and C probably occur in the missing parts of the section in block A. Of the two formations incompletely exposed in block A, occurrence of the missing parts in the lower part of the Engelmann formation seems more likely because: (1) a much greater part of it is not exposed in block A, (2) block C contains the coral, *Pachyphyllum*, which Merriam (1940, p. 59) used as a marker zone for earliest Late Devonian, and (3) the Hanauer formation contains *Cyrtospirifer*, which Merriam (1940, p. 61) used as a marker for a younger zone in the Late Devonian. Unfortunately, block B contains no fossils that are diagnostic within Late Devonian time.

Overthrusting is a second possible explanation of the differences between the sedimentary rocks in blocks B and C and those in the rest of the region. According to Baker (Baker, Huddle and Kinney, 1949, p. 1179), two different sequences of Pennsylvanian rocks are separated by a large thrust fault in the central Wasatch Mountains. Nolan, Merriam, and Williams (1956, p. 23–36) reported a western facies and an eastern facies of Ordovician rocks separated by a thrust fault in the Eureka, Nev., area, and Nolan (1935, p. 23) reported three separate facies of Carboniferous rocks brought close together by overthrusts in the Gold Hill area. Although thrust faulting is a distinct possibility, this explanation does not appear as probable as that of a sudden facies change, for the following reasons: (1) the main fault in Goshoot Canyon has a straight trace suggesting a fairly steep dip; (2) although overthrusting is common 50 miles to the west and east of this region (Nolan, 1935, pl. 1; T. S. Lovering, 1954, oral communication) and there is a large thrust in the Dugway Range, no major thrusts have been found in the Thomas Range; (3) sedimentary rocks similar to those found in blocks B and C are not known in ranges either to the west or east; and (4) large facies changes are known to occur in Upper Devonian sedimentary rocks between the Thomas and Dugway Ranges and the surrounding ranges.

Inasmuch as the exact relation of the sequence of sedimentary rocks in blocks B and C, both to the established Upper Devonian sequence and to each other, is not known and the two sequences are incomplete, the writers have not used formational names for these rocks.

SEVY DOLOMITE (LOWER (?) AND MIDDLE DEVONIAN)

Sevy dolomite was named for its exposures in Sevy Canyon in the Deep Creek Range, where it was originally described by Nolan (1935, p. 18–19).

Most of the Sevy dolomite in the area mapped crops out on hills and ridges on the west flank of Spor Mountain. A few smaller blocks of Sevy dolomite are found on Spor Mountain south of the Blowout mine and on the south end of Eagle Rock Ridge. The only Sevy in the Dugway Range is on the west side of Fandangle Canyon.

Lithology.—The Sevy dolomite is a fine-grained mouse-gray dolomite of distinctive character. The color is uniform for the most part, though a few beds in the lower part are a little darker, a few lighter, and a few show vague mottling. Toward the top of the formation some of the dolomite layers are blue gray. Weathered surfaces are rough, and exposed surfaces are characteristically grooved (fig. 9) with

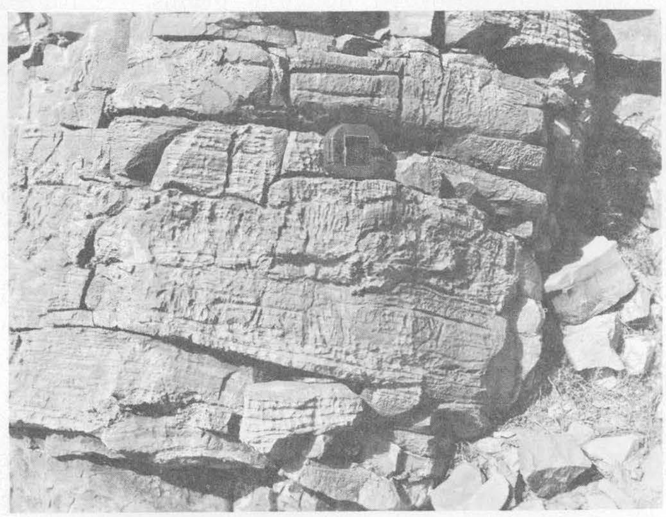


FIGURE 9.—Sevy dolomite, showing characteristic grooving along and across laminations.

numerous curving and crisscrossing channels 0.8 to 4.8 mm deep, probably formed by differential solution. The formation is thin to medium bedded. The dolomite is dense and fine-grained and has an almost lithographic texture. Toward the base of the formation a little dark-colored chert fills joints and fracture planes.

In some places the Sevy dolomite has a gradational contact with the underlying Thursday dolomite, but in others the contact is sharp. Near the contact in the northern part of Spor Mountain, beds of typical mouse-gray dolomite are interlayered with beds of white detrital dolomite in which thin chert seams fill a network of fractures. The base of the Sevy dolomite here was arbitrarily placed on the top of the uppermost white sandy dolomite layer. Near the south end of Spor Mountain the contact is abrupt, and no interlayering is evident. The upper contact with the Engelmann formation is gradational; the top of the Sevy dolomite was placed on the base of a 10-foot unit of white massive dolomite, which underlies a 3-foot bed of black massive dolomite. These two thin beds are quite persistent and constitute a prominent sedimentary marker, even though some beds of Sevy-type lithology are present above them. Nolan (1935, p. 19) found a similar break above the Sevy dolomite in the Gold Hill district.

A sample of the Sevy dolomite (table 5) collected northwest of Spor Mountain was analyzed for acid soluble MgO and CaO. The dolomite content calculated from this analysis makes up 96 percent of the carbonate fraction.

In thin section the Sevy dolomite is very fine grained and most of the rock consists of a mixture of clay and clay-sized dolomite grains. Scattered through the fine-grained matrix are numerous irregular-shaped aggregates of clear dolomite anhedra less than 1 mm across. The matrix also contains scattered clots of fine-grained clay and carbonate, all of which contain limonite.

Thickness.—No completely exposed section of the Sevy dolomite exists within the area mapped. Most of the Sevy in the mapped area occurs on the west side of Spor Mountain as isolated outcrops surrounded by gravels of Lake Bonneville. In order to obtain at least an approximate thickness of this formation, a measurement was made on the west side of Spor Mountain starting at a point 7,000 feet N. 68° W. of the Lost Sheep mine (fig. 50). Although approximately 60 percent of this area is covered and minor faulting may be present, this area is the best available for measuring a section. The total indicated thickness of the Sevy dolomite at this locality is 1,120 feet. At the type locality in Sevy Canyon, Nolan (1935, p. 19) reported 450 feet of Sevy dolomite. Osmond (1954, p. 1911–1931) made a study of the Sevy, and measured 20 sections in eastern Nevada and 1 in western Utah. His measurements included 1,600 feet of Sevy in Kings Canyon in the Confusion Range, 567 feet in the Lime Mountains south of the Snake Range, and 570 feet at Big Springs Ranch in the southern Snake Range. From all his data Osmond constructed an isopach map (1954, p. 1912), the dominant feature of which is the thinning of the Sevy along the Utah-Nevada line. Thus, the Sevy appears to be thinnest in its type area and thickens both to the east and to the west. East of the Thomas Range the Sevy dolomite again thins, for Gardner (see footnote, p. 42) reported only 700 feet in the West Tintic Range. A short distance farther east, this formation evidently pinches out or is included in the Bluebell dolomite in the East Tintic Mountains.

Age and correlation.—No fossils have been found in Sevy dolomite in the Thomas and Dugway Ranges, and it is correlated with the Sevy dolomite in the Deep Creek Range on the basis of lithology. Nolan (1935, p. 18) stated, "The Sevy dolomite is remarkably homogeneous throughout the area of outcrop. The typical rock is well-bedded mouse-gray dolomite in layers 6 to 12 inches thick and weathers to a very light gray. It is of extremely dense texture and has a conchoidal fracture. In most of the beds a faint lamination parallel to the bedding is visible, in part at least, because of slight differences in color in adjoining laminae." This description might well have been used for the rocks mapped as Sevy in the Thomas and Dugway Ranges. The only fossils Nolan (1935, p. 19) found were small crinoid stems. Because the Sevy of the type locality has an unconformity at its base and grades into the overlying Simonson dolomite, which contains Middle Devonian fossils, Nolan considers the Sevy to be Devonian in age and probably Middle Devonian. The Eastern Nevada Geological Association Stratigraphic Committee (1953, p. 146) also considers the Sevy to be Devonian in age. More recently Osmond (1954, p. 1928) has reported finding *Halysites* sp. in beds referred by him to the lower part of the Sevy dolomite in the southern part of the Egan Range in southernmost White Pine County, Nev. On the basis of this fossil, Osmond believed at least the lower part of the Sevy dolomite is Silurian in age.

Osmond (1954, p. 1914) correlated the Sevy with the Lone Mountain formation, which has Upper Silurian fossils in its upper 600 feet (Nolan, Merriam, and Williams, 1956, p. 39). His correlation is based on the striking lithologic similarity of the two formations and their comparative stratigraphic positions. Osmond's view to the contrary, the Sevy does not lithologically resemble the Lone Mountain, for the Sevy is a thin- to medium-bedded fine-grained dense rock (Nolan, 1935, p. 19) and the Lone Mountain is a thick-bedded to massive medium-grained saccharoidal rock (Nolan, Merriam, and Williams, 1956, p. 38). Hence, the rocks from which Osmond collected the *Halysites* may not be those generally considered to be Sevy.

The present writers, mainly on the basis of work by Nolan (1935, p. 18–19) and by the Eastern Nevada Stratigraphic Committee (1953, p. 146), consider the

Sevy to be entirely Devonian in age and the lowermost beds to be probably Early Devonian.

The Sevy dolomite probably can be correlated directly with the Beacon Peak dolomite member of the Nevada formation at Eureka, Nev. These two formations have the same stratigraphic position, and according to Nolan, Merriam, and Williams (1956, p. 48) are lithologically identical. The Sevy is also possibly correlated with part of the upper half of the Bluebell dolomite of the East Tintic Mountains, but Morris and Lovering (1961, p. 63–70) did not actually recognize any beds equivalent to the Sevy in that area.

ENGELMANN FORMATION (MIDDLE AND UPPER DEVONIAN

The Engelmann formation is here named from its exposures on both sides of Engelmann Canyon in the northeastern part of the Dugway Range.

The lower 350 feet of the Engelmann formation lying west of the northern part of Spor Mountain has been previously described as Simonson-Guilmette formation, undivided (Staatz and Osterwald, 1959, p. 31–32). This name was used for these poorly exposed outcrops because the Simonson dolomite and Guilmette formation overlie the Sevy dolomite in the Gold Hill district and have a somewhat similar lithology (Nolan, 1935, p. 19–21). The Simonson consists in its type section in the Gold Hill district of dark- to medium-gray dolomite, and the Guilmette formation consists of interbedded limestone and dolomite and a few sandstone beds; the two formations are separated by a dolomitic conglomerate at the base of the Guilmette. In the relatively thin section exposed west of Spor Mountain, the lower part is dolomite and the upper part is dolomite and limestone. Because no dolomitic conglomerate is present and banded beds so characteristic of the Simonson dolomite at its type section are lacking, Staatz and Osterwald (1959, pl. 1) did not map the two formations separately. Further work in the Black Rock Hills and the Dugway Range has shown that the rocks previously mapped as Simson-Guilmette, undivided, are the basal part of a much thicker formation that we now call the Engelmann.

The Engelmann formation is exposed in four general areas: (1) isolated outcrops lying west of the northern part of Spor Mountain, (2) a band 1.8 miles long extending northward from Goshoot Canyon in the Black Rock Hills, (3) on the eastern tips of several ridges and on both sides of Engelmann Canyon, the type locality, in the northeast part of the Dugway Range, and (4) several low hills on the west side of the Dugway Range, approximately 2 miles south-southeast of the mouth of Cannon Canyon. This formation also extends northward into the southern end of the Dugway Proving Ground SW quadrangle.

Lithology.—The Engelmann formation consists chiefly of a massive sandy-textured light-gray to black dolomite with some interbedded light-gray to black limestone in the lower half of the formation. The base of the formation is placed at the base of a 10-foot unit of massive white medium-grained dolomite on the northwest side of Spor Mountain and at the base of a massive black medium-grained dolomite in the northern part of the Dugway Range. In both areas the contact is placed where the first distinctly crystalline sandy-textured dolomite overlies the mouse gray aphanitic, thinly laminated dolomite typical of the Sevy. Above this horizon a few beds with Sevy-type lithology occur interbedded with the more coarsely crystalline dolomites. The top of the Engelmann formation is placed at the bottom of the first quartzite marking the base of the Goshoot formation. Several dolomite beds in the upper part of the Engelmann formation contain some quartz sand.

Dolomite makes up the greater part of this formation, and in the Dugway Range the only exceptions are several limestone beds, the largest of which is approximately 30 feet thick. In the Black Rock Hills the upper 1,000 feet of this formation is entirely dolomite. Below this part of the section, dolomite is interbedded with limestone. The dolomite is medium to fine grained and, although it ranges in color from light gray to black, medium and dark gray are the commonest colors. Chert is present in only a few beds. The crossbedding that was noted in several places indicates that in part the dolomite is of detrital origin. The dolomite beds near the base of the section northwest of Spor Mountain are commonly calcareous. The limestone, some of which is dolomitic, is similar to the dolomite in grain size and color.

A specimen of dolomite taken from near the base of the formation northwest of Spor Mountain contained 75 percent dolomite in its carbonate fraction; a specimen of limestone taken in the same area contained only 1.4 percent dolomite in its carbonate fraction (table 5).

The entire Englemann formation is present only in the vicinity of Engelmann Canyon in the Dugway Range. Because much of the formation is covered by alluvium in this area, no detailed stratigraphic section was measured. A partial section of the lower 350 feet, northwest of Spor Mountain has previously been published (Staatz and Osterwald, 1959, p. 33). A detailed section of the upper 1,036 feet in the Black Rock Hills is given below.

Section of the upper part of the Engelmann formation measured on a ridge 2,200 feet north of Goshoot Canyon, Black Rock Hills

[Fossils identified by C. W. Merriam, Jean Berdan, and Richard Rezak]

	Thickness (feet)
Goshoot formation: Quartzite, dolomitic, white, medium-grained; weathers brown.	
Engelmann formation:	
1. Dolomite, light-gray, medium-grained, sandy-textured; numerous pockets and irregular stringers of white dolomite and calcite	9
2. Dolomite, black, fine-grained, massive	15
3. Dolomite, medium-gray, medium-grained, massive; weathers drab brown; two thin beds of lighter gray dolomite at top of unit	74
4. Dolomite, black, medium-grained, massive	13
5. Dolomite, light-gray, fine-grained; weathers rust brown; contains a little quartz sand	24
6. Dolomite, like unit 4	2
7. Dolomite, light-gray, fine-grained, sandy-textured	7
8. Dolomite, like unit 4; bed 45 ft from base contains *Atrypa* sp.; unidentifiable gastropods and pelecypods at base	91
9. Dolomite, gray, fine-grained; weathers to a rust color; contains some quartz sand and chert stringers	4
10. Dolomite, black, fine-grained, massive	8
11. Dolomite, gray, fine-grained; weathers olive green; contains irregular chert lenses	12
12. Dolomite, black, medium-grained, massive, interbedded with medium-gray medium-grained dolomite. Rock is banded and sandy textured; crossbedding was noted at one place. At top of unit are the coral *Pachyphyllum* sp., massive stromatoporoids, and unidentifiable horn corals and gastropods. At 77 ft from top is 0.1 ft-bed containing *Amphipora* sp. Between 106 and 121 feet from the top of the unit occur (1) *Amphipora* sp., (2) the corals *Spongophyllum* sp., *Favosites* cf. *F. limitaris* Rominger, and a ramose favositid coral, (3) massive stromatoporoids(?), (4) *Hermatostroma* cf. *H. episcopale* Nicholson, and (5) unidentifiable gastropods. At 214 ft from top of unit occur *Favosites* cf. *F. limitaris* Rominger and stromatoporoids. At base of unit are several small beds of *Amphipora* sp	273
13. Dolomite, medium-gray, with patches and irregular lenses of lighter dolomite	11
14. Dolomite, light- to dark-gray, fine- to medium-grained, banded	48
15. Covered	27
16. Dolomite, light- to medium-gray, medium-grained, massive; weathers brown; contains numerous fractures filled with white dolomite stringers. Several beds near base contain *Amphipora* sp. and poorly preserved gastropods	112
17. Dolomite, like unit 10	19
18. Covered	11
19. Dolomite, medium-gray, medium-grained, massive; weathers brown	31
20. Covered	47
21. Dolomite, like unit 19	11

Section of the upper part of the Engelmann formation measured on a ridge 2,200 feet north of Goshoot Canyon, Black Rock Hills—Continued

	Thickness (feet)
Engelmann formation—Continued	
22. Covered	29
23. Dolomite, dark-gray to black, fine- to medium-grained, massive; weathers brown; cut by irregular stringers of white calcite	38
24. Covered	16
25. Dolomite, dark-gray, medium-grained, massive; weathers brown	16
26. Dolomite, like unit 7; thin-bedded	13
27. Dolomite, medium-gray, medium-grained, massive; weathers tan to brown; beds 0.2 to 3 ft thick. Upper part contains brachiopod *Athyris* cf. *A. angelicoides* Merriam and gastropod *Straparollus* cf. *S. ophirensis* Hall and Whitfield	60
28. Limestone, light- to medium-gray, fine-grained, thin-bedded; near top of unit are brachiopod *Atrypa* sp., minute bellerophon gastropods, and indeterminate conodonts	15
Total thickness of upper part of Engelmann formation	1,036
Lake Bonneville beds.	

Thickness.—Although the Engelmann formation occurs in several localities in our area, only in the vicinity of Engelmann Canyon are both the lower and upper contacts exposed. This area is poor for measuring a section, however, because it consists of low ridges separated by wide alluvium-filled valleys. An approximate measurement made from the map indicates that the Engelmann formation is about 2,750 feet thick at this locality. Partial sections have been measured on the north side of Goshoot Canyon, where 1,035 feet of Engelmann dolomite is exposed, and west of Spor Mountain (Staatz and Osterwald, 1959, p. 33), where the basal 350 feet was measured.

Age and correlation.—Collections of fossils were made from the Engelmann formation in three general areas: (1) northwest of Spor Mountain, (2) the northeastern part of the Dugway Range south of Engelmann Canyon, and (3) the Black Rock Hills north of Goshoot Canyon. The first collections from northwest of Spor Mountain came from the lower 300 feet of the formation and were examined by Jean Berdan, who reported unidentifiable dolomitized brachiopods and the stromatoporoid *Amphipora* sp. Later collections of slightly better preserved brachiopods from the same locality were examined by C. W. Merriam, who stated that they are too poorly preserved for positive identification, but are probably *Stringocephalus* sp. The collection from the northeastern part of the Dugway Range, which came from approximately 700 feet above the base of the section, was examined by Merriam. This collection contains a thoroughly recrystallized stromatoporoid, which may be either *Amphipora* sp. or *Cladopora* sp., and a smooth-shelled brachiopod, not generically determinable, but suggestive of *Stringocephalus* sp. If the above brachiopods are *Stringocephalus*, then a Middle Devonian age is indicated for this part of the formation. The collections from the Black Rock Hills, which came from the upper 1,000 feet of the formation, were examined by several people. Fossils from the lower 80 feet of this 1,000-feet-thick sequence were examined by Merriam, who reported the following: *Atrypa* sp., *Athyris* cf. *A. angelicoides* Merriam, minute bellerophon-like gastropods, *Straparollus* cf. *S. ophirensis* Hall and Whitfield, and indeterminate conodonts. Merriam notes that the *Atrypa* is similar to a form occurring in the Late Devonian in the upper part of the Devils Gate formation, where *Athyris angelicoides* Merriam also occurs. Stromatoporoids from approximately 390 feet below the base of the Goshoot formation were examined by Richard Rezak, who reported ?*Hermatostroma* cf. *H. episcopale* Nicholson. The remaining fossils were examined by Berdan, who reported the following: *Amphipora* sp., *Favosites* cf. *F. limitaris* Rominger, *Spongophyllum* sp., *Pachyphyllum* sp., ramose favositid coral, *Atrypa* sp., massive stromatoporoids, and an unidentifiable gastropod. *Amphipora* occurs in a number of beds. Position of the fossils in the various lithologic units in the Black Rock Hills is given in the detailed stratigraphic section on page 52. Berdan (1955, written communication) stated that the collection made from approximately 260 feet below the Goshoot formation "contains two species of the coral *Pachyphyllum*. This coral is generally considered to be indicative of Late Devonian age. It occurs in the Jefferson dolomite in Montana, and has been used by Merriam (1940, p. 59–61) as a zone fossil for the lowest Upper Devonian in Nevada." Thus a Late Devonian age is indicated for the upper part and a probable Middle Devonian age for the lower part of this formation. The position of the Middle-Late Devonian boundary is not known. However, a brachiopod closely resembling the Middle Devonian brachiopod *Stringocephalus* sp. is found about 700 feet above the base of the formation in the northern part of the Dugway Range, and inasmuch as Late Devonian fossils occur 1,000 feet below the top of formation in the Black Rock Hills, the position of this boundary is probably somewhere in the middle part of the formation.

Because the Engelmann formation conformably overlies the Sevy dolomite and contains fossils of probable Middle and Late Devonian age, it appears to be equivalent to all the Simonson dolomite and most of the Guilmette formation of the Gold Hill district (Nolan, 1935, p. 19–21). The Engelmann formation is also tentatively correlated with most of the Silverhorn dolomite and the lower part of the West Range limestone of the Pioche district, Nevada (Westgate and Knopf, 1932, p. 16–19), and with part of the upper half of the Bluebell dolomite of the East Tintic Mountains (Morris and Lovering, 1961, p. 63–70).

GOSHOOT FORMATION (UPPER DEVONIAN)

The Goshoot formation is here named from outcrops in Goshoot Canyon in the west-central part of the Black Rock Hills. Excellent exposures of this formation on the ridge on the north side of Goshoot Canyon (fig. 10) are designated the type section. Good sections are also exposed along the north side of Engelmann Canyon and in the Dugway Range on a small ridge at the northeast corner of the map area.

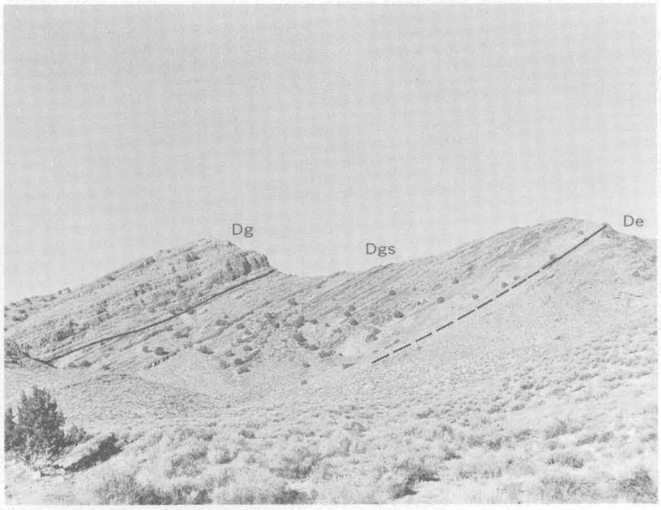


FIGURE 10.—Type section of the Goshoot formation, north side of Goshoot Canyon, Black Rock Hills, showing top of Engelmann formation (De), quartzite and dolomite beds of Goshoot formation (Dgs), and massive dolomite beds of the Gilson dolomite (Dg).

The Goshoot formation is exposed in three areas: (1) a north-trending band, 2.8 miles long, extending from Goshoot Canyon to the north end of the Black Rock Hills, (2) several disconnected bands between the north end of the map and Engelmann Canyon in the Dugway Range, and (3) outcrops on several low hills along the west side of the Dugway Range approximately 1.8 miles south of the mouth of Cannon Canyon. This formation also extends north of the area mapped into the southern part of the Dugway Proving Ground SW quadrangle.

Lithology.—The Goshoot formation consists of light- to dark-gray dolomite interbedded with brown-weathering dolomitic and calcareous quartzite units, from 0.4 to 47 feet thick. The base of the Goshoot formation is placed at the base of the lowest quartzite in a series of rather closely spaced quartzite beds. No true quartzite is found in the Upper Devonian below this horizon, although several dolomite beds, 100 to 300 feet below this quartzite bed, contain some quartz sand. The top of the formation is placed at the top of an 80- to 110-foot unit of thick quartzite beds interbedded with dolomite. This unit commonly forms a prominent cliff. Several thin quartzite beds are in the lower 160 to 250 feet of the overlying Gilson dolomite.

Carbonate rocks, chiefly dolomite, make up 70 to 85 percent of the Goshoot frmation. The percentage of carbonate rocks is greater in the northern Dugway Range than in the Black Rock Hills, apparently owing to thinning of the quartzite beds. The dolomite is a fine-grained black, dark-gray, medium-gray, or light-gray rock, which in some places in the Dugway Range shows a faint mottling. Some of the dolomite contains streaks of quartz sand, which weather brown. Limestone occurs locally as a bed of fine-grained light-gray limestone about 25 feet thick about 20 feet above the base of the formation on a ridge 4,000 feet north of Goshoot Canyon, and as a 10- to 20-foot bed of medium-gray limestone in the upper part of the formation on the ridge bounding the north side of Engelmann Canyon.

Quartzite in the Goshoot formation is a fine- to medium-grained light-gray to white rock that weathers brown. Crossbedding is present in a few places but is not nearly as common as in the younger Hanauer formation. The contacts between the quartzite and dolomite beds are straight and sharp in some places and gradational in others. In a few places the contacts are irregular, owing to slight scouring or channelling. Some of the quartzite is hard and vitreous appearing; some is friable and lacks vitreous luster. Cementing material of the harder quartzite is silica, and that of the more friable quartzite is dolomite, or in a few places, calcite. Carbonate cement is the most common.

A specimen of quartzite for mechanical analysis was collected from the lowermost quartzite bed in the Goshoot formation on the prominent ridge just north of Goshoot Canyon. Two other specimens of quartzite, one from the Hanauer formation, the other from the Upper Devonian sedimentary rocks, undivided, were analyzed at the same time for comparison. These specimens were crushed to approximately one-quarter of an inch and put in hydrochloric acid; the residue was washed, then disaggregated in a mechanical blender, and the +250-mesh size was sieved for 10 minutes by a mechanical shaker. The data for these mechanical analyses are presented in table 7 and figure 11. The soluble part of the rock is made up almost entirely of carbonates. The silt- and clay-size material (less than 250-mesh size) of the insoluble fraction was negligible and was ignored. The cumulative curves (fig. 11) of the three samples are similar, and the median diameter of the sand grains of each sample falls within a small range. The slope of the curve shows the degree of sorting. In general the steeper the curve the better sorted the sediment. The sorting may also be expressed as a figure called the coefficient of sorting (S_o) (Trask, 1932, p. 71–72). According to Trask an S_o value of less than 2.5 indicates a well-sorted sediment; the S_o for the quartzite from the Goshoot formation is 1.24 (table 7).

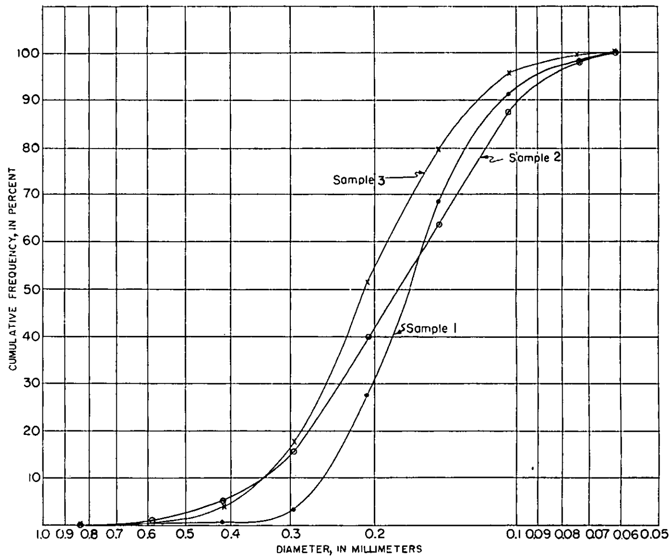


FIGURE 11.—Cumulative curves of sand in Upper Devonian quartzites. Sample 1 from the base of the Goshoot formation; sample 2 from near the top of the Hanauer formation, and sample 3 from quartzite of the Upper Devonian sedimentary rocks undivided, south of Goshoot Canyon.

TABLE 7.—*Mechanical-analysis data for three samples of quartzite from the Upper Devonian in the Black Rock Hills*

[Analyses in percent]

	Sample		
	1	2	3
Soluble matter .... percent	42.5	33.5	49.6
Insoluble matter .... do	57.5	66.5	50.4
Sand .... do	56.4	63.3	48.8
Clay and silt .... do	1.1	3.2	1.5
Median sand size .... mm	.170	.178	.212
Coefficient of sorting (S_o)	1.24	1.42	1.31

1. Sample from lowermost quartzite bed in Goshoot formation on prominent ridge on north side of Goshoot Canyon.
2. Sample from 520 ft above base of Hanauer formation on prominent ridge on north side of Goshoot Canyon.
3. Sample of calcareous quartzite of Upper Devonian sedimentary rocks, undivided, at base of mountain 1,700 ft south of Goshoot Canyon.

Examination of the various size fractions under a microscope shows that all the sand grains are quartz and all but a few of the finer grains are frosted. The coarser size grains are well rounded and have a high sphericity. The finer size grains are proportionately less well rounded, the majority being subangular. Some of the coarser material is made up of lumps of aggregated grains cemented by silica. Only traces of heavy minerals were noted in the sand, and they form but a very minor constituent in the clay and silt fraction. The data from these three samples (that is, very good sorting, scarcity of clay, feldspar, and heavy minerals, and the composite character of some of the grains) suggest that most of the sand was derived from an earlier quartzite. The almost universal frosting of the grains may indicate a cycle of wind abrasion in the history of this sand.

A comparison of mechanical analyses of these Upper Devonian quartzite beds may be made with the analyses of Osmond (1954, p. 1922–1923) on samples of the upper sandy member of the Sevy dolomite from eastern Nevada. The cumulative curves we obtained (fig. 11) are very similar to those obtained by Osmond (1954, p. 1920–1922). The mean median diameter of his 17 samples of sand from the Sevy dolomite is 0.225 mm, and his Trask sorting coefficients range from 1.18 to 1.62 and average 1.40. Thus, the conditions of deposition for the upper part of the Sevy dolomite, as inferred by Osmond, apparently persisted into Late Devonian time.

The Goshoot formation, for the most part, is believed to have been deposited in shallow water as indicated by the crossbedding and the nonconformities between some of the dolomite and quartzite beds.

The Goshoot formation in the Black Rock Hills is similar to that in the northern part of the Dugway Range, except that the quartzite units generally are thinner in the Dugway Range. Although individual quartzite beds have been traced for 1 to 2 miles in both the Black Rock Hills and the Dugway Range, few individual beds are recognizable from one area to the next. In order to show the detailed lithology and the variation between the two areas, detailed stratigraphic sections are given below.

Section of the Goshoot formation measured on ridge on north side of Goshoot Canyon, Black Rock Hills

[Fossils identified by Jean M. Berdan]

	Thickness (feet)
Gilson dolomite: Dolomite, light-gray to black, fine- to medium-grained.	
Goshoot formation:	
1. Quartzite, white, medium-grained, well-jointed; weathers brown	28

Section of the Goshoot formation measured on ridge on north side of Goshoot Canyon, Black Rock Hills—Continued

	Thickness (feet)
Goshoot formation—Continued	
2. Dolomite, dark-gray, fine-grained; lower part contains some quartz sand	21
3. Dolomite, light-gray, fine-grained; contains numerous streaks of quartz sand	2
4. Dolomite, light-gray, coarse-grained; weathers tan; numerous elliptical ⅛- to 1-in. vugs	13
5. Quartzite, gray to white, vitreous, medium-grained, well-jointed; some crossbedding	47
6. Dolomite, light- to dark-gray, fine-to medium-grained; weathers tan; beds 0.5 to 3 ft thick. Scattered throughout unit is poorly preserved fossil debris including *Amphipora*? sp., *Atrypa*? sp., unidentifiable crinoid stems, horn corals, and gastropods	111
7. Dolomite, medium- to dark-gray, medium, to fine-grained, and 14 interbeds of dolomitic white to gray medium-grained quartzite. Quartzite beds range from 0.4 to 16.9 ft thick. Some *Amphipora* sp. and unidentifiable brachiopods in the dolomite	164
Total thickness of Goshoot formation	386
Engelmann formation: Dolomite, light-gray, medium-grained, sandy-textured; numerous pockets and irregular markings of white dolomite and calcite.	

Section in the Goshoot formation measured on an east-northeast-trending ridge, 3,000 feet north of Buckhorn Canyon, Dugway Range

	Thickness (feet)
Gilson dolomite: Dolomite, black, fine-grained.	
Goshoot formation:	
1. Quartzite, dolomitic, white, medium- to fine-grained; weathers brown in places	7
2. Dolomite, black, fine-grained, with 1½- in. layer of quartz sand at top	3
3. Quartzite, dolomitic, light-gray, medium-grained; weathers brown	0.7
4. Dolomite, black, fine-grained	11
5. Dolomite, medium-gray, fine-grained; weathers somewhat lighter	2
6. Quartzite, like unit 3	0.7
7. Dolomite, like unit 4	6
8. Quartzite, light brown, fine-grained, vitreous, massive; weathers brown; dolomitic at top	18
9. Dolomite; like unit 5, except some quartzite stringers	7
10. Dolomite, like unit 4	0.6
11. Quartzite, white, fine-grained, vitreous, massive; weathers brown	17
12. Dolomite, like unit 5; massive	5
13. Quartzite, dolomitic, light-gray, fine-grained; weathers brown	2
14. Dolomite; like unit 5 except lower 4 ft is mottled	42
15. Dolomite, black, fine-grained, faintly mottled; one 2-in. oolitic bed	68
16. Dolomite, dark- and medium-gray, fine-grained; weathers a shade lighter; interbedded with thin units of fine- to medium-grained medium-gray to white vitreous quartzite. Cup corals at base	52

Section in the Goshoot formation measured on an east-northeast-trending range, 3,000 feet north of Buckhorn Canyon, Dugway Range—Continued

	Thickness (feet)
Goshoot formation—Continued	
17. Dolomite; same as unit 4, except faintly mottled in some places; contains poorly preserved brachiopods	85
18. Dolomite; same as unit 4, except banded and contains blebs of calcite and dolomite in upper 5 ft	34
19. Dolomite, calcareous, black- to medium-gray, fine- to medium-grained; weathers a shade lighter; interbedded with four beds of dolomitic medium-gray fine- to medium-grained quartzite that weathers brown	31
Total thickness of Goshoot formation	392
Engelmann formation: Dolomite, black, fine- to medium-grained.	

Thickness.—The Goshoot formation was measured along the prominent ridge bounding the north side of Goshoot Canyon, where it is 386 feet thick, and on a small ridge in the extreme northeast corner of the mapped area in the Dugway Range, where it is 392 feet thick.

Age and correlation.—Fossil remains are common in the dolomite of the Goshoot formation but are poorly preserved. Remains of cup corals, brachiopods, stromataporoids, and gastropods have been found, but most specimens could not be identified. Jean Berdan identified the dendroid stromatoporoid *Amphipora* sp. (fig. 12) from several beds in this formation. Although this genus is fairly common in some beds of the Goshoot formation in the Black Rock Hills, it is much more in the overlying Gilson dolomite. C. W. Merriam identified fossils from the other collections from the Goshoot formation. *Atrypa* sp. is found in three places: (1) just above the base of the formation in a small local limestone bed in the Black Rock Hills, (2) in the central part of the formation in dolomite on the prominent ridge north of Goshoot Canyon, and (3) near the top of the formation in local limestone beds in the northern part of the Dugway Range. With the *Atrypa* at the first locality is *Productella* sp., which according to Merriam is similar to a form in the upper part of the Devils Gate formation of central Nevada.

Although none of these fossils are distinctive of Late Devonian time alone, the position of this formation below the Gilson dolomite and above the Engelmann dolomite, both of which contain Late Devonian fossils, indicates a Late Devonian age for the entire Goshoot formation.

GILSON DOLOMITE (UPPER DEVONIAN)

Gilson dolomite, named here for Gilson Canyon in the northeastern part of the Dugway Range, is well exposed on the ridges on both sides of this canyon. In this area, however, the Gilson is cut by a number of faults; therefore, the type section is designated along Hanauer Ridge. Another excellent, but somewhat different, section of Gilson dolomite is on the ridge on the north side of Goshoot Canyon in the Black Rock Hills (fig. 10).

The Gilson dolomite occurs in four areas: (1) a north-trending band about 2.6 miles long extending from the north end of the Black Rock Hills to Goshoot Canyon, (2) a north-trending band about 2.2 miles long extending from Gilson Canyon to the north edge of the map area, (3) on low hills in the southern part of Bullion Canyon, and (4) on a number of low hills on the west side of the Dugway Range, 1.8 miles south-southeast of the mouth of Cannon Canyon. This formation also extends north of the area mapped to the north end of the Dugway Range in the Dugway Proving Ground SW quadrangle, and a short distance west of the area mapped into the central part of the Black Rock Hills.

Lithology.—The Gilson dolomite consists of light- to dark-gray dolomite. Its most distinguishing feature is the presence of numerous beds made up almost entirely of the stromatoporoid *Amphipora* (fig. 12). The base of the formation is placed on top of a thick massive brown-weathering white quartzite bed that marks the top of the Goshoot formation. In the

FIGURE 12.—*Amphipora* in dolomite near the base of the Gilson dolomite, north side of Goshoot Canyon, Black Rock Hills. Six-inch ruler for scale.

Black Rock Hills, several thin quartzite beds are found in the lower part of the Gilson dolomite above this thick cliff-forming quartzite bed. The top of the formation is placed at the base of the lowest quartzite of the overlying Hanauer formation.

The Gilson dolomite consists of beds of light-, medium-, and dark-gray dolomite, which in general are fine grained but in the Black Rock Hills may be medium grained. Most of the dolomite is thick bedded to massive but a few units, generally light gray, are thin bedded. A sample taken from near the base of the Gilson dolomite on the north side of Goshoot Canyon contained 98 percent dolomite in its carbonate fraction (table 5). The quartzite in the lower part of the Gilson in the Black Rock Hills is a gray fine- to medium-grained well-cemented rock that weathers brown and occurs in units from 1 to 12 feet thick. The quartzitic dolomite units in the northeastern part of the Dugway Range are similar in color and grain size but consist chiefly of dolomite; a discontinuous quartzite bed is found on Hanauer Ridge 150 feet above the base of the formation. On the ridge west of Engelmann Canyon near the top of the section a 20-foot thick limestone bed is exposed for several hundred feet.

The Gilson dolomite, like the Hanauer formation above and the Goshoot formation below, is believed to have been deposited in shallow water, chiefly because of the presence of large thick-shelled pelecypods (fig. 13). In Recent times, such thick-shelled forms generally live where they are subject to wave action.

The Gilson dolomite is 400 feet thicker in the northeastern part of the Dugway Range than it is in the Black Rock Hills. The differences in detailed stratigraphy between the two areas can be seen in the following sections.

Section of the Gilson dolomite measured on prominent ridge on north side of Goshoot Canyon, Black Rock Hills

[Fossils identified by Jean M. Berdan]

	Thickness (feet)
Hanauer formation: Quartzite, white to light-gray, fine-grained; weathers brown.	
Gilson dolomite:	
1. Dolomite, dark- to medium-gray, fine- to medium-grained, sandy-textured, banded; contains numerous irregular stringers of white to pinkish white dolomite. Middle part contains poorly preserved *Amphipora* sp., horn corals, and brachiopods. Large thick-shelled pelecypods near top of unit	92
2. Dolomite, gray, fine-grained, thin-bedded; weathers yellowish-gray	4
3. Dolomite, medium-gray, fine-grained; weathers drab brown	3

Section of the Gilson dolomite measured on prominent ridge on north side of Goshoot Canyon, Black Rock Hills—Continued

	Thickness (feet)
Gilson dolomite—Continued	
4. Dolomite, like unit 2; beds ¾ to 3 in. thick	8
5. Dolomite, light- to dark-gray, fine- to medium-grained, sandy-textured; contains numerous irregular stringers of white dolomite along fractures. Several beds contain *Amphipora* sp. and an unidentifiable gastropod	137
6. Dolomite, light-brown, fine-grained, thin-bedded	4
7. Dolomite, light- to dark-gray, medium-grained, sandy-textured; contains irregular fractures filled with white calcite and dolomite. *Amphipora*, a large species, present in some beds	30
8. Dolomite, light-gray, fine-grained, thin-bedded; weathers light brown	27
9. Dolomite, light- to medium-gray, medium-grained, sandy-textured; weathers drab brown. Rock contains numerous large thick-shelled pelecypods and *Amphipora*? sp	119
10. Dolomite, dark-gray, medium-grained, massive, sandy-textured; weathers drab brown. Upper 20 feet contains large thick-shelled pelecypods, poorly preserved gastropods, and *Amphipora* sp. Lower part contains beds with numerous *Amphipora* sp	240
11. Quartzite, calcareous, white, friable	2
12. Dolomite, like unit 10; contains numerous beds filled with *Amphipora* sp	24
13. Quartzite, light-gray, medium-grained; weathers brown	12
14. Dolomite, medium- to dark-gray, fine-grained; in lower part is bed containing poorly preserved brachiopods and *Amphipora*? sp	61
15. Quartzite, gray; grades upward into dolomite	1
16. Dolomite, light- to dark-gray, fine-grained, banded	42
17. Quartzite, gray, fine-grained; weathers brown	7
18. Dolomite, medium-gray, fine-grained, sandy-textured	11
19. Quartzite, like unit 17	5
20. Dolomite, like unit 16; has two layers containing a little quartz sand. A 2-ft bed containing *Amphipora* sp. occurs in upper part of unit	56
21. Quartzite, gray, medium-grained, crossbedded; weathers brown	5
22. Dolomite, light,gray to black, fine- to medium-grained	24
Total thickness of Gilson dolomite	914
Goshoot formation: Quartzite, white, medium-grained, well-jointed; weathers brown.	

Section of the Gilson dolomite measured on an east-northeast-trending ridge, 3,000 feet north of Buckhorn Canyon, Dugway Range

	Thickness (feet)
Hanauer formation: Quartzite, dolomitic, light-gray, medium-grained; weathers brown.	
Gilson dolomite:	
1. Dolomite, medium-gray, fine-grained	13
2. Dolomite, light-gray, fine-grained, thinly laminated	1

Section of the Gilson dolomite measured on an east-northeast-trending ridge, 3,000 feet north of Buckhorn Canyon, Dugway Range—Continued

	Thickness (feet)
Gilson dolomite—Continued	
3. Dolomite, dark-gray, fine-grained; beds 0.5 to 3 ft thick; numerous thin irregular white dolomite stringers	12
4. Dolomite, dark- to light-gray, fine-grained, massive; contains beds with numerous *Amphipora*? sp	165
5. Dolomite, like unit 1; massive	69
6. Quartzite, dolomitic, light-brown to light-gray, fine-grained, massive	11
7. Dolomite, medium-gray, fine-grained, massive; weathers lighter gray; contains numerous fractures filled with white dolomite and calcite	4
8. Covered	111
9. Dolomite, medium-gray, fine-grained; weathers lighter gray; upper part laminated	15
10. Dolomite, dark-gray to black, fine-grained, contains numerous thin irregular veinlets of white dolomite	13
11. Dolomite; like unit 9, except all of it is thinly laminated	4
12. Dolomite, black- to medium-gray, fine-grained; *Amphipora* sp. numerous at top	26
13. Dolomite, like unit 11	3
14. Dolomite, medium-gray, fine-grained; weathers drab brown; beds 1 to 3 ft thick; one bed contains poorly preserved gastropods and brachiopods	75
15. Covered	25
16. Dolomite, medium- to light-gray, fine-grained; beds 2 ft thick	10
17. Dolomite; like unit 14, except stringers and blebs of white dolomite and calcite are common; fragments of cup corals, brachiopods and crinoid stems noted	14
18. Covered	31
19. Dolomite, like unit 16	16
20. Covered	9
21. Dolomite, light-gray, fine-grained, thinly laminated	6
22. Covered	11
23. Dolomite; like unit 14, but massive	97
24. Covered	18
25. Dolomite, interbedded black, dark-gray, and medium-gray; fine-grained; beds 2 to 6 ft thick	27
26. Covered	18
27. Dolomite, dark- to medium-gray, fine- to medium-grained, massive; weathers somewhat lighter	57
28. Covered	39
29. Dolomite, interbedded light-gray, medium-gray, dark-gray, and black types; fine-grained; one bed contains *Amphipora* sp	64
30. Dolomite, light-gray, fine-grained; contains 20 to 30 percent quartz sand; weathers tan	7
31. Dolomite, like unit 29	37
32. Dolomite, quartzitic, light-gray, fine-grained; weathers brown	6
33. Dolomite, dark-gray, fine-grained; fine network of chert in upper half	29
34. Dolomite, like unit 32	3
35. Dolomite, fine-grained; interbedded medium-gray and dark-gray types weathers somewhat lighter gray	43
36. Dolomite, black, fine-grained; brown chert along fractures	47
37. Dolomite, medium-gray, fine-grained; weathers light pinkish gray	14
38. Quartzite, light-gray, fine-grained, thin-bedded; weathers brown	11
39. Dolomite, medium- to dark-gray, fine-grained; contains *Amphipora* sp	12
40. Dolomite, medium-gray, fine- to medium-grained, massive; weathers somewhat lighter; contains patches of quartz sand	16
41. Covered	20
42. Dolomite; like unit 39, except that it contains pockets and stringers of white dolomite	6
43. Covered	13
44. Dolomite, like unit 39; beds 1.5 ft thick	6
45. Covered	16
46. Dolomite, dark-gray, fine-grained, partly covered	22
47. Covered	26
48. Dolomite, black, fine-grained	14
Total thickness of Gilson dolomite	1,312
Goshoot formation: Quartzite, dolomitic, white, fine- to medium-grained; weathers brown in places.	

Thickness.—The Gilson dolomite was measured along the prominent ridge bounding the north side of Goshoot canyon, where it is 914 feet thick, and along an east-northeast-trending ridge 3,000 feet north of Buckhorn Canyon, where it is 1,312 feet thick. The difference in thickness between these two localities 12 miles apart is probably due to differences in rate of sedimentation.

Age and correlation.—Fossils are fairly common in the Gilson dolomite, but preservation is poor. Most of the material is fragmental and includes pieces of brachiopods, crinoid stems, cup corals, gastropods, and pelecypods. The most common fossil is the branching stromatoporoid *Amphipora* (fig. 12), which practically makes up entire beds. Jean Berdan (1955, written communication) who identified this fossil stated, "This genus is extremely abundant in dolomitic rocks of Late and Middle Devonian age in the West, and because it is commonly preserved as white dolomite in a dark dolomite matrix, the rocks containing it are often called 'spaghetti limestone.' Apparently more than one species is present in the material collected, to judge from the size of the cross-sections of the rods, but in most cases the material is not sufficiently well preserved for specific identification, as species are largely based on the character of the internal structures." C. W. Merriam examined the other collections from this formation. He identified *Cladopora* sp. from a bed 265 to 285 feet above the base of the formation in the Black Rock Hills. In the central part of the formation a large thick-shelled pelecypod (fig. 13) is common in the Black Rock Hills. This

FIGURE 13.—Large thick-shelled pelecypods characteristic of the Upper Devonian rocks, north side of Goshoot Canyon, Black Rock Hills.

type of fossil is also present in the undivided Upper Devonian rocks. About 60 feet below the top of the Gilson dolomite the coral *Syringopora* sp. was found. This coral is similar to the form found in the upper part of the Devils Gate limestone (Merriam, 1955, written communication). A Late Devonian age is indicated for the entire formation by its position between other formations containing Late Devonian fossils.

HANAUER FORMATION (UPPER DEVONIAN)

Hanauer formation is here named for exposures on Hanauer Ridge in the northeastern part of the Dugway Range, where the type section was measured.

The Hanauer formation is found in four areas: (1) an outcrop band about 1 mile long on the west edge of the map area in the central part of the Black Rock Hills, (2) a band about 2 miles long that extends from the northern end of the map area to Gilson Canyon in the Dugway Range, (3) scattered fault blocks in Bullion Canyon, and (4) on two low hills on the west edge of the Dugway Range, 1.8 miles south-southeast of the mouth of Cannon Canyon. This formation also extends north of the area mapped as far as the north end of the Dugway Range in the Dugway Proving Ground SW quadrangle, and west of the area mapped into the central part of the Black Rock Hills.

Lithology.—The Hanauer formation consists of dolomite and, in the upper part, some limestone, both interbedded with calcareous quartzite. The base of the formation is placed at the base of the lowest quartzite, which overlies the fairly massive gray dolomite of the Gilson dolomite. This basal quartzite is from about 1 to more than 20 feet thick; several other quartzite beds are interbedded in the dolomite a short distance above it. The top of the formation is placed on the top of a rather thick massive quartzite bed or series of thick beds. The formation is overlain by fine-grained light-gray Madison limestone equivalent. In a few places, such as on the north side of Buckhorn Canyon, beds containing quartz sand are found a short distance above the Hanauer-Madison equivalent contact, but these beds, which are 20 to 30 feet thick, are generally quite limy and discontinuous.

Carbonate rocks, mostly dolomite, make up a little over half of the Hanauer formation. The dolomite is light to dark gray and fine to medium grained. In general it is medium grained in the Black Rock Hills and fine grained in the northern part of the Dugway Range. Light-gray limestone is found locally in the upper part of this formation, and it resembles the overlying Madison equivalent. These beds are commonly dolomitized and individual limestone beds grade into dolomite along strike.

Quartzite, which occurs in units from 1 to 90 feet thick, is a fine- to medium-grained gray to white rock that weathers to light or dark brown. Crossbedding is conspicuous in many places. Some of the quartzite is hard and vitreous-appearing, but most of it is somewhat friable. Cementing material is generally carbonate, which commonly makes up 25 to 50 percent of the rock; in a few beds, however, the cementing material is silica. In the upper part of the formation where limestone is present, the cementing material is commonly calcite; elsewhere in the formation it is dolomite. In addition some quartzitic dolomite is present which contains from 2 to 30 percent quartz sand. Most of the quartz grains are rounded to well rounded and show a high sphericity; all are frosted.

A sample of quartzite for mechanical analysis was taken 520 feet above the base of the formation on the prominent ridge bounding the north side of Goshoot Canyon. The results of this mechanical analysis are presented in table 7 (sample 2) and figure 11. The method used is the same as that used for a quartzite in the Goshoot formation, which is described on page 54. The graph (fig. 11) shows that the cumulative curve for the quartzite from the Hanauer formation is similar to the curves for two other Upper Devonian quartzites. The high degree of sphericity, the frosting, the very good sorting of the quartz grains, and the lack of feldspars and heavy minerals suggest that the quartz sand was derived from an earlier quartzite. The conspicuous crossbedding, so persistent through much of the quartzite in the Hanauer formation, suggests deposition in shallow water.

Although the overall character of the Hanauer formation is the same in the Black Rock Hills and the north end of the Dugway Range, few individual beds can be recognized in both areas. A thick massive quartzite bed in one area may be represented by several closely spaced smaller quartzite beds in the other area. Some thickening and thinning of beds commonly takes place within short distances; but several quartzite beds have been traced for several miles along the entire front of the Black Rock Hills without any apparent change. In order to show the detailed lithology and the variation between the two areas, detailed stratigraphic sections are given below.

Partial section of the Hanauer formation measured on prominent ridge on north side of Goshoot Canyon, Black Rock Hills

[Fossils identified by C. W. Merriam and Jean M. Berdan]

	Thickness (feet)
Top of hill.	
Hanauer formation:	
1. Quartzite; calcareous in places; cream colored, medium grained, weathers brown; crossbedded	89
2. Limestone, dolomitic, light-gray, fine-grained; beds 0.5 to 2 ft thick	29
3. Quartzite, like unit 1	24
4. Limestone, like unit 2	11
5. Quartzite, white, fine-grained; weathers brown to black; somewhat friable	14
6. Limestone, dolomitic, light-gray, fine-grained, sandy-textured	1
7. Quartzite, like unit 5; beds are 0.2 to 2 ft thick	50
8. Limestone, like unit 6	16
9. Quartzite, somewhat calcareous, white, medium-grained	34
10. Limestone; like unit 6, except that some bands weather brown; layer 2 ft from base contains the brachiopods ?*Rhipidomella* sp. and ?*Paracyclas* sp. and an indeterminate gastropod resembling *Baylea*	34
11. Quartzite, calcareous, white, medium-grained; weathers brown	4
12. Limestone, like unit 6	16
13. Quartzite, gray, medium-grained; weathers brown; crossbedded	29
14. Dolomite, medium-gray, fine-grained, sandy-textured	5
15. Quartzite, like unit 13	35

Partial section of the Hanauer formation measured on prominent ridge on north side of Goshoot Canyon, Black Rock Hills—Continued

	Thickness (feet)
Hanauer formation—Continued	
16. Dolomite; like unit 14 except smooth-weathering	10
17. Quartzite, like unit 13	21
18. Dolomite, light-gray, medium-grained, both thin- and thick-bedded. Several feet below top of unit are found the brachiopods *Cyrtospirifer monticola* (Haynes) and *Productella* sp	79
19. Quartzite, dolomitic, light-gray, medium- to coarse-grained, friable	4
20. Dolomite, dark-gray, medium-grained, sandy-textured; *Amphipora* sp. are abundant	29
21. Quartzite, gray, medium-grained; weathers brown in places	1
22. Dolomite, medium-gray, medium-grained, sandy-textured. Beds contain numerous *Amphipora* of a large species	69
23. Quartzite, white, fine-grained; weathers gray and brown	2
24. Dolomite, dark- to medium-gray, medium-grained	27
25. Quartzite, tannish-gray, medium-grained; weathers gray	7
26. Dolomite, medium- to light-gray, medium-grained; quartz sand in some layers	24
27. Quartzite, light-gray, medium-grained	2
28. Dolomite, like unit 24; upper 8 ft contains numerous *Amphipora*? sp. and some large thick-shelled pelecypods	35
29. Dolomite, quartzitic, light-gray, medium-grained, sandy-textured	2
30. Quartzite, white, medium-grained, massive: weathers brown	4
31. Dolomite, dark-gray, medium-grained, sandy-textured	3
32. Quartzite, white to light-gray, fine-grained; weathers brown	22
Total thickness of exposed Hanauer formation	732
Gilson dolomite: Dolomite, dark- to medium-gray, fine- to medium-grained, sandy-textured, banded.	

Section of the Hanauer formation measured on Hanauer Ridge, Dugway Range

	Thickness (feet)
Madison equivalent: Limestone, medium- to light-gray, fine-grained; contains about 5 percent quartz sand.	
Hanauer formation:	
1. Quartzite, calcareous, white, medium-grained; weathers light brown	89
2. Dolomite, light-gray, fine-grained	6
3. Dolomite, medium-gray, fine-grained; beds 2 in. to 3 ft thick	21
4. Dolomite, medium-gray, fine-grained; weathers lighter gray; beds 2 to 6 ft thick; unit contains thin irregular nodes and stringers of white calcite and dolomite	48
5. Dolomite, dark-gray, fine-grained; contains thin irregular stringers of white dolomite	6
6. Dolomite, light-gray, fine-grained; silty at the top	19
7. Dolomite, quartzitic, light-gray, fine-grained; weathers brown	15

Section of the Hanauer formation measured on Hanauer Ridg, Dugway Range—Continued

Hanauer formation—Continued	Thickness (feet)
8. Dolomite, medium-gray, fine-grained; weathers lighter gray	15
9. Covered	13
10. Quartzite, dolomitic, light-gray; weathers brown	32
11. Dolomite, light-gray, fine-grained, massive	37
12. Quartzite, white, massive, vitreous	9
13. Dolomite, like unit 11	4
14. Quartzite, somewhat dolomitic; white, fine-grained, vitreous	11
15. Dolomite, like unit 11	8
16. Quartzite, olive-green, fine-grained; weathers brown; vitreous	4
17. Dolomite, like unit 11	10
18. Dolomite; like unit 11, but contains streaks of quartz sand	6
19. Quartzite, white, medium-grained, massive; weathers dark brown	7
20. Dolomite, like unit 11	1
21. Quartzite, like unit 19	9
22. Dolomite, quartzitic, light-gray, fine-grained; weathers tan; banded; varies from dolomitic quartzite to quartzitic dolomite	31
23. Dolomite, medium-gray, fine-grained; weathers light gray	12
24. Quartzite, dolomitic, light-gray, medium-grained; weathers tan	3
25. Dolomite; like unit 23, but with about 20 percent quartz sand in upper 4 ft	14
26. Quartzite, dolomitic, very light gray, medium-grained; weathers brown; some covered areas	42
27. Dolomite; like unit 23, but with a little fine quartz sand toward top	8
28. Quartzite, dolomitic, light-gray, medium-grained; weathers brown	1
Total thickness of Hanauer formation	481

Gilson dolomite: Dolomite, medium, gray, fine-grained.

Thickness.—In complete section measured on Hanauer Ridge in the northeastern part of the Dugway Range, the Hanauer formation is 481 feet thick. A partial section was measured along the prominent ridge just north of Goshoot Canyon in the Black Rock Hills. This section ends on the westward-facing dip slope of the hill where the angle of slope approximates the dip of the beds. At the foot of this dip slope the Hanauer formation is covered by Tertiary rhyodacite. The total thickness of this partial section is 732 feet. The much greater thickness of the Black Rock Hills section may be due to some unobserved faulting that repeated part of the section, or, more likely, it may be due to variation in sedimentation, which is common in other parts of the Upper Devonian sequence.

Age and correlation.—Fossils are uncommon in the Hanauer formation. None have been noted in the northern part of the Dugway Range, and in the Black Rock Hills they are scarce. Jean Berdan identified *Amphipora* sp. from the lower 150 feet of the formation. Also present were the large thick-shelled pelecypods (fig. 13) so common in the Gilson formation. A short distance above these fossils, C. W. Merriam collected and identified a poorly preserved rhynchonellid brachiopod resembling *Hypothyridina emmonsi* (Hall and Whitfield). Merriam also identified the brachiopods *Cyrtospirifer monticola* (Haynes) and *Productella* sp. from a bed 300 feet above the base of the formation and the brachiopod ?*Rhipidomella* sp., the pelecypod ?*Paracyclas* sp., and an indeterminate gastropod resembling *Baylea* from a bed 465 feet above the base of the formation.

Merriam (1955, written communication) made the following notations on these fossils: *Hypothyridina emmonsi* (Hall and Whitfield) occurs in the Late Devonian *Pachyphyllum* zone of central Nevada; the most diagnostic fossil is *Cyrtospirifer monticola* (Haynes), which is found in the upper Upper Devonian rocks. This fossil marks the highest faunal zone in the Devils Gate formation of the Eureka district, and is also found in the Three Forks limestone of Montana and Idaho. The suite of fossils including ?*Rhipidomella*, ?*Paracyclas*, and the indeterminate gastropod resembling *Baylea* is too poorly preserved for positive identification; these fossils, if correctly identified, may be either Late Devonian or Early Carboniferous.

Thus, the greater part of the Hanauer formation is known to be Late Devonian in age. The Devonian-Mississippian boundary may lie in the upper part of this formation. In the absence of any diagnostic Mississippian fossils the entire formation is here discussed under the Devonian system.

The Hanauer formation is correlated in part with the Pinyon Peak limestone of the East Tintic Mountains.

UPPER DEVONIAN SEDIMENTARY ROCKS, UNDIVIDED

The undivided Upper Devonian sedimentary rocks are found in the southeastern part of the Black Rock Hills and in several outlying hills a short distance to the southeast. This area probably represents the locus of greatest sedimentation during Late Devonian time. These sedimentary rocks show a diverse lithology which does not match that found in the Dugway Range. The presence of Late Devonian fossils identifies their age, but the isolation of these rocks in fault blocks obscures their true position within the Upper Devonian. The sedimentary rocks are, therefore, mapped and described separately.

Lithology.—The rocks mapped as Upper Devonian sedimentary rocks, undivided, occupy blocks B and C in the Black Rock Hills (pl. 3). Although each block contains dolomite, limestone, and quartzite, the thickness of the individual units, their sequence, and lithologic details vary between the two blocks (pl. 3).

The sedimentary rocks in block B consist chiefly of a uniform fine-grained medium-gray limestone, which is overlain by a unit of calcareous quartzite 115 feet thick. Several thinner units of friable calcareous quartzite are also found in block B. In the southern part of this block a light-gray fine-grained limestone and a medium-gray medium-grained dolomite are present. An analyzed sample of the medium-gray limestone contained 2.3 percent dolomite in its carbonate fraction (table 5).

The quartzite that caps the medium-gray limestone was examined in thin section; it contained approximately 50 percent quartz grains, 15 percent microcline grains, 5 percent plagioclase grains, and 30 percent calcite cement. Accessory tourmaline and zircon were also noted. This was the only Devonian quartzite in which feldspars were noted. The mineralogy of this quartzite suggests that it was derived from a granitic rock. Another quartzite exposed near the base of the hill was examined and found to consist of well-rounded frosted quartz grains in a calcite cement. Mechanical analysis data from a specimen of this rock are presented in table 7 (sample 3) and figure 11. A description of the method used is given on page 54. As can be seen from the shape of the cumulative curve, this quartzite is similar in character to the other two Upper Devonian quartzites.

A detailed stratigraphic section of the thickest unfaulted area in block B is given below. Measuring began at a point 7,200 feet S. 16° E. of peak 5,712 in the Black Rock Hills.

Section of the Upper Devonian sedimentary rocks, undivided, exposed in block B

[Fossils identified by E. L. Yochelson and A. J. Boucot]

	Thickness (feet)
Top of hill.	
Upper Devonian sedimentary rocks, undivided:	
1. Limestone, dark-gray, fine-grained; beds 3 to 6 ft thick; gastropods	8
2. Sandstone, calcareous, light-gray to cream-colored, medium- to coarse-grained; weathers brown	15
3. Limestone, medium-gray, fine-grained, mottled; numerous gastropods at top	5
4. Limestone- light-gray, fine-grained; some layers contain a little quartz sand; 3 to 5 percent thin brown chert along fractures and bedding planes	23
5. Sandstone, calcareous, white to light-tan, medium-grained; weathers brown; faintly crossbedded	37
6. Limestone, light- to medium-gray, fine-grained	4

Section of the Upper Devonian sedimentary rocks, undivided, exposed in block B—Continued

	Thickness (feet)
Upper Devonian sedimentary rocks, undivided—Con.	
7. Limestone, gray, coarse-grained; interbedded with calcareous coarse-grained sandstone. Crossbedding is conspicuous	16
8. Quartzite, calcareous, white, medium-grained; weathers brown	24
9. Dolomite, light-gray, fine-grained; weathers tan	3
10. Limestone, medium-gray, fine-grained; gray and brown mottling with upper 11 ft most heavily mottled; gastropods and crinoid stems	64
11. Limestone, medium-gray, fine-grained; a little chert in upper part; bellerophontid gastropods	15
12. Limestone, medium-gray, fine-grained, mottled; bellerophontid gastropods	3
13. Limestone, like unit 12, with a little faint mottling and numerous thin white calcite stringers, gastropods	40
14. Limestone, like unit 12	3
15. Limestone, medium-gray, fine-grained; a few stringers of white calcite along fractures; beds 1 to 4 ft thick. Poorly preserved cephalopods at several places	97
16. Limestone, like unit 12; irregular thin bedding planes	2
17. Limestone, like unit 15	19
18. Limestone, like unit 13	32
19. Limestone, like unit 15; a little brown chert along bedding planes and fractures; a few bellerophontid gastropods	105
Total thickness of this section	515
Base of hill.	

The sedimentary rocks in block C consist chiefly of dolomite and quartzite at the south end of the block, and limestone and quartzite at the north end. The limestone beds either thin southward or end abruptly against small faults near the middle of the block. Although the fault displacement appears large on the west side of the main group of hills because of the sudden change from limestone to dolomite, only a small offset is indicated by the quartzite band along the eastern margin of the hills. The sudden change from limestone to dolomite is, therefore, believed to be due to dolomitization of the limestone either by fluids that rose along the faults and went southward or by fluids that spread northward from an unknown source and were stopped at the faults.

The limestone is similar to that in block B, being a medium-gray to black fine- to medium-grained rock. The most distinctive bed is a light-gray limestone conglomerate containing numerous coral "heads" broken from a reef. This bed, which is a little more than 20 feet thick, is exposed for about 500 feet on the southeast side of block C. The dolomite in block C is also similar to the other Upper Devonian dolomites, being a light-gray to black fine- to medium-grained sandy-textured, generally thick-bedded to massive rock.

Some of the quartzite units are similar to those in the Hanauer and Goshoot formations, but several are quite distinctive. These rocks are hard olive-green fine-grained quartzite with little to no carbonate cement. The quartzite in block C commonly thins considerably in a short distance, and thus are unlike those in block A, which vary but little in a strike length of several miles. The thickest quartzite bed in block C, which occurs on the east side of the main group of hills, thins from more than 260 feet at its southernmost exposure to less than 30 feet in thickness at its northernmost outcrop (pl. 3).

A detailed section up the eastern face of the main group of hills is given below. It crosses both the thickest quartzite and the limestone conglomerate. Measuring began at a point 17,000 feet S. 13° E. of peak 5,712 in the Black Rock Hills.

Section of the Upper Devonian sedimentary rocks, undivided, exposed in the southern part of block C

[Fossils identified by C. W. Merriam]

	Thickness (feet)
Top of hill.	
Upper Devonian sedimentary rocks, undivided:	
1. Dolomite, black, medium-grained, sandy-textured; numerous large circular white calcitic and dolomitic areas in upper part. Large thick-shelled pelecypods common	9
2. Dolomite, light-gray, medium-grained, sandy-textured	4
3. Dolomite, medium- to dark-gray, medium-grained, sandy-textured, massive; upper 13 ft contains numerous *Amphipora* sp. and poorly preserved thick-shelled pelecypods	105
4. Dolomite, medium-gray, medium-grained, sandy-textured; weathers drab brown; contains two species of *Amphipora*	23
5. Quartzite, olive-green, fine-grained; weathers light tan; thin bedded	18
6. Dolomite, light-gray, fine-grained, smooth-weathering	9
7. Dolomite, like unit 4	6
8. Covered	11
9. Quartzite, olive-green, fine-grained; upper 4 ft weathers tan, rest weathers rusty brown; beds 1 in. to 1 ft thick	264
10. Covered	13
11. Conglomerate, limestone, light-gray; some of matrix is brown sandy-textured limestone. Made up of large pieces of coral reef including numerous large coral "heads" and stromatoporoids. Fossils include: stromatoporoids; corals *Pachyphyllum* sp., *Tabulophyllum* sp., and *Macgeea* sp.; brachiopods *Atrypa* sp., ?*Hypothyridina* sp., ?*Tylothyris* sp., *Cranaena* sp., and *Nudirostra* sp., gastropod *Straparolus* sp.; and large thick-shelled pelecypods	24

Section of the Upper Devonian sedimentary rocks, undivided, exposed in the southern part of block C—Continued

	Thickness (feet)
Upper Devonian sedimentary rocks, undivided—Con.	
12. Limestone, medium-gray, fine- to medium-grained, massive; lower part has a small amount of brown chert along fractures. Limestone pebbles occur in thin layer near base. Coral ?*Macgeea* sp. and large thick-shelled pelecypods	86
13. Limestone, medium-gray, medium-grained, massive, with irregular patches of sandy-textured limestone. Fossils include: stromatoporoids; large thick-shelled pelecypods; unidentifiable gastropods; coral *Phacelophyllum* sp.; and brachiopods *Cyrtina* sp., *Atrypa* sp., and ?*Productella* sp	28
Total thickness of this section	600
Base of hill.	

Thickness.—The total thickness of the rocks mapped as Upper Devonian sedimentary rocks, undivided, can only be approximated because faults and covered areas separate individual blocks of these sedimentary rocks from one another. In block B, 515 feet of sedimentary rocks was measured in the thickest unbroken section; more than 285 feet of sedimentary rocks was measured in two smaller sections and from the map. Total thickness of sedimentary rocks in block B is at least 800 feet. The sedimentary rocks in block C are considerably thicker. The measured section contained 600 feet but only went to the top of the first ridge. Beyond this ridge to the west edge of this group of hills and in the easternmost group of hills in block C, there is at least an additional 2,100 feet of sedimentary rocks. The minimum thickness for the rocks mapped as Upper Devonian sedimentary rocks, undivided, appears to be 3,500 feet, and the thickness may be considerably greater.

Age and correlation.—Fossils representing at least 20 distinct genera were collected from 12 localities within the Upper Devonian rocks, undivided. A complete list of the fossils collected from these rocks is given in table 8. Collections 1 through 4 came from block B, and 5 through 12 from block C. Collections 1, 5, and 8 came from measured sections, and the position of the fossils within these sections is given on pages 62 and 63. Some of the stromatoporoids were examined by Richard Rezak and R. S. Boardman, some of the gastropods by E. L. Yochelson and A. J. Boucot. Foraminifera were examined by L. G. Henbest, and the other fossils were examined by C. W. Merriam.

Block C has at least 18 genera of fossils as compared to only 5 in block B. Most of the fossils in block C, however, came from locality 5, which is a conglomer-

TABLE 8.—*Fossils collected at various localities in the Upper Devonian sedimentary rocks, undivided, of the Black Rock Hills*

[Fossils identified by C. W. Merriam, Richard Rezak, E. L. Yochelson, A. J. Boucot, R. S. Boardman, and L. G. Henbest]

Fossil	Locality											
	1	2	3	4	5	6	7	8	9	10	11	12
Coelenterata:												
Stromatoporoids, genera undet.	----	----	----	----	×	----	----	----	×	----	----	----
Amphipora sp.	----	----	----	×	----	----	----	×	×	----	----	×
Idiostroma sp.	----	----	----	----	----	----	----	----	×	----	----	----
Pachyphyllum sp.	----	----	----	----	×	----	----	----	----	----	----	----
Macgeea sp.	----	----	----	----	×	×	×	----	×	----	----	----
Syringopora sp.	----	----	----	----	×	----	----	----	----	----	----	----
Tabulophyllum sp.	----	----	----	----	×	----	----	----	----	----	----	----
Phacelophyllum sp.	----	----	----	----	×	----	----	----	----	----	----	----
Brachiopoda:												
Atrypa sp.	----	----	×	----	×	×	----	----	----	----	----	----
Nudirostra sp.	----	----	----	----	×	----	----	----	----	----	----	----
Productella sp.	----	----	----	----	×	----	----	----	----	----	----	----
?*Hypothyridina* sp.	----	----	----	----	×	----	----	----	----	----	----	----
?*Tylothyris* sp.	----	----	----	----	×	----	----	----	----	----	----	----
Cranaena sp.	----	----	----	----	×	----	----	----	----	----	----	----
Cyrtina sp.	----	----	----	----	×	----	----	----	----	----	----	----
Mollusca:												
Bellerophontid gastropod	×	×	----	----	----	----	----	----	----	----	----	----
Straparolus cf. *S. ophirensis*, Hall and Whitfield	----	----	----	----	×	----	----	----	----	----	----	----
Large thick-shelled pelecypod	----	×	×	×	×	----	----	×	×	×	×	×
Cephalopod	×	----	----	----	----	----	----	----	----	----	----	----
Protozoa:												
Nanicella gallowayi (Thomas)	----	----	----	----	----	----	----	----	×	----	----	----

Localities

Number	*Block*	*Description*
1	B	In measured section.
2	B	In limestone, 10,850 ft S. 6° W. of peak 5,712.
3	B	In limestone, 11,200 ft S. 12° W. of peak 5,712.
4	B	In limestone, 10,300 ft S. 14° W. of peak 5,712.
5	C	Lower limestone unit in measured section.
6	C	Lower limestone unit, 18,600 ft S. 5° E. of peak 5,712.
7	C	Lower limestone unit, 15,900 ft S. 17° E. of peak 5,712.
8	C	Dolomite in measured section.
9	C	Limestone, 17,500 ft S. 17° E. of peak 5,712.
10	C	Dolomite, 14,250 ft S. 18° E. of peak 5,712.
11	C	Limestone, 17,700 ft S. 31° E. of peak 5,712.
12	C	Dolomite, 17,200 ft S. 28° E. of peak 5,712.

ate made of limestone fragments and "heads" of coral broken from a reef (fig. 14). Merriam called this conglomerate Upper Devonian, and stated that its fossil suite represents the *Pachyphyllum* zone which underlies the *Cyrtospirifer* zone in the Devils Gate formation of Nevada. Most of the other fossils in this block are not distinctive age markers, with the possible exception of *Macgeea*. Merriam stated (1955, written communication) that "*Macgeea*, where I have found it, is Late Devonian." Inasmuch as the limestone conglomerate occurs near the base of the section exposed in block C, the entire block is probably Late Devonian or younger in age.

Fossils in block B are fewer and less distinctive. *Amphipora* sp. is found in both Middle and Upper Devonian rocks. A Late Devonian age is favored for the rocks, however, owing to the presence of the large externally smooth thick-shelled pelecypods. This fossil appears to be a new genus, which, according to Merriam, resembles the pelecypods *Pycinodesma* and *Megalomus* in external form but differs in hinge structure. This pelecypod is widespread in the Black Rock Hills and is found in the Upper Devonian Gilson dolomite and in block C in several places, including the limestone conglomerate containing such typical Late Devonian forms as *Pachyphyllum*. This pelecypod has not been found in the Middle Devonian part of the Engelmann formation. In the Thomas and Dugway Ranges it appears confined to Upper Devonian sedimentary rocks. It is worthy of note that Kirk reported "*Pycinodesma*? sp." from near the top of the Guilmette formation at Gold Hill (Nolan, 1935, p. 21). According to Merriam (1955, written communication), the upper part of the Guilmette formation is now known to be Late Devonian, and the pelecypods found near Gold Hill, therefore, may be the same species as those found in the Black Rock Hills.

FIGURE 14.—Coral, *Pachyphyllum*, in limestone breccia reef, Upper Devonian sedimentary rocks, undivided, in Black Rock Hills about 2.5 miles northwest of Wildhorse Spring.

ROCKS OF MISSISSIPPIAN AGE

Sedimentary rocks of Mississippian age are found only in the northern part of the Dugway Range (pl. 1), where they form the uppermost part of the Paleozoic section. Butler first mentioned rocks of this age in this area (Butler, Loughlin, Heikes, and others, 1920, p. 460); he made a small collection of fossils in the Dugway mining district. The lithology of these rocks, however, was not described.

Rocks of Early Mississippian age in northern and western Utah consist chiefly of limestone that is equivalent to the Madison limestone of the northern Rocky Mountains (Nolan, 1943, p. 154). These rocks range in thickness from 600 to 1,600 feet in northern Utah. They are thinner on Promontory Point—430 feet (Olson, 1956, p. 57)—and south of Salt Lake, where on an west-east line in western Utah through Gold Hill (Nolan, 1935, p. 26), Dugway Range, Oquirrh Range (Gilluly, 1932, p. 7), and the Cottonwood-American Fork area (Calkins and Butler, 1943, pl. 5), the so-called Madison is 400, 315, 460, and 450 feet, respectively.

The lithology of the sedimentary rocks of Late Mississippian age in western Utah varies more than that of the rocks of Early Mississippian age. Upper Mississippian sedimentary rocks in the Gold Hill mining district (Nolan, 1935, p. 27–31) and the Dugway Range have calcareous siltstone and silty limestone at the base overlain by a thick sequence of limestone. Sedimentary rocks of the same age in the Oquirrh Range (Gilluly, 1932, p. 7) have phosphatic shale at the base overlain by blue-gray cherty limestone, followed by limestone interbedded with lenticular sandstone and quartzite, and finally light-blue limestone with partings of reddish shale. Upper Mississippian rocks in the East Tintic Mountains (Morris and Lovering, 1961, p. 93–114) are carbonaceous shale and shaly limestone with one or more phosphatic layers at the base overlain by cherty limestone with minor dolomite and sandstone, followed by a thick limestone unit with a central part of shale. The Upper Mississippian rocks range in thickness in western Utah from about 4,000 feet in the East Tintic Mountains (Morris and Lovering, 1961, p. 93) to about 6,000 feet in the Gold Hill mining district (Nolan, 1935, p. 28, 30). The total thickness of the Upper Mississippian sediments deposited in the vicinity of the Dugway Range is unknown because only the lower 1,570 feet of section is exposed.

Little lithologic similarity is noted between the rocks of Mississippian age in the Dugway Range and those in the Oquirrh Range and East Tintic Mountains to the east with the exception of the Lower Mississippian rocks in the Oquirrh Range. A striking similarity is noted, however, between the rocks of Mississippian age in the Dugway Range and those of the same age in the Gold Hill mining district to the west. Hence, the terminology of the Gold Hill district is used in the Dugway Range. The three Mississippian formations mapped are Madison limestone equivalent, Woodman formation, and Ochre Mountain limestone.

MADISON LIMESTONE EQUIVALENT (LOWER MISSISSIPPIAN)

The Madison limestone was orginally named by Peale (1893, p. 32–33) for exposures in the vicinity of Three Forks, Mont. This name has widespread usage for Lower Mississippian rocks in Montana, Idaho, Wyoming, and Utah. Some of the Utah localities of Lower Mississippian limestone described as Madison are the Randolph quadrangle (Richardson, 1941, p. 20–22), the Logan quadrangle (Williams, 1948, p. 1141–1142), the Sheeprock Mountains (Cohenour, 1959, p. 87–89), Gold Hill district (Nolan, 1935, p. 24–27), and Promontory Point (Olson, 1956, p. 56–57). We are dubious that the name Madison limestone, as used for the lower Mississippian limestones in Utah, is applied in the same sense as it is in its type area in Montana. Hence, to avoid confusion, we have called the Lower Mississippian rocks in the mapped area (pl. 1) Madison limestone equivalent.

The Madison limestone equivalent crops out only in the northern part of the Dugway Range. The largest outcrop band in the area mapped is 2 miles long, and extends from the Buckhorn thrust fault near the head of Buckhorn Canyon across Hanauer Ridge to the north edge of the map area (pl. 1). This formation crops out in several places in the vicinity of the Four Metals mine. The Madison equivalent also is well exposed in the northern tip of the Dugway Range in the adjoining Dugway Proving Ground SW quadrangle.

Lithology.—The Madison equivalent is a uniform medium-gray limestone with chert in its uppermost part. The base of the unit is placed at the top of a massive cliff-forming quartzite that forms the top of the Hanauer formation. North of the Four Metals mine in the adjoining Dugway Proving Ground SW quadrangle, this upper unit of the Hanauer is represented by the uppermost bed containing quartz sand. East of Bullion Canyon, however, several beds in the lower 150 feet of the Madison equivalent contain considerable quartz sand. These sandy units (fig. 15), which are of calcareous quartzite and quartzitic limestone, are best developed on Hanauer Ridge. Both southward and northward these units contain less quartz sand. Nevertheless, the base of the Madison equivalent on Hanauer Ridge is easily located because it lies at the top of a 90-foot cliff-forming quartzite. The top of the unit is placed at the base of a thin-bedded brownish-gray calcareous siltstone of the Woodman formation.

The Madison equivalent for the most part is fine-grained medium-gray or bluish-gray limestone. Beds range from 2 inches to 12 feet in thickness. In some areas the unit forms prominent cliffs. The upper 60 feet of the formation contains 5 to 10 percent gray chert that weathers brown and occurs in nodules and lenses as much as 4 inches thick and 6 feet long parallel to the bedding. Quartz sand is rare in this formation north of the Four Metals mine. East of Bullion Canyon, however, besides the units previously described that contain quartz sand at the base of the formation, a bed of calcareous quartzite, about 10 feet thick, is found approximately 50 feet from the top of the formation.

The Madison limestone equivalent has been dolomitized in the vicinity of the Four Metals mine, and is here a medium-grained thick-bedded dolomite that weathers chocolate brown. Outcrops of Madison equivalent between the Buckhorn thrust fault and the Four Metals mine are dull-white bleached dolomite. Northward from the Four Metals mine in the Dugway Proving Ground SW quadrangle, the chocolate-brown dolomite grades laterally into medium-gray limestone.

A detailed description of one of the best exposed sections of Madison limestone equivalent is given below.

Section of the Madison limestone equivalent, three-quarters of a mile north of the Four Metals mine, north part of Dugway Range

[Fossils identified by Mackenzie Gordon, Jr.]

	Thickness (feet)
Woodman formation: Siltstone, calcareous, thin-bedded, brownish-gray; weathers brown.	
Madison limestone equivalent:	
1. Limestone, bluish-gray, fine-grained; contains 5 to 10 percent gray chert that weathers brown; brachiopods, cup corals, crinoid stems, *Fenestella* sp., *Avonia* sp., *Schizophoria* sp., *Composita*? sp., *Brachythyris* aff. *B. chouteauensis* Rowley	59
2. Limestone, medium-gray, fine-grained; beds 2 in. to 2 ft thick; *Brachythyris* aff. *B. chouteauensis* Rowley	23
3. Limestone, medium-gray, fine-grained; contains as much as 5 percent scattered quartz sand	4
4. Limestone, medium-gray, fine-grained; beds 1 to 3 ft thick	39
5. Limestone, white, medium-grained, massive; contains stylolites	5
6. Covered	13
7. Limestone, medium blue-gray, fine-grained; beds 2 to 6 in. thick	4
8. Limestone, medium light-gray, fine-grained; beds 2 to 12 ft thick; a bed 136 ft above base contains stringers of quartz sand	168
Total thickness of Madison limestone equivalent	315
Hanauer formation: Quartzite, dolomitic, medium-grained, light-gray, massive; weathers brown.	

FIGURE 15.—Crossbedding in quartzitic limestone at the base of the Madison limestone equivalent, Hanauer Ridge. Field of view is about 5 feet across.

Thickness.—The upper and lower contacts of the Madison limestone equivalent are exposed in the area mapped only near the head of Buckhorn Canyon, but valley fill, broad covered areas, and the rolling topography made it impractical to measure the Madison equivalent in this area. Instead, it was measured up a steep east-facing slope about three-quarters of a mile north of the Four Metals mine in the Dugway Proving Ground SW quadrangle. The upper contact of the section was covered but is probably located within 20 feet of its true position. The thickness of the unit at this locality is at least 315 feet.

Age and correlation.—Fossils are common in certain intervals in the Madison limestone equivalent, but none were found in the lower 230 feet.

The corals were identified by W. J. Sando and the other fossils by Mackenzie Gordon, Jr., both of the U.S. Geological Survey.

The most conspicuous fossil horizon is in limestone beds that overlie the 10-foot quartzite bed in the upper part of the Madison equivalent in the northeastern part of the Dugway Range. Four fossil collections (U.S. Geol. Survey collections 16731, 16732, 16734, and 16738) were made from this horizon in the outcrop band that crosses Buckhorn Canyon. The following were identified in the Buckhorn Canyon collections:

Horn corals, indet.
Zaphrentites sp.
Cyathaxonia sp.
Rylstonia sp.
Amplexus sp.
Crinoid columnals

Fenestella sp.
Productid, indet.
Brachythyris aff. *B. chouteauensis* Weller
Cleiothyridina sp.
Camarotoechia? sp.
Cyrtina cf. *C. burlingtonensis* Rowley
Spirifer centronatus Winchell
Martinia? sp.
Hustedia sp.
Composita sp.
Loxonema sp.

A short distance above this horizon on a ridge just east of hill 5,424 in the upper part of Buckhorn Canyon the U.S. Geol. Survey collection 16735 was made:

Horn corals, indet.
Cladochonus sp.
Rylstonia sp.
Permia? sp.
Chonetes cf. *C. logani* Norwood and Pratten
Indeterminate productid brachiopod, cf. *Productina* sp.
Rhipidomella sp.
Schizophoria sp.
Camarotoechia sp.
Tetracamera sp.
Spirifer centronatus Winchell
Brachythyris aff. *B. chouteauensis* Rowley
Crurithyris sp.
Hustedia sp.
Cleiothyridina sp.
Composita sp.

U.S. Geol. Survey collections 16733, 16736 and 16737 made in the upper 70 feet of the Madison equivalent three-quarters of a mile north of the Four Metals mine, where the section was measured, included the following:

Horn corals, indet.
Fenestella sp.
Brachythyris aff. *B. chouteauensis* Rowley
Schizophoria sp.
Avonia sp.
Composita? sp.

These three collections or groups of collections are all Early Mississippian in age. In referring to the fauna in the first two groups, Gordon (1957, written communication) noted that an Early Mississippian age is witnessed by such brachiopod species as *Spirifer centronatus* Winchell, *Brachythyris* aff. *B. chouteauensis* Weller, and *Cyrtina* cf. *C. burlingtonensis* Rowley, all of which have been found previously in rocks of Madison age in the western United States. Sando (1957, written communication), in reference only to the coral fauna from these two groups, noted that this fauna is suggestive of that in the Madison limestone of Montana, Wyoming, and Utah. In referring to the fauna of the third group, Gordon (1957, written communication) noted that although smaller, it is also Early Mississippian in age.

The age of the lower part of the Madison limestone equivalent in the Thomas and Dugway Ranges is not known. The lower part of the unit as mapped might be Late Devonian in age, but in the absence of fossils the Devonian-Mississippian boundary is tentatively placed at the base of the Madison equivalent, where a sharp change in lithology takes place.

The Lower Mississippian rocks in the Dugway Range resemble the rocks of this age in the Gold Hill district (Nolan, 1935, p. 25–26) in that both are principally medium-gray dense limestone with considerable chert in the upper part and both conformably underlie the fine-grained reddish-brown sandy Woodman formation. In addition, the following fossils have been found in the Lower Mississippian rocks of both regions: *Spirifer centronatus* Winchell and species of *Zaphrentites*, *Amplexus*, *Fenestella*, *Chonetes*, *Composita*, *Schizophoria*, and *Cleiothyridina*.

The upper part of the Madison limestone equivalent in the Dugway Range also contains the following fossils in common with the Madison as mapped in the Stockton and Fairfield quadrangles (Gilluly, 1932, p. 23–24), the Cottonwood-American Fork area (Calkins and Butler, 1943, p. 24), and the Randolph quadrangle (Richardson, 1941, p. 22): *Spirifer centronatus* Winchell and species of *Fenestella*, *Chonetes*, *Camarotoechia*, *Composita*, *Cleiothyridina*, *Brachythyris*?, and *Loxonema*.

Fossils also indicate that the Madison limestone equivalent of the Dugway Range correlates at least with parts of the Fitchville formation and the Gardison limestone of the East Tintic Mountains (Morris and Lovering, 1961, p. 85–86, 91–92), the Joana limestone of east-central Nevada (Nolan, Merriam, and Williams, 1956, p. 55–56), and the Bristol Pass limestone of the Pioche district, Nevada (Westgate and Knopf, 1932, p. 20–21).

WOODMAN FORMATION (UPPER MISSISSIPPIAN)

The Woodman formation was named by Nolan (1935, p. 27) from its exposure on Woodman Peak on the southside of Dutch Mountain in the Gold Hill mining district. Rocks of similar lithology are found in the northern part of the Dugway Range overlying the Madison limestone equivalent.

The Woodman formation occurs in the mapped area only in the extreme northern part, within 1½ miles of the northern boundary. The largest exposure is a little more than a mile long on a series of low hills along the east side of Bullion Canyon. Other exposures are found in small fault blocks northwest of the Bertha mine and west of the Four Metals mine, on the west side of Bullion Canyon, and northwest of Kellys Hole. The Woodman also is exposed on the northern tip of the Dugway Range in the adjoining Dugway Proving Ground SW quadrangle.

Lithology.—The Woodman formation consists in general of two parts: the lower half, made up chiefly of reddish-brown calcareous siltstone, and the upper half, made up chiefly of light-gray silty limestone. The base of the Woodman formation is placed at the base of the lowest siltstone, and the top of the Woodman is placed at the top of the uppermost silty limestone. The rocks directly above and below the Woodman are limestone and do not contain any silt. Some beds higher in the overlying Ochre Mountain limestone contain a little silt but generally much less than do the beds of the Woodman formation, and they are bounded by limestone beds containing no silt.

The lower half of the Woodman formation is chiefly siltstone, although some limestone units and one quartzite unit are present. The siltstone weathers readily, and commonly is covered by rubble. Hills underlain by this rock are generally low, rounded, and red or brown in color. The siltstone is gray or pinkish gray on a fresh surface but weathers to reddish brown or brown. These rocks are almost all thin bedded; beds commonly range from ¼ to 4 inches thick. The siltstone consists of approximately equal amounts of subangular to well-rounded grains of quartz and of calcite cementing material with a few percent hematite. Diameters of both the quartz and calcite grains range from 0.02 to 0.10 mm. In some places the siltstone contains concentric diffusion bands consisting of a sequence of alternating thin light-gray and reddish-brown bands. The only difference observed between the two types of bands is that one set was colored with hematite and the other was not.

Limestone is not common in the lower half of the Woodman formation; beds that are present resemble the limestone in the upper half of the formation.

A 20-foot bed of massive resistant quartzite occurs in the upper part of the lower half of the Woodman formation. It forms a prominent ledge and is the only good marker bed in the formation. This rock is white medium-grained calcareous quartzite that weathers brown. It is coarser grained than the siltstone, having grains that range from 0.06 mm to 0.75 mm in diameter. The quartzite also differs from the siltstone in having more quartz and less calcite; the quartzite contains from 60 to 70 percent quartz grains.

The upper half of the Woodman formation is chiefly silty limestone, although a little siltstone similar to that described previously occurs near the base. The silty limestone is a fine-grained light-gray rock with irregular patches of brown-weathering silt. Its beds are from ½ to 4 inches thick, and this rock consists of about two-thirds calcite and one-third detrital material. The latter is chiefly subangular to well-rounded grains of quartz, but minor amounts of orthoclase and of plagioclase and traces of muscovite are also present. Grain size of the silty limestone is similar to the siltstone, ranging from 0.02 mm to 0.20 mm in diameter.

The details of the lithology are given below in the only complete section of the Woodman formation found within the area mapped.

Section of the Woodman formation along the north side of Buckhorn Canyon, north part of Dugway Range

[Fossils identified by Mackenzie Gordon, Jr., and W. J. Sando]

	Thickness (feet)
Ochre Mountain limestone: Limestone, coarse-grained, medium-gray, fossiliferous.	
Woodman formation:	
1. Covered	79
2. Limestone, fine-grained, light-gray, thin-bedded; contains numerous reddish-brown- and brown-weathering silty patches, poorly preserved gastropods, cup corals, and brachiopods	28
3. Covered; limestone float	27
4. Limestone, fine-grained, light-gray, thin-bedded; patches of brown silt	34
5. Covered	21
6. Limestone, like unit 4; bryozoan and cup coral fragments, including *Zaphrentites*? sp., in upper part	53
7. Covered; limestone and siltstone float	28
8. Limestone, like unit 4; *Zaphrentites* sp., *Rhopalolasma* sp., *Productella hirsutiformis* Walcott, *Rhipidomella* aff. *R. arkansana* Girty	11
9. Limestone, fine-grained, light-gray, thin-bedded; numerous patches of reddish-brown silt	14
10. Siltstone, calcareous, fine-grained, reddish-brown, thin-bedded	14
11. Limestone, like unit 9	13
12. Siltstone, like unit 10	16
13. Limestone, like unit 4; fragments of brachiopods and crinoid stems	29
14. Limestone, fine-grained, gray, massive, with brown silt showing conspicuous crossbedding	12
15. Siltstone, calcareous, fine-grained, light-gray, massive; weathers dark brown; lower 4 ft is crossbedded	24
16. Siltstone, calcareous, fine-grained, gray, thin-bedded; weathers reddish brown; has concentric banding	50
17. Limestone, fine-grained, light-gray, thin-bedded; contains thin lenses of brown chert	5
18. Covered	14
19. Quartzite, calcareous, medium-grained, white, massive; weathers dark brown	19
20. Covered	24
21. Siltstone, like unit 16	4
22. Covered	127

Section of the Woodman formation along the north side of Buckhorn Canyon, north part of Dugway Range—Continued

	Thickness (feet)
Woodman formation—Continued	
23. Siltstone, calcareous, fine-grained, pinkish-gray; beds from less than 1/16 to 4 in. thick; concentrically banded in part	56
24. Limestone, fine-grained, gray; beds from 1/4 to 1 in. thick	25
25. Covered; calcareous siltstone float	23
26. Siltstone; like unit 16 but does not have any concentric banding	36
Total thickness of Woodman formation	786
Madison limestone equivalent: Limestone, fine-grained, medium-gray; contains about 10 percent chert in lenses and nodules.	

Thickness.—The upper contact of the Woodman formation is exposed only in two small areas on the east side of the head of Bullion Canyon. The lower contact is exposed only on the ridges between the various branches of Buckhorn Canyon. A section was measured between the two contacts along a ridge on the north side of the main branch of Buckhorn Canyon. This section was partially covered and a fault 0.4 mile to the northeast trends towards the measured section. If this fault cuts the section, then the thickness measured is less, probably by not more than 100 feet, than the true thickness. The Woodman formation was measured at this locality because it was the only place where even an approximate thickness could be obtained. The measured thickness of the Woodman here is 786 feet.

The thickness of the Woodman formation in the Dugway Range is about half that in the Gold Hill mining district where Nolan (1935, p. 28) measured approximately 1,500 feet.

Age and correlation.—Fossils are not common in the Woodman formation and none were found in the lower calcareous siltstone. The corals in these collections were identified by W. J. Sando, and the other invertebrates by Mackenzie Gordon, Jr. Fossil collections were small and were obtained from a number of widely scattered localities.

U.S. Geol. Survey collection 16723, made on the north side of Buckhorn Canyon between 170 and 180 feet from the top of the Woodman formation, contained the following:

Zaphrentites sp.
Rhopalolasma sp.
Productella hirsutiformis Walcott
Rhipidomella aff. *R. arkansana* Girty
Brachiopod, indet.

Fossils (U.S. Geol. Survey collections 16722, 16724, 16726, 16727, 16729, and 16730) collected in small fault blocks from six other widely scattered localities in the upper part of the Woodman are given below:

Zaphrentites sp.
Cladochonus sp.
Rhopalolasma cf. *R. sympecta* Hudson
Crinoid columnals
Productella hirsutiformis Walcott
Rhipidomella aff. *R. arkansana* Girty
Schizophoria sp.
Spirifer sp.
Striatifera brazeriana (Girty)
Productid brachiopod, indet.

The most common species in these collections is *Productella hirsutiformis* Walcott, which, according to Gordon (1957, written communication), is a facies fossil that is commonly found in calcareous shale, siltstone and impure limestone. The above fossils indicate a Late Mississippian age (Gordon, 1957, written communication).

The unfossiliferous lower part of the Woodman formation in the Dugway Range is probably also Late Mississippian, inasmuch as fossils of this age were found just above the base of the Woodman formation in the Gold Hill district (Nolan, 1935, p. 28).

The fauna of the Woodman formation does not differ greatly from that of the overlying Ochre Mountain limestone. Even with the much larger collections from the Gold Hill district, Girty (Nolan, 1935, p. 28, 30) noted that he could not easily distinguish between the fauna of the two formations. Hence, the older Upper Mississippian rocks of the Dugway Range are correlated with the Woodman formation of the Gold Hill district chiefly on the basis of their stratigraphic position directly above the Madison limestone equivalent and their lithologic similarity to the Woodman of the Gold Hill district. The Woodman in both areas consists of a lower part of reddish-brown calcareous siltstone and fine-grained sandstone, and an upper part of silty limestone.

The lack of distinct faunal zones within the Woodman formation prevents positive correlation with beds containing the same faunas in other formations. Thus, correlation of the Woodman with other formations depends on the general Late Mississippian age, the stratigraphic position within this epoch, and to a lesser extent on lithology. The Woodman formation is tentatively correlated with the Deseret limestone and the Humbug formation of the East Tintic Mountains (Morris and Lovering, 1961, p. 93–107), of the Stockton and Fairfield quadrangles (Gilluly, 1932, p. 26, 28–29), and of the Cottonwood-American Fork area (Calkins and Butler, 1943, p. 26–28).

OCHRE MOUNTAIN LIMESTONE (UPPER MISSISSIPPIAN)

The Ochre Mountain limestone was named by Nolan (1935, p. 29–31) from exposures on Ochre Mountain in the Gold Hill mining district. Rocks of somewhat similar lithology are found in the northern part of the Dugway Range, where they overlie the Woodman formation. The Ochre Mountain limestone is exposed in the mapped area only within 1½ miles of the northern border (pl. 1) where it occurs chiefly in isolated fault blocks. The basal beds in depositional contact on the Woodman formation are exposed in two small areas along the east side of Bullion Canyon. The largest and best exposed outcrop of the Ochre Mountain is 2,900 feet long by 1,400 feet wide and is at the northwest end of Kellys Hole (fig. 48). Other exposures are along the northeast side of Kellys Hole, in the conspicuous valley northeast of Kellys Hole, and on the hills west of the Four Metals mine.

Lithology.—A description of the Ochre Mountain limestone is difficult to make because it is only partly exposed and the relation between the outcrops of this formation in the various fault blocks is not clear. Hence, only a general description of the formation exposed in the mapped area will be given.

The Ochre Mountain limestone consists largely of medium-gray limestone with interbeds of dark-gray dolomite. The base of the formation, which is exposed only in several small outcrops along the east side of the head of Bullion Canyon, is placed at the top of the uppermost fine-grained silty limestone of the underlying Woodman formation. The basal part of the Ochre Mountain contrasts with the Woodman in being a medium- to coarse-grained medium-gray fossiliferous limestone, with no visible detrital material other than fossil fragments. The top of the Ochre Mountain is not exposed.

The most common rock type is a fine-grained light- to medium-gray limestone. Beds of this rock are 2 inches to 3 feet thick, and most commonly 1 to 2 feet thick. Nodules or lenses of gray chert as much as 6 inches thick and 4 feet long are found in some beds. Silt has been noted in a few beds, but is much less common than in the underlying Woodman formation. Much of this limestone is similar in lithology to the Madison equivalent.

The dolomite that is interbedded with the limestone is a fine- to medium-grained dark-gray rock that weathers brownish gray. It is thick bedded or massive and in a few places has a faint mottling. Dolomite units range from about 1 to more than 75 feet thick.

Thickness.—The Ochre Mountain limestone is the uppermost of the Paleozoic formations mapped and is only partly exposed. On the east side of Bullion Canyon only 40 feet of this unit is found overlying the Woodman formation. The other outcrops of the Ochre Mountain occur in fault blocks, and the thickness in the largest exposure, measured near the east edge of the outcrop in Kellys Hole, is 470 feet. Inasmuch as Nolan (1935, p. 30) estimated the thickness of the Ochre Mountain limestone in the Gold Hill district to be approximately 4,500 feet, probably only a small part of this formation is exposed in the Dugway Range.

Age and correlation.—Fossils are fairly common in certain beds in the Ochre Mountain limestone. The eight collections made in this formation were examined by Mackenzie Gordon, Jr., W. J. Sando, and Helen Duncan. U.S. Geol. Survey collection 16719 made between 23 and 33 feet above the base on the ridge top 0.2 mile northeast of the head of Bullion Canyon contained the following:

Horn corals, indet.
Pentremites aff. *P. pyramidatus* Ulrich
Dimegelasma aff. *D. neglectum* (Hall)
Spirifer sp.

Lintz and Lohr (1958, p. 978–979) noted that *Dimegelasma* is characteristic of Early to Late Mississippian, and, according to Galloway and Kaska (1957, p. 26), the type of Pentremites found in this collection is limited to the Late Mississippian.

The position of the other seven collections within the Ochre Mountain limestone is not known because all came from fault blocks. U.S. Geol. Survey collections 16717 and 16718 made on the south side of a valley 1,400 feet southwest of the Four Metals mine contained:

Amplexus sp.
Ekvasophyllum cf. *E. inclinatum* Parks
Faberophyllum cf. *F. languidum* Parks
cf. *F. leathamense* Parks
Horn corals, indet.
Crinoid columnals
Spirifer sp.

U.S. Geol. Survey collection 16716 from the northeast side of Kellys Hole 1,900 feet southeast of road junction 4986 contained:

Striatifera brazeriana (Girty)

U.S. Geol. Survey collection 16721, which came from the northeast side of Kellys Hole 1,100 feet northeast of road junction 4,986, contained:

Caninia aff. *C.* sp. A of Parks
Dictyoclostus cf. *D. inflatus* (McChesney)
Schizophoria sp.
Spirifer cf. *S. brazerianus* Girty

Four U.S. Geol. Survey collections (16714, 16715, 16720, and MHS–300–55) were made along the ridge that forms the northwest end of Kellys Hole. These contained:

Ekvasophyllum cf. *E. inclinatum* Parks
Faberophyllum cf. *F. languidum* Parks
cf. *F. leathamense* Parks
sp.
Turbophyllum multiconum Parks
Syringoporoid coral
Horn coral, indet.
Septopora sp.
Spirifer sp.
Striatifera brazeriana (Girty)

These fossils indicate that the rocks from which they were collected are Late Mississippian in age. Gordon (1957, written communication) stated that "*Striatifera brazeriana* (Girty), *Dictyoclostus* cf. *D. inflatus* (McChesney), and *Spirifer* aff. *S. brazerianus* Girty are likely to be found in the middle and upper parts of the Upper Mississippian, and not in the lower part." Sando (1957, written communication) noted that the corals described above are typical of the corals described by Parks (1951, p. 171–186) from the "Brazer limestone," 8 to 12 miles southeast of Logan, Utah.

The difficulties in distinguishing the faunas of the Woodman formation from those of the Ochre Mountain limestone were pointed out in the section on the Woodman formation (p. 69). The Ochre Mountain limestone probably correlates most closely with the Great Blue limestone of the Stockton and Fairfield quadrangles (Gilluly, 1932, p. 29–31) and the East Tintic Mountains (Morris and Lovering, 1961, p. 107–113).

ORIGIN OF THE PALEOZOIC DOLOMITES

The origin of dolomite is a much discussed problem for which numerous theories have been advanced. One of the most complete summaries on the subject was made by Van Tuyl (1916, p. 257–420), who discussed eight possible methods of origin. Dolomites of the Thomas and Dugway Range can be divided roughly into two genetic classes—those formed prior to uplift from the sea bottom and those formed subsequent to uplift.

The dolomites formed prior to uplift in the Thomas and Dugway Ranges could have resulted from direct chemical precipitation, alteration of original limestone while it was still in the sea, or deposition of detrital dolomite reworked from previously existing dolomites. Whether direct chemical precipitation formed any of these dolomites is not known. The Sevy dolomite, however, suggests a chemical precipitate because of its widespread homogeneity, dense aphanitic character, and thin laminations. In some of the other dolomites the presence of local cross-bedding, piles of fossil debris, thick-shelled fossils, and local unconformities suggests shallow water deposition and reworking of the bottom sediments by waves. Nolan (1935, p. 22) pointed out that the dolomites in the Gold Hill district were for the most part formed in a shallow-water environment, and Raymond (1925, p. 168) has briefly noted the common association of dolomite with diastems and unconformities. The detrital character of some of the dolomite in the Thomas and Dugway Ranges may be due either to reworking of sediments by the waves or to deposition of sediments derived from elsewhere. In the latter case the sediments could have been either dolomite or limestone which was changed to dolomite shortly after being redeposited. The genesis of dolomite by alteration of limestone, probably during reworking of the original sediment by wave action in shallow water, is favored by us for most of the dolomites formed prior to uplift. Nolan (1935, p. 22) believed that the dolomites in the Gold Hill region, with the exception of those in the Abercrombie formation and the conglomerates near the base of the Sevy dolomite, were formed in this manner. In the Thomas and Dugway Ranges, the Dugway Ridge, Fish Haven, Floride, Bell Hill, Harrisite, Lost Sheep, Thursday, and Gilson dolomites, the dolomite of the Goshoot, and lower part of the Hanauer formations, and some of the dolomite in the Engelmann formation were probably formed during reworking in the sea.

Formation of dolomite prior to uplift does not mean that limestone units cannot occur in some places in the dolomite. Such limestone would probably occur in definite lenses which could be traced laterally for as much as several miles. A limestone bed in the upper part of the Fish Haven dolomite on the southern part of Spor Mountain appears to be a lens of this type. This limestone unit, which is about 70 feet thick, can be traced in various fault blocks from 3,700 feet south of the Floride mine to at least 2,000 feet north of it. A 40- to 60-foot bed of limestone believed to be of similar origin occurs in the upper part of the Goshoot formation and extends for about a mile along the north side of Engelmann Canyon. Smaller lenslike bodies of limestone only a few hundred feet long are found near the base of the Goshoot formation in the Black Rock Hills and in the upper part of the Gilson dolomite on the ridge north of Hanauer Canyon.

Much of the dolomite, particularly in the Dugway Range, was formed after uplift and probably by hydrothermal solutions. Criteria for distinguishing this type of dolomite might include (1) steep crosscutting of limestone beds by dolomite, (2) sharp or gradational changes along strike of beds, (3) islands of limestone in dolomite and vice versa, (4) mottling of limestone in which the mottled patches are dolomitic, (5) change to dolomite across fractures, and (6) association of dolomite with faults. Dolomites showing some of the above features are noted in the Dugway Range and in part of the Black Rock Hills, and include dolomites in the Cambrian Fandangle, Lamb, Straight Canyon, and Fera formations; the Ordovician Garden City formation; the Upper Devonian sedimentary rocks, undivided; parts of the Devonian Engelmann formation; and the Mississippian Madison limestone equivalent and Woodman formation. These rocks were all formerly limestones, and many were altered after most of the deformation of the area took place.

In the Dugway Range hydrothermally dolomitized rock is most common in the western and northern parts—north of Castle Mountain and west of Bullion Canyon and the Buckhorn thrust fault. In this region large areas of such sedimentary rocks as the Fandangle limestone, Fera limestone, Garden City formation, and Madison limestone equivalent have been dolomitized. In many of these areas the formations are extremely difficult to distinguish from each other and from other formations which are normally dolomite. Dolomitized rock in the Dugway Range is least common along the steep eastern face of the range. In this area only the Lamb dolomite and parts of the Straight Canyon formation are dolomitized. The Lamb is mainly dolomite, but in some areas it contains dark-gray and black limestone patches. Nolan (1935, p. 22) believed the Lamb in the Gold Hill district to have been altered to dolomite in shallow water shortly after original deposition. In the Dugway Range, however, the change from limestone to dolomite commonly takes place on small breaks, and in this area the rocks were dolomitized subsequent to uplift.

In the Black Rock Hills hydrothermally dolomitized rocks are found most commonly in the undivided Upper Devonian sedimentary rocks; they also occur in the lower part of the Engelmann formation.

At some places in the Dugway Range and the Black Rock Hills, limestone traced along strike is seen to grade into dolomite within a few feet; at others, the change from limestone to dolomite is abrupt and may start on a fracture which has little or no displacement (fig. 16). Irregular patches of limestone locally occur in large areas of dolomite; in some places as in the Straight Canyon formation

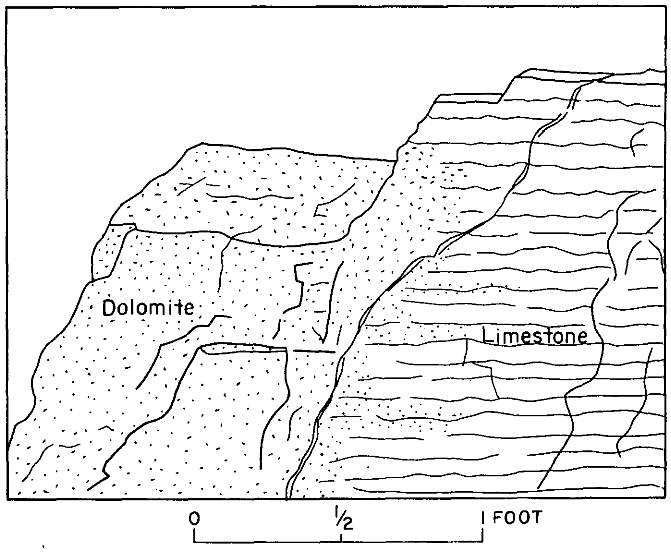


FIGURE 16.—Sketch of dolomitized area in thin-bedded limestone unit between quartzite layers at top of Lamb dolomite, north side of Straight Canyon. Stippled area to left is yellow-gray-weathering dolomite which becomes orange-gray toward contact with limestone. Limestone on right is gray. Note partial control of dolomitization by fracture in center of sketch, tendency of dolomite to spread laterally along bedding planes, and obliteration of bedding in dolomitized rock.

the reverse is true. Limestone with mottled color patches is commonly the first result of dolomitization, and in some places the central darker patches are dolomite and the rest is limestone.

The transformation from limestone to dolomite is generally accompanied by changes in color, texture, and bedding. The dolomite may be either darker or lighter than the original limestone. In general the textural change is from fine-grained and smooth-weathering limestone to medium-grained dolomite that has a sandy texture on weathered surfaces. The bedding of the dolomite tends to be thicker than that of the limestone and, as in some places in the Straight Canyon and Garden City formations, can be traced along strike from thin-bedded limestone into thick-bedded or massive dolomite. An example of several of these characteristics is shown in figure 17, where thin-bedded limestone is altered first to sandy-textured mottled limestone and then to massive dolomite.

Probably the most diagnostic feature in distinguishing dolomites formed prior to uplift from those formed after uplift is their relation to faults. In the mapped area dolomitized rock is most common and most thoroughly altered adjacent to faults. Along the east side of the Dugway Range dolomitized rock is rare in the Fandangle limestone, but at one place it occurs in a small area adjacent to the north side of the fault cutting across Shadscale Canyon. These relations are also clearly seen in the Fandangle lime-

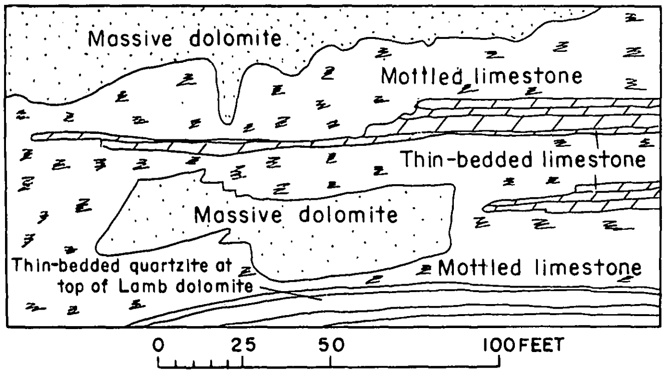


FIGURE 17.—Sketch showing several stages of dolomitization from unaltered thin-bedded limestone to sandy-textured mottled limestone to massive dolomite in base of Straight Canyon formation, 3,300 feet northeast of Dugway Pass.

stone and Lamb dolomite on either side of the fault down the center of Straight Canyon.

Hewett (1928, p. 856) discussed the relation of hydrothermally dolomitized rock to ore bodies, and noted that it is most commonly found near lead-zinc deposits. Lovering (1949, p. 21–24) in discussing the alteration in the East Tintic mining district cited dolomitization of the limestone and chloritization of the rhyolite as the first stage of hydrothermal alteration. He pointed out that some formations, like the Cole Canyon dolomite, change abruptly to limestone north of a large fault. In the East Tintic district the area of dolomitized rock is many times larger than that containing ore. Lovering believed that the fluids producing ore followed the same main channels as those which produced the dolomitized rock but branched out near the surface, in part following old channels and in part new ones. Gilluly (1932, p. 110–111) reported a small amount of hydrothermal dolomite adjacent to the Ophir Hill Consolidated mine, a lead-silver-zinc-copper deposit in the Stockton and Fairfield quadrangles.

The areas of most intensely dolomitized rock in the Dugway Range are chiefly west of the Buckhorn thrust fault and include the mines of the Dugway district. Although all the mines are within this area of most intensely dolomitized rock, not all the limestones in this area have been dolomitized; and some ore bodies, such as the one at the Francis mine, are in limestone.

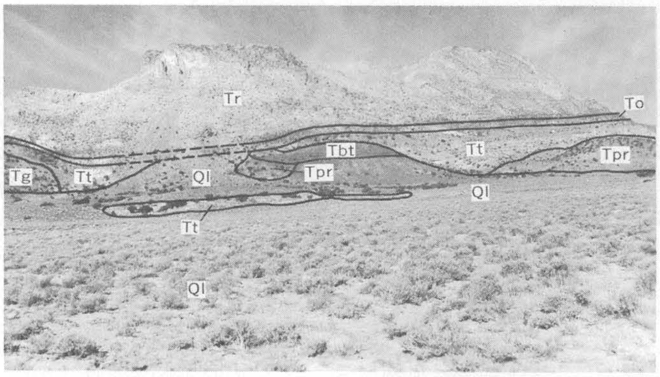
ROCKS OF TERTIARY AGE

VOLCANIC ROCKS

Volcanic rocks compose more than 50 percent of the bedrock in the Thomas and Dugway Ranges. The main mass of volcanic rocks makes up the entire eastern part of the Thomas Range and extends for 5½ miles northward into the Dugway Range. Small intrusions and flows are also found in and around Spor Mountain, the Dugway Range, and the Black Rock Hills. The Keg Mountains to the east of the mapped area and the unmapped part of the Black Rock Hills to the west consist chiefly of volcanic rocks; some volcanic rocks also occur to the south in the Drum Mountains.

The volcanic rocks may be divided according to their mode of emplacement into lava flows, intrusions, and pyroclastics. In composition they are predominantly rhyolitic, but in minor part rhyodacitic. They are divided on the basis of age into an older and a younger group. The younger group forms the upper part of the main or eastern part of the Thomas Range; the older group underlies the younger unconformably and forms low hills in the flats adjacent to the higher mountains (fig. 18). The rocks of the younger group are well exposed, and the relations between its constituent rocks are clear, but the rocks of the older group are poorly exposed and their relations to one another are in part obscure. The marked unconformity separating the two groups is an old erosion surface that has considerable relief in some places. Although this unconformity is quite striking in many places, it is commonly obscured by alluvium. Near the center of The Dell this unconformity is near the valley floor, but about a mile farther north it is about 500 feet higher. Near the Autunite No. 8 claim several narrow gullies on the old land surface have been filled with white vitric tuff of the younger group, and the original dips of the tuff beds on the two sides of the gully form a small syncline. About 300 feet west of this point the vitric tuff contains large boulders of the black glass welded tuff of the older group.

Distinct flow structure in lavas and bedding in tuffs are fairly common in the volcanic rocks of the younger group but much less so in those of the older group. Although flow laminae in rhyolite of the younger group are commonly bent and in places are highly contorted, the general attitude of the rocks is relatively flat. Local steepenings of the attitude of the volcanic rocks are due to the irregularities of the surface on which the younger volcanics were deposited. In the older group, on the other hand, there are some fairly steep dips that are due to deformation; near Spor Mountain, flow laminae in porphyritic rhyolite and bedding planes in welded tuff strike from N. 50° E. to N. 45° E. and dip from 29° to 47° NW. Inasmuch as these strikes and dips are similar to those of Paleozoic rocks exposed nearby, the old volcanic rocks probably were tilted at the same



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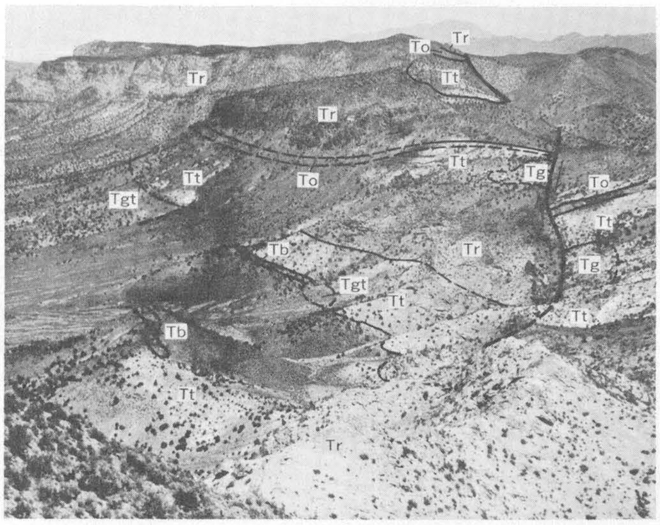


B

FIGURE 18.—*A*, Relations between volcanic rocks of the older and younger groups on the east side of Topaz Mountain. Older volcanic group: Tpr, porphyritic rhyolite; Tbt, black glass welded tuff. Younger volcanic group: Tt, vitric tuff; To, obsidian facies of the rhyolite; Tr, rhyolite; Tg, green glass; Ql, Lake Bonneville beds and alluvium. *B*, West-facing escarpment of the Thomas Range viewed facing north from a point south of Colored Pass. Cliffs in the distance are 500 to 800 feet high. Note the flat upland which represents the slightly eroded top of the flow in the distance, the Colored Pass fault, and the distribution of volcanic rocks of older and younger groups. Older group: Tqt, quartz-sanidine crystal tuff; younger group: Tt, vitric tuff; Tb, volcanic breccia, To, obsidian facies of the rhyolite; Tr, rhyolite, Tg, green glass.

time as the Paleozoic rocks and before the younger volcanics were erupted.

The rocks of the older and younger volcanic groups have certain similarities. Both groups are mainly rhyolitic in composition; both include lavas, tuffs, and intrusive rocks. Some of the rhyolites and rhyolitic tuffs in one group are very similar to rocks of the same classes in the other group. In general, however, the two groups have distinctive differences. All the rocks in the younger group are rhyolitic in composition, but some of those in the older group are rhyodacitic. The tuffs in the older volcanic group are mostly crystal tuffs, whereas those of the younger group are almost all vitric, and welded tuffs occurs mainly in the older group. Exceptions do occur, however: in some small areas thin layers of vitric tuff are interbedded with the crystal tuffs of the older group, and small discontinuous areas or layers of welded vitric tuffs occur in the younger group. Coarsely porphyritic rhyolite occurs mainly in the older group, and nonporphyritic rhyolite in the younger group; however, in some places, such as the north end of the Thomas Range, there is gray rhyolite in the younger group that is so distinctly porphyritic as to be hard to distinguish from the older porphyritic rhyolite. Although glass units are present in both groups, they are quite rare in the older rocks.

The difference in texture between the highly porphyritic rhyolite prevalent in the older group and the nonporphyritic rhyolite prevalent in the younger group may be due in part to mode of emplacement; the porphyritic rhyolite is intrusive, and the nonporphyritic rhyolite is mostly extrusive.

The older volcanic group consists mainly of the more coarsely crystalline rocks, including rhyodacite, porphyritic rhyolite, and crystal tuff, whereas the younger group consists mainly of nonporphyritic rocks, including aphanitic rhyolite, vitric tuff, volcanic breccia, and glass.

CLASSIFICATION

The approximate composition of a holocrystalline igneous rock can best be determined from its quantitative mineral composition, or mode. But because virtually all the volcanic rocks in the Thomas and Dugway Ranges consist in large part of glassy or microcrystalline groundmass, modal analyses of them would give only the composition of the phenocrysts, which generally differs widely from that of the rock as a whole. A rhyodacite, for example, may contain no phenocrysts of either potassium feldspar or quartz, although a chemical analysis would show that the groundmass contains enough potassium and silicon to have formed both minerals in abundance if the rock had been holocrystalline. In other words the norm of the rock, which can be calculated from the chemical analysis, more accurately portrays the true composition of the rock than does the mode.

The volcanic rocks are classified in this paper by a system based on chemical analyses proposed by Rittmann (1952, p. 75–100). He prefixed the word "dark" to the name of any rock in which dark minerals are more prevalent than is normal for this class, and used the prefix "alkali," as in "alkali-rhyolite," for any rock in which at least seven-eighths of the total feldspar as indicated by the chemical analyses is sanidine, anorthoclase, or albite.

The pyroclastic rocks are classified texturally according to the proposal by Wentworth and Williams (1932, p. 45–53).

In estimating the anorthite percentage of plagioclase phenocrysts from extinction angles, measurements were confined so far as possible to sharply twinned grains having some clearly identifiable orientation. These included Carlsbad-albite twins, albite-pericline twins, and sections virtually normal to the *a* axis. Crump and Ketner's curve (Emmons and others, 1953, fig. 6) was used for combined albite-pericline twins, Wright's (Rogers and Kerr, 1933, p. 212) for combined Carlsbad-albite twins, and Wahlstrom's (1947, p. 73) for plagioclase microlites. As shown by Crump and Ketner, the results obtained by such measurements can be statistically accurate only to about ±10 percent.

OLDER VOLCANIC GROUP

GENERAL FEATURES

Although the older volcanic group has a much smaller area of exposure than the younger, 10 units were distinguished in the older group as compared with only five in the younger. The rock types in the older group are rhyodacite and dark labradorite-rhyodacite, rhyodacite breccia and associated tuffs, plagioclase crystal tuff, black glass welded tuff, sanidine crystal tuff, quartz-sanidine crystal tuff, vitric tuff, red vitric tuff with associated conglomerate and sandstone, porphyritic rhyolite, and intrusive breccia.

The rocks of the older group are exposed here and there throughout the Thomas and Dugway Ranges, but only the rhyodacite and the porphyritic rhyolite are widely distributed. The red vitric tuff, with the associated conglomerate and sandstone, is found only in scattered outcrops within a northeast-trending band approximately 3 miles long in the southern part of the Dugway Range; the plagioclase crystal tuff is limited to a northwest-trending band along the northeastern part of the Thomas Range and in the adjacent part of the Keg Mountains; the black glass-welded tuff is found only in the vicinity of the Autunite No. 8 property. The sanidine crystal tuff occurs only at the south end of the Thomas Range, and the rhyodacite breccia and associated tuffs in the northwest corner of the Dugway Range. The quartz-sanidine crystal tuff is found in the central part of The Dell and at the northeast end of the Thomas Range.

As already noted, most of the volcanic rocks in the older group crop out only in comparatively small areas. One reason for this fact, no doubt, is that these rocks are partly covered by volcanic rocks of the younger group, Lake Bonneville sediments, and overburden. It appears possible, however, that some of these rocks never covered large areas, that is, that some were formed as small intrusive bodies and that some were extruded over small areas from a single center or at most a few centers.

Because of their small areal extent and poor exposures, the relations between the rocks of the older volcanic group are not fully known.

RHYODACITE AND DARK LABRADORITE-RHYODACITE

Two types of volcanic rocks containing pyroxene and a median plagioclase are found in the Thomas Range. According to Rittmann's classification (1952, p. 95) these rocks are rhyodacite and dark labradorite-rhyodacite. The former contains conspicuous lath-shaped phenocrysts of plagioclase and only a few small pyroxene crystals; the latter contains abundant phenocrysts of dark-green pyroxene and no visible plagioclase. Chemically the dark labradorite-rhyodacite differs from the rhyodacite in having a higher content of MgO, FeO, and CaO and a lower content of SiO_2, Al_2O_3, Na_2O, and K_2O.

Occurrence and relations.—The dark labradorite-rhyodacite is much less common than the rhyodacite and crops out only as a dike 120 feet long by 4 to 5 feet wide in the Black Rock Hills, and in 5 small areas of lava or intrusive rock near Spor Mountain. The largest of these areas, which is only 700 feet long by 280 feet wide, lies 5,000 feet south of the Bell Hill mine. Two of the other areas lie 3,200 to 3,500 feet south and southwest of the Bell Hill mine. Another is on the Harrisite property, and the fifth is 500 feet northwest of Eagle Rock Ridge.

The rhyodacite is widespread, occurring in both the Thomas and Dugway Ranges. In the Thomas Range it crops out in four main areas: (1) in the Black Rock Hills, where in addition to the small patches shown on the map (pl. 1), it covers a large tract northwest of the mapped area, (2) adjacent to Eagle Rock Ridge, (3) along the south end of Spor Mountain, and (4) along the south end of the eastern part of the Thomas Range. The last occurrence is at the north end of a belt containing scattered outcrops of rhyodacite that extends into the central part of the Drum Mountains. It also crops out in two smaller areas, one 6,500 feet southwest and one 600 feet north of Spor Mountain. In the Dugway Range, rhyodacite crops out in three main areas: (1) along the east edge of the volcanic rocks in the southern part of the range, (2) in scattered areas from the head of Green Grass Valley northward along Fandangle Canyon, and (3) along the Buckhorn fault between Bullion and Engelmann Canyons. There are also a number of small dikes of this rhyodacite in the northern part of the Dugway Range, but because these dikes weather more readily than the country rock, their position in most places is marked only by scattered pieces of float. Several of these small dikes are exposed in the workings of the Buckhorn mine.

The rhyodacite and dark labradorite-rhyodacite generally form small rounded hills, which are commonly surrounded by alluvium. The relation between the two rock types is unknown, and their relation to other rocks, especially the volcanic rocks in the Thomas Range, is hard to determine. In several small outcrops north of Spor Mountain, however, altered rhyodacite is cut by dikes of porphyritic rhyolite (fig. 19). In the southern part of the Dugway Range,

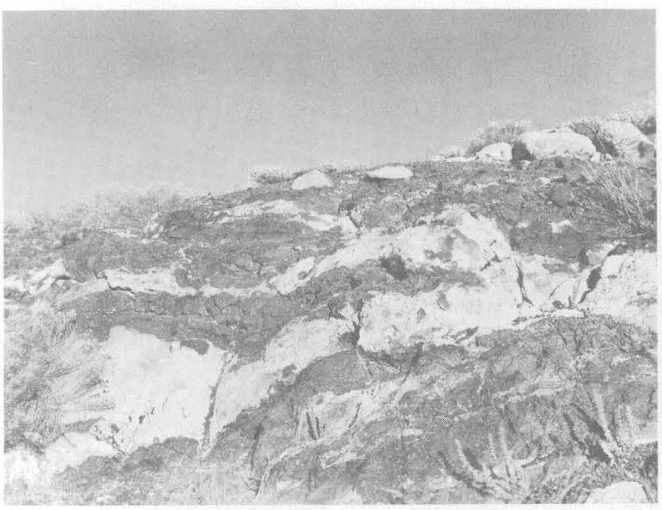


FIGURE 19.—Rhyodacite (dark gray) intruded by white porphyritic rhyolite, edge of main wash, 1.4 miles west-southwest of Wildhorse Spring.

rhyodacite probably cuts Cambrian sedimentary rocks and underlies gray porphyritic rhyolite of the older volcanic group and green glass of the younger volcanic group.

There is evidence in several places that the rhyodacite and dark labradorite-rhyodacite are intrusive. A contact of the dark labradorite-rhyodacite with the Lost Sheep dolomite exposed in trenches on the Harrisite property at the south end of Spor Mountain dips 60° to 90°. This steep dip, together with the oval outline of the outcrop (pl. 1), suggests that at this place this rock is a small plug. A small plug of rhyodacite cuts dolomite along a steep-sided gulch 1,200 feet southeast of the main workings on the Harrisite property. Some of the outcrops of rhyodacite adjacent to Spor Mountain and in Fandangle Canyon and Green Grass Valley show linear alinement along conspicuous faults; rhyodacite, commonly brecciated, also crops out along the Buckhorn thrust fault. These relations seem to indicate that this rhyodacite was intruded along fissures, but some of it may have reached the surface and formed small flows.

Lithology.—Both the rhyodacite and dark labradorite-rhyodacite weather dark rusty brown but are dark gray to dark grayish brown on fresh fracture. Both contain 15 to 50 percent phenocrysts, as much as 5 mm long, in a brown glass groundmass. In the dark labradorite-rhyodacite, however, most of the phenocrysts are pyroxene and a few are quartz, whereas in the rhyodacite most of the phenocrysts are of plagioclase and some are of pyroxene. The pyroxenes in the dark labradorite-rhyodacite are generally enstatite and augite, though hypersthene was found in one specimen. In the rhyodacite the pyroxenes are hypersthene and augite.

In the dark labradorite-rhyodacite the augite and enstatite are about equal in abundance, though locally either may be 2 to 3 times as abundant as the other. Many of the augite crystals are twinned and some are distinctly zoned. The quartz phenocrysts may constitute as much as 3 percent of the rock; they are anhedral, commonly embayed, and in a few places surrounded by dark reaction rings. Plagioclase phenocrysts were noted in a few thin sections; they are small, ragged, and lath-shaped, and commonly zoned. The plagioclase in the one thin section in which measurements were obtained is labradorite (An_{56}). Other minerals that form small phenocrysts in some of the rocks are magnetite, biotite partly altered to hematite, and hornblende.

The groundmass consists of a felted mass of plagioclase microlites in a brown glass commonly containing small particles of magnetite. The composition of the microlites in the individual thin sections ranged from An_{59} to An_{72}.

The dike in the Black Rock Hills is different from the rock described above, in being finer grained, in having fewer phenocrysts, in having a diabasic texture, and in containing many small ellipsoid-shaped vesicles as much as 0.1 inch in diameter, some of which are filled with calcite. The phenocrysts, which make up only 4 percent of this rock, consist entirely of subhedral to euhedral crystals of enstatite; no augite is present in this rock. The groundmass contains crystals of enstatite and magnetite and microlites of plagioclase, together with glass.

In the rhyodacite, plagioclase crystals make up 14 to 38 percent of the rock and those of pyroxene from less than 1 to 14 percent. The plagioclase phenocrysts are subhedral to euhedral crystals, which in thin section show well-developed albite twins and are commonly zoned. Their anorthite content, determined in 19 thin sections, ranges from An_{33} to An_{64}; the average is An_{54}. The plagioclase phenocrysts in specimens from the Dugway Range are commonly highly altered and largely replaced by clay and potassium feldspar. The most abundant pyroxene is generally hypersthene. Phenocrysts of hypersthene constitute as much as 10 percent of some specimens, though in some they are very scarce. They are subhedral to euhedral and are easily recognized by their parallel extinction and light-pink to light-green pleochroism. Augite is somewhat less abundant in most places but not everywhere; it locally makes up as much as 7 percent of the rock. It occurs in subhedral to euhedral phenocrysts which in some specimens are twinned. In the rhyodacite from the Dugway Range the augite is the varietal form pigeonite and has a 2V of only a few degrees (fig. 20). Hornblende was noted in two specimens, one from the Black Rock Hills and the other from the southern border of the mapped area. It constitutes as much as 4 percent of the specimen in the latter place and forms dark-green euhedral phenocrysts as much as half an inch long. A trace of biotite was also found in this specimen, and biotite makes up several percent of some specimens from Green Grass Valley in the Dugway Range (fig. 20). Small rounded anhedra of magnetite occur in almost all specimens and make up as much as 2 percent of some thin sections. Minute quantities of apatite were found in some specimens.

The groundmass of this rhyodacite consists of a felted mass of plagioclase microlites in light-brown glass. The average composition of the microlites in all the individual thin sections except one is An_{48}–An_{53} (in one slide it was An_{23}). The microlites are thus less calcic than the phenocrysts.

Chemical composition.—The fact that the refractive index of the brown glass groundmass of both rock types was less than that of balsam suggests the presence of considerable occult potassium feldspar in the groundmass. In order to check the potassium content, sawed sections from which thin sections were cut were stained with a cobaltinitrite solution according to the method of Gabriel and Cox (1929, p. 290–292). The results indicated that the groundmass of all specimens is high in potassium. Chemical analyses (table 15, nos. 1, 2, and 3) of one specimen of dark

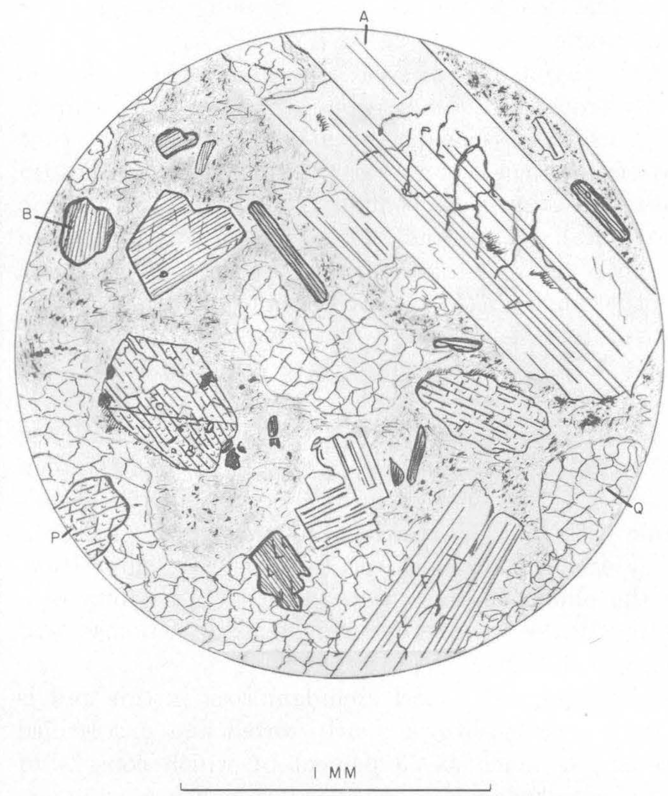


FIGURE 20.—Camera-lucida drawing of rhyodacite with phenocrysts of augite (pigeonite) (p), andesine (a), and biotite (b) in brown glass matrix with mosaic areas of secondary quartz (q). Head of Green Grass Valley.

labradorite-rhyodacite from the rock exposed on the Harrisite property and two specimens of rhyodacite from the south end of Eagle Rock Ridge and south of the eastern part of the Thomas Range support this conclusion. The two specimens of rhyodacite, though collected 4½ miles apart, are as similar in composition as two specimens from the same outcrop usually are. The norms of the three specimens contain from 26 to 30 percent orthoclase and from 12 to 22 percent quartz.

RHYODACITE BRECCIA AND ASSOCIATED TUFFS

Occurrence and relations.—The rhyodacite breccia and associated tuffs are found in isolated patches in the northwest corner of the Dugway Range (pl. 1), where the largest area underlain by a body of these rocks is 5,000 feet long and as much as 800 feet wide in the central and eastern parts of Kellys Hole. Smaller exposures are in the northwest corner of Kellys Hole, 3,400 feet west of the Four Metals mine; about 1,000 feet northwest of the Bertha mine; and 11,000 feet southeast of the Four Metals mine, just east of the Buckhorn thrust fault. There are several other scattered outcrops to the north of the mapped area just inside the Dugway Proving Ground SW quadrangle.

The rhyodacite breccia and associated tuffs are easily eroded in most places, and known masses probably are only remnants of a body that at one time covered a much larger area. Within the area mapped these rocks are now confined to low, flat areas such as the Kellys Hole and Bertha grabens, where erosion has been slower than on the steep mountain sides. To the north of the mapped area, however, this rock caps a prominent hill, 3,100 feet N. 52° W. of the Four Metals mine, being there well cemented and resistant.

In the area mapped, these pyroclastic rocks all rest on rocks of Late Devonian and Late Mississippian age and, being nowhere in contact with the other volcanic rocks, their relations to them are unknown. They are here included, on the basis of composition, in the older volcanic group because this group contains all the other rhyodacite in the Thomas and Dugway Ranges.

Lithology.—The most abundant rock in this unit is a dark greenish-brown poorly sorted and unstratified breccia, as much as 85 percent of which consists of rhyodacite fragments embedded in a dense ashy matrix. The fragments, which are generally angular, are mostly about 1/10 inch to 1½ feet across; in most areas, however, they are all less than 1 inch across. Although the fragments are generally somewhat altered, they can be seen in thin section to contain considerable plagioclase in long rectangular laths. The average composition of the plagioclase is about An_{47} (calcic andesine). Small amounts of altered pyroxene (at least in part augite) have also been identified, together with a little chlorite, calcite, and magnetite. In addition to the fragments of rhyodacite a few of siltstone have been noted. Crystal fragments make up from 2 to 10 percent of the rock; these consist chiefly of quartz and sanidine, but include minor amounts of plagioclase, magnetite, and hematite. The matrix of the breccia is partly glassy but consists in part of very fine grains. Its dark color and the presence of plagioclase microlites suggest that it is rhyodacitic in composition.

The tuffs generally occur in small isolated poorly exposed outcrops, but on the prominent hill just north of the mapped area they can be seen to be interbedded with the breccia. They are of several types. Some, especially north of the mapped area, are dark brown and appear to be made up of small rhyodacite fragments. Most in the mapped area are light tan to light gray and contain considerable quartz and sanidine. Much of the tuffs are very fine grained, and in the southeast end of Kellys Hole the only minerals recognizable in them are quartz and a smaller amount of calcite. They are well stratified, and this fact, together with the presence of much well-rounded quartz and of some calcite cement, strongly suggests they are waterlaid.

The occurrence of the coarser grained rocks to the west and to the north suggests that the vent from which the material came was to the northwest, probably in the adjoining Dugway Proving Ground SW quadrangle.

PLAGIOCLASE CRYSTAL TUFF

Occurrence and relations.—A northwest-trending band 15,000 feet in length, along the northeast edge of the Thomas Range, contains a series of small isolated exposures of plagioclase crystal tuff. This band extends from just south of the large fault which passes south of Bittner Knoll to the easternmost extension of the Thomas Range (pl. 1). Outcrops of this same rock are also found in the Keg Mountains, which lie just east of the quadrangle.

The plagioclase crystal tuff crops out on low knolls surrounded by Lake Bonneville sediments. At one place near the east end of the Thomas Range, however, this tuff overlies Prospect Mountain quartzite and contains large fragments of quartzite and limestone. In the Keg Mountains the tuff is overlain by rhyolite of the younger volcanic group. In some localities it shows a distinct bedding that dips from 13° W. to 61° E. The relations of this rock to other volcanic rocks are not fully known, but the following evidence is believed to indicate that it is a member of the older volcanic group: (1) the abundance of crystals in the tuff, (2) its position directly overlying the Paleozoic rocks and below the rhyolites known to belong to the younger group, and (3) its locally steep dips.

Lithology.—The plagioclase crystal tuff varies in color through white, gray, brownish gray, light greenish gray, and pale red purple. It is a compact, well-indurated rock that contains from 20 to 45 percent crystals—chiefly white grains of plagioclase with lesser amounts of biotite—in a dense ashy matrix. In some outcrops the tuff appears massive, but in others it is slabby and forms layers from ½ to 2 inches thick. Rock fragments are common near its base, but in most outcrops they are rare.

In thin section the plagioclase is seen to make up from 15 to 30 percent of the rock and to form subhedral to euhedral crystals that are commonly zoned (fig. 21). These crystals are from 6.5 to 0.5 mm long and 2.0 to 0.2 mm broad. The average anorthite content has a range from about An_{56} to An_{64}, which cor-

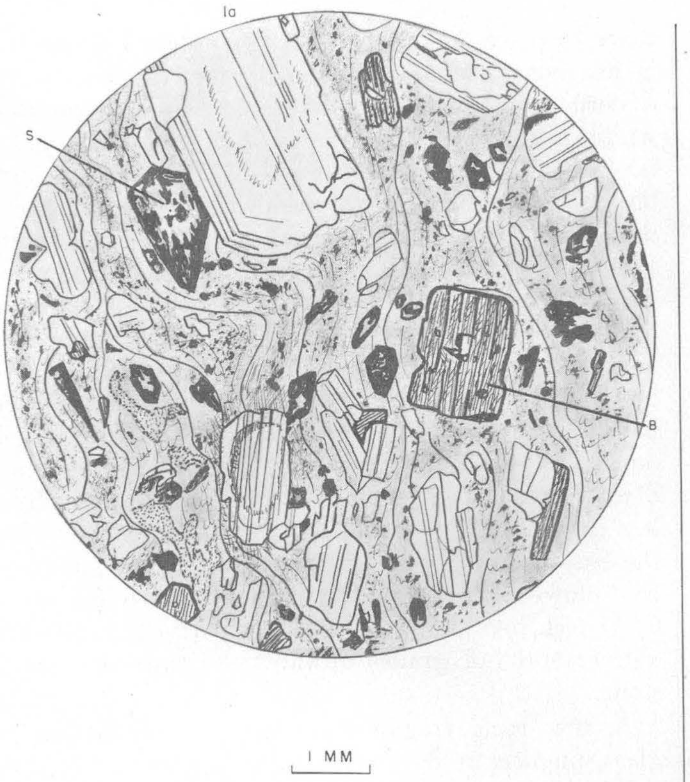


FIGURE 21.—Camera-lucida drawing of plagioclase crystal tuff containing zoned labradorite (la), and sphene (s) altering to hematite, brown and green biotite (b), and magnetite grains (black) in brown glass matrix with flow lines; specimen collected one-half mile south of Bittner Knoll.

responds to labradorite. All the crystals are fractured and are partially replaced along a fine network of fractures which commonly follow cleavage planes. The replacing material differs from place to palce; it consists mainly of calcite and clay minerals, but in one slide it appeared to be potassium feldspar. Biotite occurs in thick pseudohexagonal books, ranging from 0.2 to 2.0 mm in diameter. It contains numerous inclusions, chiefly of plagioclase. In some thin sections green and red-brown biotite were noted (fig. 21), both partly altered to hematite or magnetite. Magnetite, in small rounded anhedra, makes up from 1 to 2 percent of every thin section of these rocks. Sphene, largely replaced by calcite, was noted in some thin sections. Calcite, some of it irregularly replacing other minerals and some of it forming distinct rhombohedrons, can constitute as much as 4 percent of the rock. Very small amounts of apatite and zircon were found in all specimens, and isolated crystals of quartz, sanidine, and topaz in single specimens. The crystals show parallel to subparallel alinement.

The crystal fragments are in a matrix of small fragments of brown glass. In some specimens this glass is entirely devitrified and in others contains only a few scattered microlites. In some places it contains microscopic cavities. The index of refraction of the glass is less than that of balsam, and stain tests (Gabriel and Cox, 1929, p. 290–292) have shown it to contain considerable potassium. This fact, together with the presence of numerous labradorite crystals, suggests that the plagioclase crystal tuff has the chemical composition of rhyodacite.

SANIDINE CRYSTAL TUFF

Occurrence and relations.—A crystal tuff containing abundant sanidine occurs in four areas at the south end of the Thomas Range (pl. 1): (1) an area about 2,200 feet long by 1,500 feet wide, about a mile west of the mouth of Topaz Valley, (2) a small area about half a mile west of the mouth of Topaz Valley, (3) an elliptical area about 1,500 feet long by 150 feet wide crossed by the main east-west road just west of the southern tip of Antelope Ridge, and (4) a small area 7,500 feet west-northwest of the one last mentioned. The comparatively small area covered by this unit suggests that it was formed by explosion from a single vent in the southern part of the Thomas Range.

The sanidine crystal tuff forms rolling hills and rounded outcrops resembling those of porphyritic rhyolite. Little is known of the relations of this tuff to the other volcanic rocks of the older group. The largest area of outcrop is entirely surrounded by alluvium, and though the rocks to the north and west are vitric tuff and rhyolite of the younger volcanic group and those to the south and east are rhyodacite, the contacts are nowhere exposed.

Lithology.—The sanidine crystal tuff is a compact welded tuff, light gray to dark brown on fresh fractures but dark brown on weathered surfaces. The rock also contains small fragments of dark glass, light-colored devitrified glass, and pumice in some places; one fragment of siltstone was found. Small cavities are common in this tuff. Crystals, chiefly of sanidine, make up 20 to 70 percent of the rock, and are imbedded in a light-gray to brown ashy matrix.

One can see a distinct pyroclastic texture, shown largely by the many fractured crystals in thin section. The sanidine, which makes up as much as 55 percent of this rock, is in euhedral crystals or fragments of euhedral crystals, ranging in diameter from 0.15 mm to nearly 2 mm. Smaller enhedral to subhedral crystals of andesine (An_{43}) make up from 1 to 6 percent of the rock. Quartz constitutes about 5 percent of the rock; it forms rounded grains commonly rimmed with clay or sericite. Plates of green and brown biotite make up 1 to 3 percent of the tuff.

Still less abundant are magnetite, sphene, hornblende, and zircon.

The matrix of the crystals is a light-brown homogeneous glass, vesicular in some places and containing some shards. Fractures in the glass are commonly lined with highly birefringent clay minerals.

The sanidine crystal tuff is similar in mineralogy to the quartz-sanidine tuff described in the following section, but it is compacted and generally contains about 10 times as much sanidine as quartz.

QUARTZ-SANIDINE CRYSTAL TUFF

Occurrence and relations.—A tuff containing abundant crystals of quartz as well as of sanidine is found mainly in scattered outcrops in the central part of The Dell and at the base of the steep scarp in the northeast part of the Thomas Range (pl. 1).

The quartz-sanidine crystal tuff forms rounded hills, some several hundred feet high, in the flats that bound the area underlain by massive flows of the younger volcanic group. In most places the outcrops are surrounded by alluvium or Lake Bonneville sediments; in the northeast part of the Thomas Range, however, the tuff is unconformably overlain by rocks of the younger volcanic group, and in the vicinity of the Good Will property (fig. 50) it is conformably overlain by vitric tuff of the older volcanic group. There are no well-exposed contacts between the quartz-sanidine tuff and other members of the older volcanic group.

In most places the quartz-sanidine crystal tuff lacks internal structure, but in several outcrops north of Eagle Rock Ridge it has a distinct bedding that strikes northeast and dips 35° to 47° NW. Inasmuch as this strike and dip are parallel to those of the Paleozoic sedimentary rocks on Spor Mountain, the tuff was probably tilted at the same time as the Paleozoic rocks, long before the eruption of the younger volcanic rocks. The crystal tuff exposed in The Dell and the northeastern part of the Thomas Range may be of the same age, for the two localities are on the same line of strike.

Lithology.—The quartz-sanidine crystal tuff is a white, pale to dark yellowish-brown, or grayish-red, generally well-compacted rock. About 25 to 75 percent consists of crystals, which are embedded in a dense aphanitic groundmass. The crystals are chiefly clear quartz and sanidine, but a little biotite is visible in some specimens. Cavities, which may be as large as a half inch in diameter, are numerous in some areas. Some of this rock can be classified as a welded tuff, but the degree of welding varies from place to place, and in general the lighter colored tuff is less consolidated than the darker. In the northeastern part of the Thomas Range white to pinkish-white, moderately consolidated tuff grades into grayish-red tuff that is firmly welded. In The Dell hard brown welded tuff is interbedded with more friable white tuff. The differences in consolidation and welding are probably due to differences in the temperature of the particles when they came to rest, and the darker colors of the more firmly welded tuffs may be due to more complete oxidation of the iron caused by higher temperature. At one place in the central part of The Dell the fragments were apparently molten, and cooled so quickly that the matrix became a black glass. A conspicuous layer of black glass, from less than a foot to more than 75 feet thick, lies near the base of the largest exposure of this tuff, and can be followed discontinuously northeastward for about 6,500 feet. At the Good Will property (fig. 50) friable crystal tuff grades upward into tuffaceous sandstone.

A few rock fragments, nearly all consisting of glass, pumice, or devitrified glass, are generally present in the quartz-sanidine crystal tuff, but in some places these fragments are absent and in others may make up as much as 10 percent of the rock. Although some of the fragments noted are an inch across, most are less than a quarter of an inch across. One piece of quartzite was noted in a specimen from the outcrop by the road just east of the Fluorine Queen (fig. 50).

As determined in thin sections (fig. 22), quartz crystals make up from about 15 to 50 percent of the rock and sanidine crystals from 10 to 40 percent. Although most of the mineral fragments in the tuff are bounded by fractures, the quartz is commonly in euhedral bipyramidal crystals, which weather out from the more friable tuff.

Many of the quartz crystals are broken and embayed. The quartz grains range in diameter from 0.05 mm to 3.5 mm, and the sanidine grains from about 0.05 to 4.5 mm. Plagioclase crystals make up from less than 1 to about 15 percent of the rock and average about 5 percent. They are generally smaller than the quartz or sanidine crystals, having a maximum length of 2.5 mm. The plagioclase occurs in anhedral to subhedral crystals, a few of which show zoning. The average composition of the plagioclase in a thin section ranges from An_{34} to An_{45}. Biotite makes up from less than 1 to 4 percent of the rock. Magnetite is the most common accessory mineral, making up about 1 percent of the rock; zircon and

FIGURE 22.—Camera-lucida drawing of welded crystal tuff containing biotite (b), magnetite (black), quartz (q), sanidine (s), and plagioclase (p) in a groundmass of partly devitrified brown glass, showing relict shards and flow lines. One mile southeast of Dugway Pass.

sphene are found in many specimens in smaller amounts, and apatite, topaz, fluorite, and calcite were noted in one or two specimens. The calcite partially replaces the feldspars.

The groundmass is a light- to dark-brown glass that is partly devitrified. It commonly contains shards (fig. 22), and in a few places it contains trichites or belonites. Small amounts of tridymite have been noted in a few specimens, and bands and spherulites of chalcedony in several.

Chemical composition.—Chemical analysis (table 15, no. 4) indicates that the quartz-sanidine crystal tuff is rhyolitic in composition (Rittmann, 1952, p. 95). The norm contains more orthoclase and anorthite and less albite than that of the porphyritic rhyolite flows of the younger volcanic group. Although topaz is rare, the analysis indicates that this rock contains more fluorine than any other rock except the porphyritic rhyolite from the plug on Eagle Rock Ridge. The heavy-mineral fraction separated from a specimen of brown welded tuff contained only 0.01 percent fluorite. In view of the scarcity of fluorine-bearing minerals, it appears likely that the fluorine is largely in the glassy matrix.

VITRIC TUFF

Occurrence and relations.—Relatively thin layers of vitric tuff, both unwelded and welded, occur in the older volcanic group at several widely scattered localities. The largest body is exposed in outcrops scattered over an area 3,500 feet long by 700 feet wide in the northern part of the Thomas Range, about 1½ miles south of the main east-west road connecting Callao with Vernon (pl. 1). Exposures several hundred feet long are common in The Dell near the Good Will property (fig. 50), and isolated exposures, too small to show on plate 1, occur in the flat just northeast of the Thomas Range and also a mile north-northeast of Dugway Pass in the Dugway Range.

The vitric tuff is best exposed in the northern part of the Thomas Range, where it forms low cliffs along the gently sloping sides of some ridges. At most other localities it is poorly exposed because it is friable and occurs in flat debris-covered areas.

The rocks described in this section include all but one of the layers of vitric tuff in the older volcanic group, and these layers must differ in age. The age of the vitric tuff in the northern part of the Thomas Range is uncertain. This rock overlies porphyritic rhyolite of the older group and is overlain in turn by white vitric tuff of the younger volcanic group. The underlying vitric tuff, however, may itself belong to the younger group: It is welded, as is much of the older tuff, but it contains numerous lithic fragments, as does most of the tuff in the younger group.

Most of the vitric tuff here described, however, is of about the same age as the quartz-sanidine crystal tuff (p. 80). Vitric tuff more clearly of the older group, interbedded with quartz-sanidine crystal tuff, is exposed just southwest of Colored Pass and also near the Good Will property.

In the southern part of the Dugway Range, there is a narrow discontinuous layer of vitric tuff between rhyodacite and porphyritic rhyolite.

Lithology.—The vitric tuffs believed to be in the older volcanic group—other than the red one to be described later (p. 84)—are cream-colored, light- to medium-brown, moderate greenish-yellow, and pale-green rocks containing as much as 50 percent small angular to rounded fragments of glass in a dense ashy matrix. Most of these fragments are pumice, although in the welded tuff in the northern part of the Thomas Range they are more commonly devitrified glass or parts of spherulites.

Small crystals can be seen in thin sections, but they nowhere make up more than 5 percent of the rock.

Most are either sanidine or quartz, but minor amounts of plagioclase, biotite, magnetite, and calcite are present in some places, and one thin section contains a few grains of altered pyroxene.

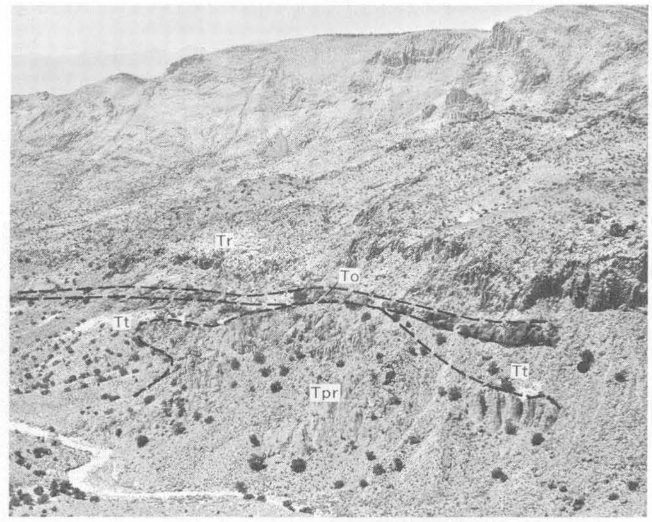
The matrix as seen in thin section is a brown glass, which is partly devitrified in the welded tuff. Some of the glass is commonly in shards.

PORPHYRITIC RHYOLITE

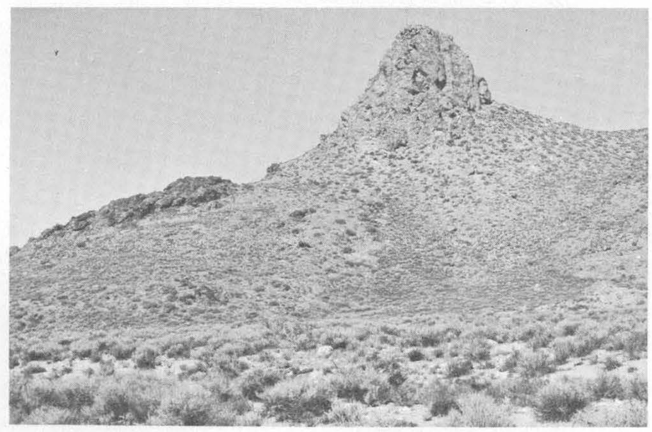
Occurrence and relations.—Porphyritic rhyolite is widely distributed in the Thomas and southern Dugway Ranges (pl. 1). This rock is found generally either on the margins of the main mass of younger volcanic rocks or in valleys within that mass. The larger areas of outcrop are: (1) along the east margin of the volcanic rocks in the southern part of the Dugway Range, (2) in the north-central part of the Thomas Range, (3) at the northwest end of The Dell, (4) in the central part of The Dell, east of Eagle Rock Ridge, (5) along the southern and southeastern part of Spor Mountain, (6) at the south end of the Thomas Range, and (7) on the east side of the southern part of the Thomas Range, in the vicinity of the Autunite No. 8 claim. Many smaller areas occur in the eastern part of Thomas Range, on Spor Mountain, and in the southern part of the Dugway Range.

The porphyritic rhyolite forms rounded ridges or hills with as much as 700 feet relief. It is unconformably overlain by tuff, breccia, and rhyolite of the younger volcanic group (fig. 23*A*). The relations of the porphyritic rhyolite to other members of the older volcanic group are difficult to determine in most places. In the southern part of the Dugway Range, however, porphyritic rhyolite overlies rhyodacite, and at the north end of Spor Mountain small porphyritic rhyolite dikes cut the rhyodacite (fig. 19). At the Autunite No. 8 claim, the porphyritic rhyolite is apparently overlain by black glass-welded tuff (fig. 25). In the southeastern part of the Dugway Range it is underlain by a small bed of vitric tuff of the older volcanic group, but in the central part of The Dell it is probably overlain by a bed of the older vitric tuff. The relations of the porphyritic rhyolite to the quartz-sanidine crystal tuff, the sanidine crystal tuff, and the plagioclase crystal tuff are not known.

The porphyritic rhyolite unconformably overlies Cambrian limestone and dolomite in the southeastern part of the Dugway Range, and plugs and small dikes of the rhyolite cut Silurian dolomite on Spor Mountain. One of the larger plugs, an oval body 1,600 feet long by 750 feet wide near the south end of Spor Mountain, is partly surrounded by a narrow rim of glassy rock containing phenocrysts identical with those in the main mass. Other evidence of an intrusive origin for at least part of this rhyolite is the occurrence of two small volcanic necks on the flats at the southeast end of the Thomas Range (fig. 23*B*). The central part of the southernmost neck (fig. 23*B*) forms a prominent spire of lighter color than the rhyolite surrounding it. Although much of the porphyritic rhyolite is clearly intrusive, some of it may be extrusive.



A



B

FIGURE 23.—*A*, Hill of porphyritic rhyolite (Tpr) in Searle Canyon unconformably overlain by vitric tuff (Tt), obsidian facies of the rhyolite (To), and rhyolite (Tr) of the younger volcanic group. *B*, Volcanic neck of porphyritic rhyolite about 1 mile southeast of Topaz Valley.

Lithology.—The porphyritic rhyolite is mostly light gray, but some is light brownish gray or pale brown. It contains 15 to 70 percent phenocrysts of sanidine, quartz, and plagioclase, in a matrix of glass. In some places where intrusive rhyolite magma has cooled quickly, as in the rim of the large plug in the southern part of Spor Mountain and in the outer part of one of the small volcanic necks southeast of the Thomas Range, the matrix is black glass.

Sanidine generally forms the most numerous phenocrysts but varies widely in abundance; it makes up as little as 2 percent to as much as 55 percent of the rock. It is in anhedral to euhedral crystals that vary widely in size, even in the same thin section, but are generally between 0.5 and 3.5 mm in diameter. Quartz makes up from 3 to 45 percent of the rock. It forms anhedral to euhedral crystals about 0.5 mm to 3.0 mm in diameter that in some places are embayed by the matrix. Plagioclase, in smaller crystals, makes up 1 to 15 percent of the rock. Its observed composition ranges from An_4 to An_{45}, but the overall composition of most crystals is between An_{20} and An_{43}. Biotite, the chief dark mineral, occurs in ragged or well-developed crystals that may be very scarce or may constitute as much as 3 percent of the rock. Magnetite, which is always present but never forms more than 3 percent of the rock, generally occurs in small rounded or irregular grains. Small crystals of zircon and sphene are found in amounts of less than 1 percent in some specimens. Topaz is absent in most specimens, but is commonly present in the plugs on and around Spor Mountain (fig. 24) and forms as much as 3 percent of one specimen. Hornblende, apatite, fluorite, and muscovite have been noted in a few specimens.

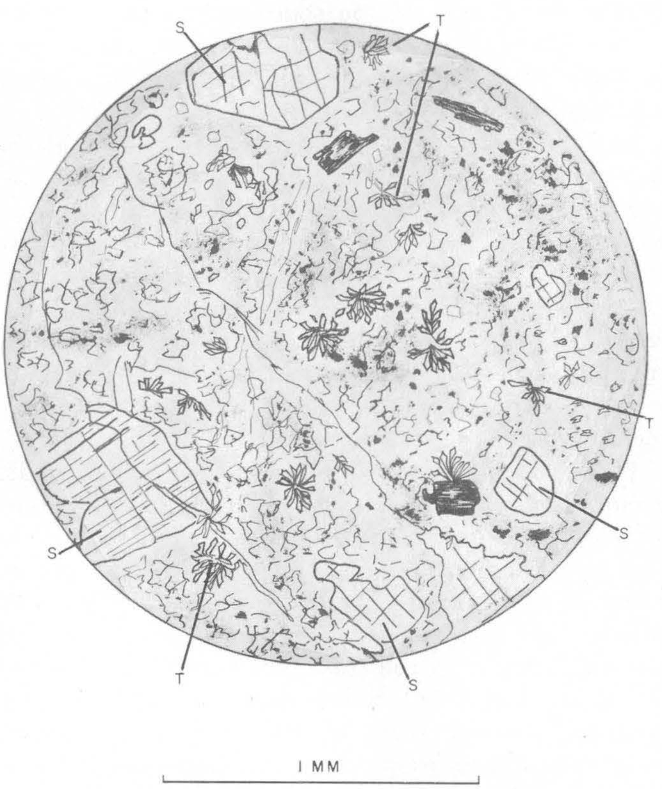


FIGURE 24.—Camera-lucida drawing of porphyritic rhyolite showing topaz (t) rosettes and sanidine (s). Groundmass is glass and fine-grained quartz. Northern part of Eagle Rock Ridge.

In thin section the groundmass is seen to be mainly clear light-brown or deep-brown glass, most of which contains small microlites and crystallites (belonites and trichites). In many places the glass has been partly or completely devitrified, and in some places the groundmass consists mostly of small spherulites. When the glass is clear, it contains perlitic cracks. Some specimens contain tridymite and a little cristobalite in minute grains that generally fill small cavities.

Most of the porphyritic rhyolite at the southeast end of the Thomas Range, from a point about 1.3 miles west of the mouth of Topaz Valley to a point 1 mile north of the Autunite No. 8 prospect, contains broken crystals and is texturally similar in many respects to a tuff, but it is regarded as a flow breccia for the following reasons: (1) In the vicinity of the Autunite No. 8 property the rock is made up of irregular and wedge-shaped pieces recemented with rhyolite of similar composition; (2) there are two small volcanic necks that consist of this rock; (3) some thin sections contain broken crystals whose parts have moved only a small distance apart, as if their movement had been restricted by a viscous medium; (4) cracks in some crystals are filled with glass; (5) in some places no fracturing is visible; and (6) the glass commonly shows flow lines. Fracturing somewhat similar to that in this rock was observed by Minakami, Ishikawa, and Yagi (1951, p. 131–133) in the andesite of the active volcano Showa-Shinzan, a small roofed volcanic dome that was formed on the flank of the Usu volcano in 1944. The fresh lava exposed at the top of this dome is broken into irregular or wedge-shaped pieces, which those geologists believed to have been formed when lava that had consolidated early was fractured by upward movement of underlying still-fluid lava. Some brecciated porphyritic rhyolite in the southeastern part of the Thomas Range is probably of similar origin.

Chemical composition.—Chemical analyses were made (table 15, nos. 5 and 6) of two samples, one (no. 5) collected at the north end of Eagle Rock Ridge and the other (no. 6) 0.3 mile east of the Autunite No. 8 prospect; both analyses indicate that the rock has a rhyolitic composition, according to the classification of Rittmann (1952, p. 15). The two samples, however, show a greater difference in chemical composition than any two of the rhyolitic rocks in the younger volcanic group (table 15, nos. 7–16). The norm of no. 6 is higher in quartz, anorthite, and the iron oxides (magnetite, ilmenite, and hematite) and lower in orthoclase and albite, while that of no. 5 is lower in quartz, anorthite, and iron oxides and higher in albite than any rock of the younger group.

BLACK GLASS-WELDED TUFF

Occurrence and relations.—Black glass welded tuff is limited to three small areas in the southeastern part of the Thomas Range. One of these areas, 600 feet long by 450 feet wide, lies just north of the discovery pit on the Autunite No. 8 property (pl. 1); another, 800 feet long by 200 feet wide, is 1,500 feet S. 20° W. of this same pit, and the third, 200 feet long by 100 feet wide, is 500 feet west of the first.

This welded tuff is fairly well exposed on many small knolls. It rests on an irregular eroded surface cut on porphyritic rhyolite (fig. 25), and is unconformably overlain by white vitric tuff of the younger group. Near the Autunite No. 8 discovery pit the vitric tuff fills a gully of northeasterly trend cut into the welded tuff. About 300 feet farther west there are boulders of the welded tuff in the lower part of the vitric tuff. The smallness of the area in which this welded tuff occurs suggests that it consists of material thrown out during one brief eruption from a single vent.

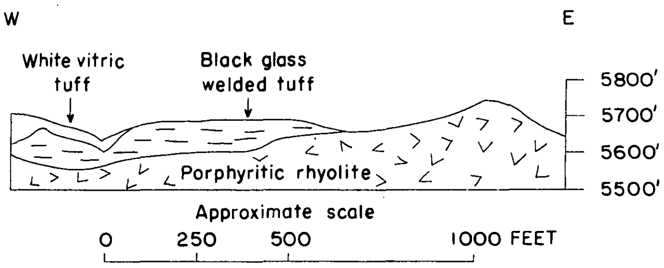


FIGURE 25.—Sketch showing the relation of black glass welded tuff just north of the Autunite No. 8 prospect to the underlying porphyritic rhyolite and the overlying white vitric tuff.

Lithology.—This welded tuff is a dark-brown to black glassy porphyritic rock containing elongate fragments of brown pumice as much as 10 inches long, which make up from less than 1 percent to as much as 20 percent of the rock.

The welded tuff is distinctly layered because of alinement of lenticular pumice fragments, flakes of biotite, rectangular plagioclase crystals, and shards of glass. Phenocrysts of plagioclase, together with much less biotite, make up from 30 to 50 percent of the rock. Small cavities one-half to three-quarters of an inch long were noted in some places.

The plagioclase is seen to form subhedral to euhedral crystals from 0.13 to 2.75 mm in diameter. Some crystals are zoned and range from about An_{45} to An_{57}. Biotite makes up 4 to 5 percent of the rock and forms euhedral crystals 0.25 to 1.6 mm in length. Small anhedral grains of magnetite make up about 1 percent of the rock. A few small grains of quartz were noted in one slide, and very small quantities of apatite and hornblende were observed. The groundmass consists of brown glass, largely in the form of shards. Some of the groundmass occurs as partly devitrified areas or bands and consist largely of spherulites. Small cavities in the rock are commonly filled with tridymite, and in some places with cristobalite.

The plagioclase phenocrysts in this tuff are similar to those of the plagioclase crystal tuff in the northeastern part of the Thomas Range, but this rock is distinguished from the other by its black glass matrix and elongate pumice fragments.

RED VITRIC TUFF AND ASSOCIATED CONGLOMERATE AND SANDSTONE

Occurrence and relations.—Red vitric tuff intimately associated with red conglomerate and sandstone is exposed in scattered outcrops in the following areas in the southwestern part of the Dugway Range (pl. 1): (1) on the flats about 3½ miles northwest of Dugway Pass, (2) at the foot of the rhyolite flow along the southwest edge of the Dugway Range, and (3) in the valleys of the south-central part of this range. The tuff is confined to the westernmost parts of these areas, and grades eastward within a short distance into red conglomerate and sandstone.

Small ledges of the red vitric tuff crop out in the bottoms of washes and the cut banks of stream channels, and the rock forms low ridges partly covered with alluvium between washes. Good outcrops are scarce, particularly on the low rounded spurs which extend westward from the volcanic foothills of the range. The conglomerate is more weathered, as a rule, than the tuff, but the presence of conglomerate is indicated by boulders and cobbles of sedimentary rock resting on a reddish-brown soil.

These rocks probably belong to the older volcanic group. In many places the red tuff appears to be intruded by a green spherulitic glass, and is overlain by highly fractured red rhyolite of the younger group. Many of the fractures in this rhyolite are filled with pebble dikes in which the pebbles consist of hard red material similar to the tuff. In most places the red sandstone and conglomerate probably rest directly upon sedimentary rocks of Paleozoic age, although no actual contacts were seen. The sandstone and conglomerate are overlain in some places by white to pink vitric tuffs at the base of the younger volcanic group, but in other places the tuffs are absent and the sandstone and conglomerate are directly overlain by rhyolite of the younger group.

The steepest dip observed in this unit is 16°, but the average dip is about 5°. The strike is variable, probably because the material was laid down in most places on the eroded surface of the Paleozoic sedimentary rocks.

Lithology.—The vitric tuff has a distinctive brick-red color, is well-indurated, and consists of scattered rock fragments in an ashy matrix. The tuff commonly has flaggy bedding and in places it has a conchoidal fracture. The rock fragments are mostly angular pieces of volcanic rock, but they consist in small part of sedimentary rocks. Vesicles are common in the tuff, and in places make up as much as 30 percent of volume of the rock. Quartz-lined vugs are present locally.

Thin sections show that about 20 percent of the red tuff consists of small broken corroded crystals, chiefly quartz but including considerable sanidine and a very little biotite and magnetite. The crystals are generally less than 0.25 mm in diameter. The groundmass consists almost entirely of iron-stained shards of devitrified glass (fig. 26), but locally contains some interstitial calcite. The shards have undergone little or no compression.

By lateral gradation and interbedding, the tuff passes into dark-red, moderately to slightly indurated sandstone and into conglomerate that consists chiefly of rounded to subrounded fragments ranging in size from sand to boulders. The fragments are chiefly of limestone and dolomite, but include some cobbles of volcanic rocks. Much of the sand-size material consists of round frosted quartz grains. Cross-bedding is common, and the conglomerate contains lenses of sand in most exposures. The conglomerate and sandstone contain a small proportion of pink to red clay, probably derived from ash. Red iron-staining is common in the pieces of sedimentary rock as well as in the matrix.

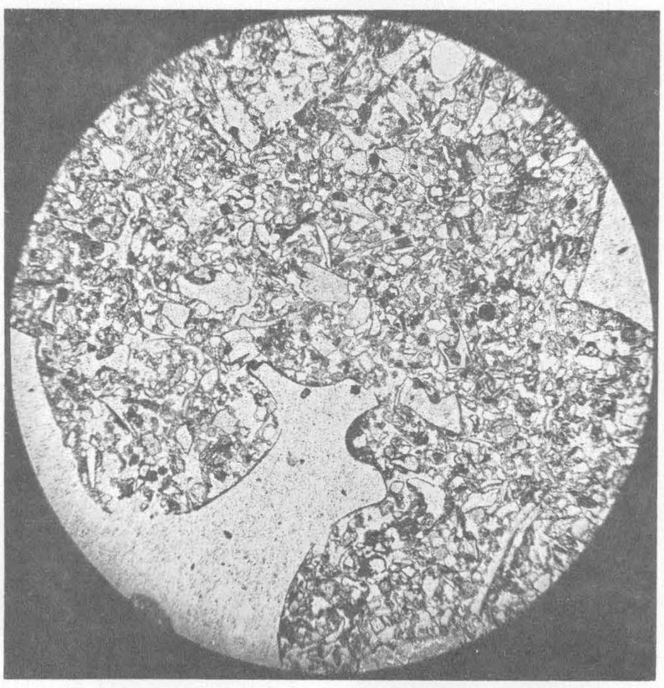


FIGURE 26.—Photomicrograph of red vitric tuff showing closely packed shards and relict outlines of shards. X 18; plain transmitted light.

The presence of well-rounded clastic particles and the distinct bedding indicate that the sandstone and conglomerate were deposited by running water.

INTRUSIVE BRECCIA

Occurrence and relations.—The breccia now to be described is exposed mainly in the north-central and northeastern parts of Spor Mountain. It there forms bodies of widely differing size; many are only a few feet across, but one on the east side of Spor Mountain is 1,500 feet wide by 6,000 feet long. Outside the vicinity of Spor Mountain the breccia occurs in an area about a square mile in extent south of Wildhorse Spring, and in a small area near the head of Shadscale Canyon, in the southern part of the Dugway Range.

The breccia is much weathered, and generally forms smooth slopes thickly covered with brick-red soil strewn with oriented blocks as much as 100 feet across derived from several older formations. Where small bodies of this breccia have been intruded into fault fissures, they are often rather hard to distinguish from rhyolite dikes, which weather to red soils near their contacts with carbonate rocks, and from rocks in fault zones altered by solutions moving along these fissures.

Most of the bodies of intrusive breccia cut Paleozoic sedimentary rocks, which are generally shattered near the contact. On Spor Mountain the breccia has been emplaced in rocks of Silurian and Ordovician age, and near the head of Shadscale Canyon in rocks of Cambrian age. Although the breccia is in contact with rocks of the younger volcanic group at several places along the east side of Spor Mountain, none of its contacts with these rocks are well exposed. The available evidence, however, suggests that the intrusive breccia belongs to the older volcanic group rather than to the younger. This correlation is supported by the fact that the intrusive breccia contains fragments of porphyritic rhyolite and rhyodacite of the older volcanic group but no fragments of the younger volcanic rocks; the younger volcanic group, moreover, is not known to be cut by any body of intrusive breccia.

Lithology.—Although the intrusive breccia varies considerably in composition from place to place, it consists for the most part of small to large pieces of sedimentary and volcanic rocks in a matrix of secondary dolomite or volcanic material. Many masses of rock mapped as intrusive breccia consist of dolomite blocks in a red matrix of secondary dolomite. Some contain blocks of igneous rock mixed with blocks of dolomite; some are composed almost entirely of igneous blocks in a red dolomitic matrix; and a few of the smaller masses are made up of igneous blocks in an igneous matrix, mainly glass. Although most of the sedimentary blocks are dolomite, a few of limestone and quartzite have been noted. In some places the smaller dolomite fragments are completely or partly silicified. The igneous rock in the intrusive breccia is mostly porphyritic rhyolite, but in a few places it is partly rhyodacite. About 3,000 feet south-southeast of the Bell Hill mine, in outcrops along both sides of a wash, small fragments of rhyodacite are intermixed with blocks of dolomite as much as 15 feet in diameter. Intrusive breccia composed almost wholly of porphyritic rhyolite is well exposed in the cut leading into the main Lost Sheep pipe and also near the mouth of the lower adit at the Blowout pipe.

The rock fragments that make up part of this breccia ranges from grains less than 1 mm in diameter to blocks as much as 100 feet in diameter. The larger blocks are chiefly of dolomite; the pieces of igneous rock rarely exceed 6 inches in diameter.

The breccia on Spor Mountain is believed to have been formed by gaseous explosions, or "blowouts," that shattered volcanic and sedimentary rocks, fragments of which fell into the "blowout" craters and were in some places cemented with lava. Walker (1928, p. 942) in a proposed classification for explosion pipes containing similar breccias, divided them into four types: (1) those consisting only of exploded material, (2) those in which the interstitial spaces between the breccia fragments are filled with lava, (3) those in which the breccia is penetrated by one or more dikes or small columns of lava, and (4) those in which the breccia is nearly or completely displaced by lava. All four types are found on Spor Mountain. Breccia pipes of explosive origin have been found in the Inner Hebrides, Scotland, by Geikie (1897, p. 276–297) and in Missouri by Rust (1937, p. 48–75).

YOUNGER VOLCANIC GROUP

GENERAL FEATURES

About 95 percent of the volcanic rocks in the Thomas and Dugway Ranges are assigned to the younger volcanic group. This group rests unconformably on the older volcanic group and is probably of Pliocene age (See p. 116). The younger volcanic group consists in the main of five subgroups. Each of the subgroups, where it is completely represented, is accordingly made up, in ascending order, of vitric tuff, volcanic breccia, and lava flows. These rocks exhibit considerable variety of color and texture, but are all rhyolitic in composition. The dominant rock in all the subgroups is gray rhyolite.

In addition to these products of cyclic eruption, the younger volcanic group includes a material, briefly designated as "green glass" because of its prevailing color and texture, that was formed by local remelting of the volcanic rocks. This material cuts across the flows and pyroclastic beds in some places but is concordant with them in others.

PARTIAL SECTIONS

Sections of parts of the younger volcanic group exposed at several localities are given below.

Section of part of the younger volcanic group (bottom about half a mile southwest of Colored Pass, east side of The Dell, Thomas Range)

	Thickness of unit (feet)	Cumulative thickness (feet)
Rhyolite unit:		
Rhyolite, red, spherulitic; enclosing blocks of brown glass near the base.		
Breccia, consisting of blocks of obsidian in an obsidian matrix	14. 5	314
Tuff unit:		
Tuff, white, consisting of fragments of pumice, rhyolite, and obsidian. Obsidian becomes more common toward the top	24. 0	299
Tuff, brown, vesicular, well-indurated; fragments of pumice and glass	2. 2	275
Tuff, white, compact, slightly vesicular; abundant small fragments	2. 9	273
Tuff, brown, vesicular, massive; subround to round fragments of glass and pumice	65. 2	270
Covered	26. 2	205
Breccia; fragments from 1 in. to 1 ft in diameter, chiefly of purple rhyolite	1. 0	179
Tuff, mostly white but locally pale-green; contains fragments as much as 1½ in. across of purple rhyolite and pumice	59. 3	178
Tuff, white to pale-green, massive well-indurated; fragments chiefly of brown rhyolite and green glass	11. 6	118
Tuff, white, friable; fragments ⅛ to ¾ in. of brown rhyolite and glass	106. 8	107
Base covered.		

Section of part of the younger volcanic group (base of section 2.0 miles northeast of the Lost Sheep mine, east side of The Dell, Thomas Range)

	Thickness of unit (feet)	Cumulative thickness (feet)
Rhyolite unit:		
Rhyolite, aphanitic, with vugs containing topaz; mostly light gray but lower part has some faintly reddish-gray areas.		
Rhyolite, pinkish-gray aphanitic, flow-banded; contains a few clear phenocrysts of quartz and feldspar and a few lithophysae	3.4	106
Obsidian, black, massive, spherulitic; gray toward top	48.5	103
Breccia unit:		
Breccia, gray; contains angular fragments of pumice ½ in. to 3 ft across	35.6	54
Breccia, orange; angular fragments of pumice as much as 2 ft across	15.2	19
Tuff unit:		
Tuff, white; fragments ⅛ to 1 in. across of pumice, glass, and purple rhyolite	3.4	3
Rhyolite unit: Rhyolite, pink to purplish-gray, aphanitic; contains phenocrysts of clear feldspar and smoky quartz.		

Section of part of the younger volcanic group (base of section 600 feet west of Autunite No. 8 prospect on southeast end of the Thomas Range)

	Thickness of unit (feet)	Cumulative thickness (feet)
Rhyolite unit:		
Rhyolite, light-gray, aphanitic, laminated, thin-layered. Weathering forms a honeycomb structure.		
Rhyolite, reddish-gray, porphyritic; interbedded with light-gray rhyolite	2.7	326
Rhyolite, red, porphyritic, with phenocrysts of clear sanidine; some glass in matrix	6.8	324
Flow-breccia, red, rhyolitic	16.5	317
Glass, medium-brown, massive; contains a few lenticular fragments of dark-brown fine-grained volcanic rock; some quartz phenocrysts	13.0	300
Welded tuff, chocolate-brown, massive; numerous elongate lenticular fragments of black or brown glass; matrix is brownish-black glass	37.3	287
Tuff unit:		
Tuff, white, well-indurated; contains numerous fragments of brown glass and white pumice	7.5	250
Tuff, white, indurated; subangular fragments of porphyritic rhyolite, pumice, glass, quartzite, limestone, and obsidian. Obsidian appears only in the upper half and becomes increasingly abundant upward	158.6	243
Breccia consisting of subangular fragments of porphyritic rhyolite and sedimentary rock ½ to 1 in. in diameter	0.8	84
Covered	27.1	83
Tuff, well-indurated; consists of subrounded fragments of porphyritic rhyolite, rhyodacite, brown glass, and quartz	56.0	56
Unconformity.		
Older volcanic group: Rhyolite, porphyritic, pink to cream, bleached; contains phenocrysts of quartz, sanidine, and biotite.		

GEOLOGIC RELATIONS

The five main subgroups overlap each other, roughly en echelon. The lowest rests on the older volcanic group and Paleozoic sedimentary rocks in the Dugway Range, and the highest rests on the same rocks in the southern part of the Thomas Range. At no place in the mapped area are all five subgroups found lying one on top of the other. In most places only two are superposed (pl. 4), but three are superposed in a few areas, for example on Antelope Ridge in the southern part of the Thomas Range (pl. 1).

ORIGIN AND HISTORY

The five subgroups in the younger volcanic group were presumably formed by repeated cyclic eruptions. Each cycle began with a number of explosions, which released gas pressure and removed rock debris from the ducts and craters, and ended with extrusion of rhyolite flows. Such a sequence of events is common; it has occurred, for example, at Parícutin in Mexico (Williams, 1950, p. 223) and at the Usu volcano in Japan (Minakami, Ishikawa, and Yagi, 1951, p. 56–70). Tuffs in this group, like tuffs in general, thicken, thin, and pinch out, and their physical characteristics vary correspondingly. Their thickness and their presence or absence in any particular place probably depend on a combination of factors, including (1) character of erupted material, (2) size of fragments, (3) strength and direction of the explosion, (4) distance from an explosive center, and (5) direction and strength of the wind at the time of the explosion. The breccia which overlies the tuff in some places is less widely distributed than the tuff and shows greater changes in thickness and texture within a given distance. These are expectable results of its coarser texture. Inasmuch as the breccia beds half a mile east of the south end of Spor Mountain and on Pyramid Peak (fig. 27) are as much as 150 and 170 feet thick, respectively, the explosive centers from which they came were probably nearby.

The extensive extrusion of rhyolite flows that followed the clearing of the conduits could not generally have begun until after the pyroclastic rocks were fairly cool, because a layer of obsidian, evidently formed by rapid chilling of the rhyolite magma, is at the base of each flow (fig. 28).

Certain minor features of these rocks, not yet described, may be noted here because of their bearing on origin.

In addition to the five major subgroups of flow and pyroclastic rocks, smaller subgroups or parts of subgroups were noted. One crops out about a mile northwest of the Autunite No. 8 claim, where a series

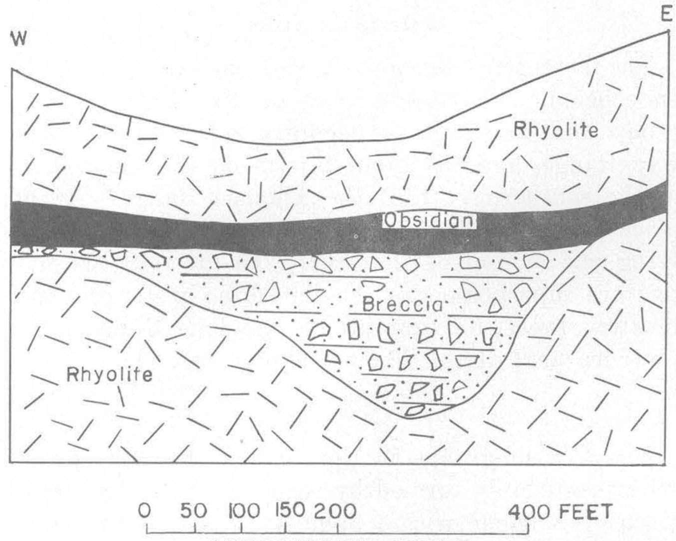


FIGURE 27.—Diagrammatic sketch showing abrupt thickening of the volcanic breccia on the north side of Pyramid Peak, Dugway Range.

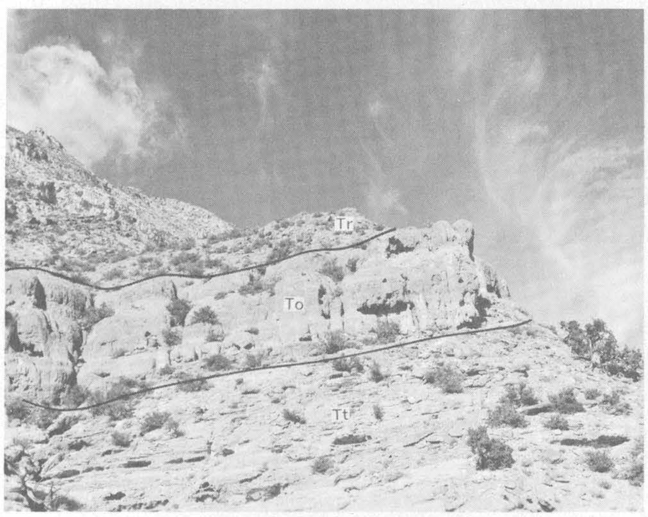


FIGURE 28.—Succession of rocks of the younger volcanic group, exposed about 2,000 feet west of Autunite No. 8 prospect. Note obsidian layer at base of thick rhyolite flows. Tt, vitric tuff; To, obsidian facies of the rhyolite; Tr, rhyolite.

topped by a 50-foot flow is exposed in an outcrop more than three quarters of a mile long. The distribution of the rocks in this minor subgroup indicates that the vent was probably a short distance north of what is now the summit of Topaz Mountain. In other areas, such as the one just south of Dugway Pass, discontinuous layers of obsidian within a thick rhyolite flow indicate that the extrusion of the flow was interrupted by periods of quiesence and cooling. No volcanic necks have been found, however, from which the rocks in the younger volcanic group could have issued.

Flow layering, due to subparallel orientation of phenocrysts, microlites, and crystallites caused in turn by differential movement within the lava, is generally conspicuous in the rhyolite flows; the layers exhibit abrupt variations of strike and dip and form numerous folds with amplitudes that do not exceed a few hundred feet—too small to be adequately represented on the scale of the mapping (pl. 1). Toward the tops of the flows, the layers commonly form even more contorted folds that may have an amplitude of only a few inches (fig. 29). The bases of the flows are some-

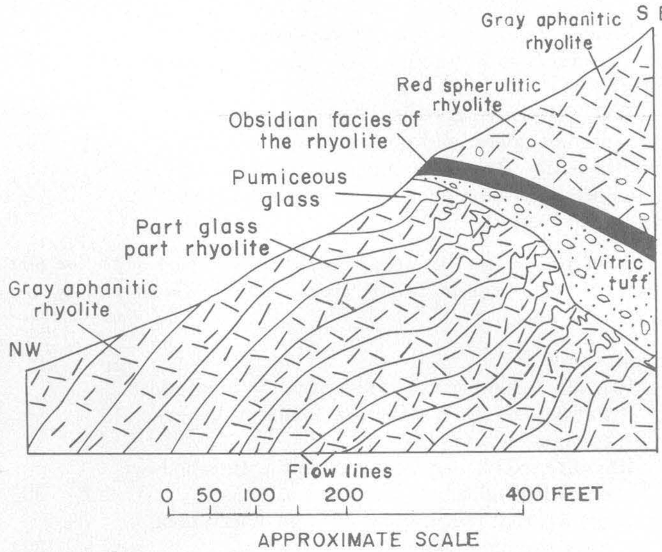


FIGURE 29.—Schematic diagram showing the upper part of a rhyolite flow on the south side of Searle Canyon in the Thomas Range.

what irregular and undulating, but in general are fairly flat (pl. 4). In most places the flow layering is not parallel to the bases of the flows. Irregularities in the bases of the flows, as marked by the varying attitudes of basal obsidian layers, are believed to reflect the initial attitude of flows extruded on irregularly undulating surfaces, though it may include the effects of weak folding in continuance of the deformation that affected the older volcanic group. Small domal protuberances on these flows, formed either by erosion between periods of eruption or by the piling up of volcanic rocks during the flow, are believed to be fairly common, and in the northeastern part of the Thomas Range (pl. 1) a valley that cuts through a flow exposes one of these structures on an underlying flow (pl. 4). In other areas, especially in the northern part of the Thomas Range, a group of small patches of obsidian surrounded by rhyolite may represent the tops of such domal structures. Such knobs have been noted on the Autunite No. 8 property, where

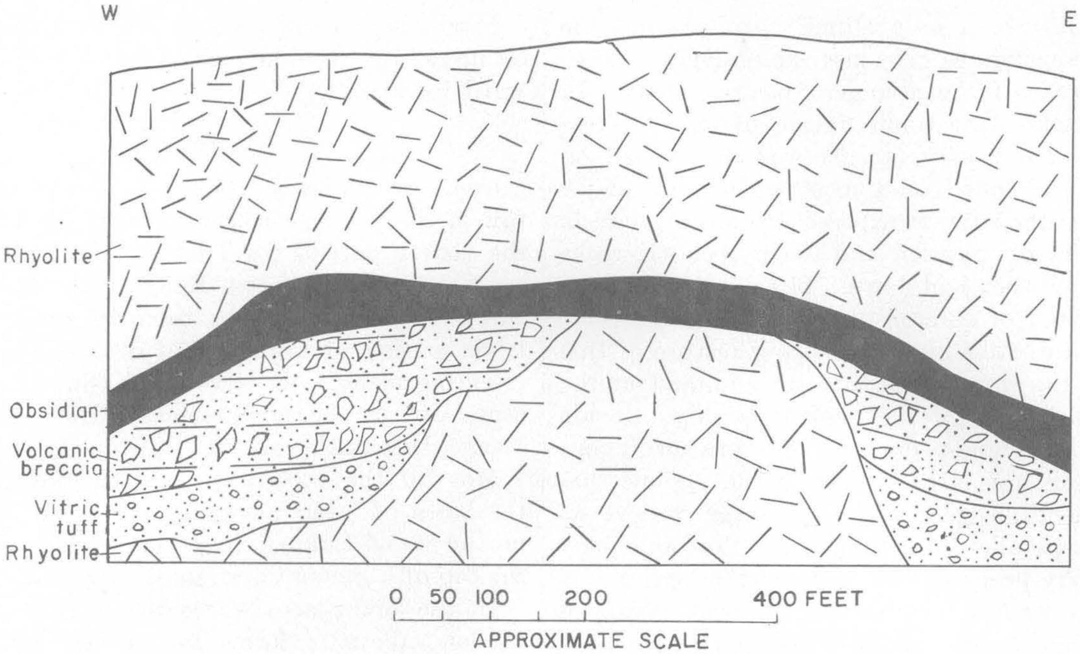


FIGURE 30.—Diagrammatic sketch of pyroclastic rocks pinching out against topographic high in underlying rhyolite along the east side of the central part of The Dell.

porphyritic rhyolite of the older volcanic group was eroded before the deposition of white vitric tuff of the younger group (fig. 25). The white tuff laps up on these hills, and near their sides it has an initial dip of 15°. Higher up the tuff is almost horizontal. A section of another knob can be seen in the steep scarp east of the central part of The Dell, where the gray rhyolite of the younger volcanic group is overlain by a series of pyroclastic rocks and flows. These rocks are fairly thick along the sides of the knob but pinch out near its top. An obsidian band at the base of the overlying rhyolite is separated from the underlying rhyolite by tuff and volcanic breccia except at the top of the knob (fig. 30).

Because rhyolite is a viscous lava, it commonly has uneven tops. Hardening of the surface of a flow may cause irregular swelling and rising as more lava is added underneath the top. Irregularities of surfaces may also result from erosion between periods of eruption. About a mile northwest of Colored Pass, there is a cliff more than 200 feet high cut in the top of a rhyolite flow; the flow was subsequently buried under vitric tuff that has been partly removed (fig. 31). This cliff cuts across the flow lines of the obsidian and gray rhyolite and was almost certainly formed by erosion.

Tuffs commonly fill or partly fill the deeper depressions in the underlying flows, but where a flow of rhyolite reaches a depression that is not filled with tuff, the obsidian layer at the base of the flow bends over the underlying irregularities and may acquire a steep dip; abrupt steepening in the dips of obsidian layers is quite common. Dips of more than 45° are rare, but in a small gully on the south side of Searles Canyon, near its upper end, an obsidian layer is exposed that is almost vertical. Most of these changes in dip, however, are only local; the obsidian layer as a whole is flat lying.

Each of the flows was poured out on a broad undulating surface that resembles a mature land surface

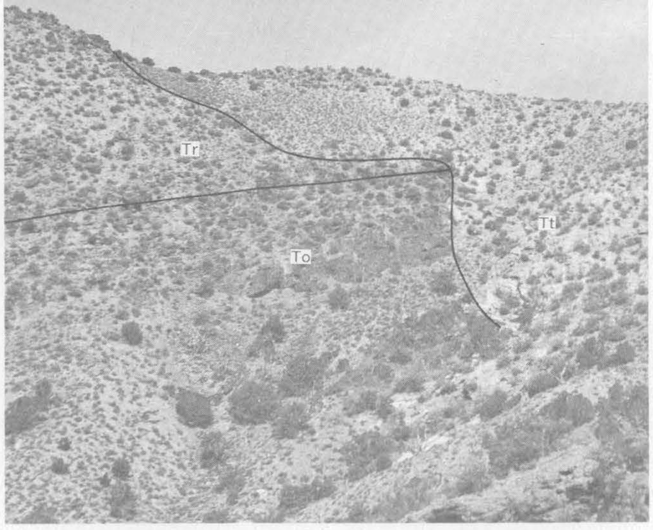


FIGURE 31.—Tuff (Tt) of a younger flow-pyroclastic subgroup overlapping obsidian facies of the rhyolite (To) and rhyolite (Tr) of an older flow-pyroclastic subgroup of the younger volcanic group; 1 mile northwest of Colored Pass.

but has in fact been only slightly eroded, and the forms of these surfaces give indirect evidence regarding the sources of the younger volcanic rocks. In order to illustrate the configuration of one of these surfaces, a contour map (pl. 5) was constructed on the base of the fourth and most widespread major flow. This is the surface exposed after the products of three cycles of eruption and the pyroclastic rocks of a fourth had been laid down. The same map shows the present limit of outcrop of the flow and the present topography. The most interesting feature of this map is that the three areas that were highest at the time the fourth flow was extruded roughly coincide with the three highest parts of the present topography and that the large valleys in the preflow surface correspond in general to the large valleys of today. This parallelism between intra-flow and present topography probably signifies that the high points on the present surface are near the centers of volcanism from which the fourth rhyolite flow and presumably the subsequent flows were erupted; for these flows, even though mobile enough to cover an area of several square miles, were sufficiently viscous to pile up highest near the vents. Inasmuch as the same topographic highs persisted through several successive eruptions, all these flows must have originated from the same vent or clusters of vents; otherwise the topography would have been smoothed out as the later flows filled the valleys left between earlier ones.

An attempt was made to contour the base of the third flow, but the data available were inadequate for doing this completely. In the northern part of the Thomas Range, however, for which data were most abundant, the structure contours at the base of the third rhyolite flow paralleled those at the base of the fourth. Hence, the third and fourth series of eruptions had virtually the same source.

As shown in plate 5, three areas of high ground that probably represent centers of extrusion lie on a north-south line through the center of the Thomas Range. Others, not shown in plate 5, include Topaz Mountain, which is covered with lava of the fifth subgroup, and Pyramid Peak, which is covered with lava of the second and third subgroups.

The flows are so widespread as to indicate that they were erupted simultaneously from several vents. The earliest two major extrusions of lava, which occurred in the northern part of the mapped area, may have come from a single vent, for they covered a relatively small area. Too little is known, however, about the configuration of the surface during these extrusions to say whether or not they came from the same vents as the later ones.

From the general position of the major vents it is estimated that in some places the rhyolite flowed eastward for about 3 miles.

VITRIC TUFF

Occurrence and relations.—Outcrops of the vitric tuff in the younger volcanic group are widespread in the eastern part of the Thomas Range and southwestern part of the Dugway Range. This rock generally forms thin layers at the bases of subgroups. Each layer consists of a number of overlapping lenses representing many falls of volcanic ash. In some places, especially in the northeastern part of the Thomas Range, this tuff is absent.

Most of the exposures of vitric tuff extend along the bases of steep mountain sides, but about a mile northwest of Colored Pass this rock is exposed near the top of a mountain at an elevation of 6,800 feet.

In the few places where the vitric tuff crops out in flat valleys it forms low, gently rounded knolls with few exposures. In most places where it is well exposed it underlies massive resistant rhyolite and is therefore partly covered with rhyolite talus. The tuff at the base of the lowest subgroup commonly overlies either volcanic rocks of the older group or Paleozoic sedimentary rocks, but because of overlap these same rocks are overlain in places by higher layers of tuff. Along the east side of the flows in the Dugway Range, a vitric tuff of the second subgroup overlies the Garden City formation and at the south end of the Thomas Range a vitric tuff of the fifth flow subgroup overlies the same formation. Vitric tuff rests unconformably on quartz-sanidine crystal tuff of the older volcanic group southeast of Dugway Pass and in the central part of The Dell, and on porphyritic rhyolite of the older group in the eastern part of the Dugway Range, at the northwestern end of the Thomas Range, in the east-central part of The Dell, at the east end of Searles Canyon, and in the vicinity of the Autunite No. 8 property. At the last-named locality, small valleys eroded in the black glass-welded tuff were filled with vitric tuff and then recarved almost in their original positions by partial removal of that soft material (fig. 25). In some places these tuffs appear to have been laid down on the tops of lava flows that were almost uneroded. About 1.3 miles northwest of the Autunite No. 8 prospect, for example, it overlies glassy lava, with contorted flow lines that must have been at or near the upper surface of a flow. In other places the vitric tuff appears to rest unconformably upon an irregular much-eroded surface of lava (fig. 31).

Lithology.—The vitric tuff is generally a friable white rock containing volcanic fragments, chiefly of pumice in a matrix of ash and small crystal fragments. Most of the tuff is white, but much of it is of some pastel shade such as greenish white, tan, yellowish gray, yellowish green, greenish tan, or grayish orange pink. The rocks mapped as vitric tuff have a wide range in grain size. A few layers consist almost wholly of ash with no visible rock fragments. Most of the layers, however, contain numerous fragments ranging from $\frac{1}{16}$ to 1 inch in diameter, and some layers from 4 inches to 2 feet in thickness consist of volcanic breccia containing a few fragments as much as a foot in diameter. The breccia generally grades into tuff. These layers of breccia, which are too thin to map separately, differ from the thicker layers of breccia described below in containing smaller and rounder fragments and in having a more ashy matrix. The proportion of coarse to fine material in tuff varies widely; rock fragments make up as little as 10 percent of the rock in some places and as much as 50 percent elsewhere. More than 95 percent of the rock fragments consists of volcanic materials, the most abundant of which is white pumice. The abundance of this material serves as a convenient distinction from the tuffs of the older volcanic group. Other rocks common among the fragments are gray or reddish gray glass, devitrified glass, porphyritic rhyolite, and tuff. Much less common are fragments of rhyodacite, quartzite, limestone, and dolomite. Obsidian fragments occur only sparsely in most of the tuff, but they increase in abundance toward the top of each tuff layer, and just below the glassy base of the overlying lava they may be more abundant than the fragments of other rocks.

Pore spaces and small cavities, generally elliptical in shape, are common in the vitric tuff, and may make up as much as 30 percent of the volume of the rock. Some of the cavities are 6 mm across, but most are much smaller and many are less than 1 mm across.

Crystal fragments are rarely visible in hand specimens of the vitric tuff, but in thin sections they are seen to make up from 3 to 25 percent of the rock or, on the average, about 10 percent. Most of the crystals are of quartz and sanidine, quartz being the more common in some places and sanidine in others. Quartz makes up less than 1 to 15 percent of the rock, and sanidine 3 to 20 percent. These minerals form anhedral to euhedral crystals and also many fragments, from 0.05 mm to 2 mm in diameter. Plagioclase in small anhedral to subhedral crystals, some zoned, is present in many places but rarely exceeds 3 percent of the rock. The overall composition of the crystals ranges from An_{25} to An_{40}. Biotite and magnetite are commonly present, but each generally makes up less than 1 percent of the rock. Biotite occurs in small, partly altered prismatic grains and magnetite in small rounded grains. In several specimens a few crystals of zircon were noted, and small amounts of hornblende, topaz, and microcline were found, but each in only one specimen.

The matrix of the tuff is a fine-grained ash, which in thin section is seen to consist of fragments of clear light- or medium-brown glass, in part devitrified, with many irregular cavities. In some specimens much of the glass is in shards, but in others no shards were found. Some of the cavities in certain specimens are lined with minute crystals of tridymite and cristobalite. A few specimens contain opal and chalcedony. The glass contains few crystallites.

The vitric tuff of the younger volcanic group can be easily distinguished from the crystal tuffs of the older volcanic group by the following characteristics: (1) This vitric tuff consists chiefly of fragments of glass, whereas the crystal tuffs in the older group consist chiefly of pieces of crystals; (2) the crystal fragments in this vitric tuff are small and generally not visible except under the microscope, whereas those in the older crystal tuffs are large and easily visible in hand specimens; (3) welding in the vitric tuffs is restricted to thin layers no more than a few feet thick and of small extent, whereas in the older crystal tuffs it affected thick beds over wide areas; and (4) pore spaces and cavities are numerous throughout the vitric tuffs, whereas they are either scarce or absent in the older crystal tuffs. Vitric tuffs within the older and younger volcanic groups are much alike in lithologic character and can best be distinguished by their relations to other volcanic rocks.

Chemical composition.—A chemical analysis (table 15, no. 7) of a specimen of white vitric tuff collected 0.6 mile northeast of the portal of the Bell Hill tunnel indicated a rhyolitic composition according to the classification of Rittmann (1952, p. 95). The norm of this rock differs from those of the rhyolite and green glass in the younger volcanic group in containing somewhat less orthoclase and albite and more anorthite, corundum, and hypersthene. The vitric tuff consists of rhyolitic material with some small pieces of rhyodacite and carbonate rocks. Of the other samples from the younger volcanic group, the one that is nearest in chemical composition to this rock is a sample of green glass from Colored Pass (table 15, no. 14). This latter rock is a mixture of volcanic material from at least two periods of eruption.

712-190 O—64——7

Fossils.—The vitric tuff is the only volcanic rock in the Thomas and Dugway Ranges that is known to contain any fossil remains. Petrified wood was found at two localities. One of these is a broad northwest-trending band of tuff, a mile and a half long, the center of which is about a mile northeast of Colored Pass. The other locality is at the south end of the Thomas Range, where several logs were found on the eroded surface of the Garden City formation, half a mile from the nearest exposures of the tuff. These logs, however, were presumably once enclosed in tuff that has been removed by erosion.

The petrified wood consists of branches or logs from less than an inch to 3 feet in diameter and as much as 8 feet in length. The wood, together with some remnants of its bark, has been completely replaced by brown, gray, or black siliceous material. Several specimens of this wood were submitted for identification to R. C. Scott of the U.S. Geological Survey, who reported, "The wood is recognizable as gymnospermous wood, but due to poor preservation no further determination can be made. The wood has lost most of its original organic structure and has undergone extensive compression and distortion." Inasmuch as gymnosperms have persisted from Devonian to Recent time, this material gives no help in determining the age of the tuff.

VOLCANIC BRECCIA

Occurrence and relations.—The volcanic breccia of the younger volcanic group occurs mainly in the western part of the Thomas Range and the southern part of the Dugway Range. Although it has a wide extent in a north-south direction, there is little of it in the eastern part of the Thomas Range except on Antelope Ridge. The breccia is known to be present at the bases of all the subgroups except the first, whose base is not exposed, and it is especially abundant below the upper two rhyolite flows.

As was pointed out in describing the general features of the younger volcanic group, the lavas of that group were erupted mainly from five centers roughly on a north-south line extending through the middle of the volcanic tract in the Dugway and Thomas Ranges. The northernmost volcanic center, on Pyramid Peak in the Dugway Range, may have given rise to explosive eruptions as well as lava flows, for it is surrounded by one of the thickest masses of breccia. Other masses of breccia lie either near the western margin of the zone containing the four main eruptive centers in the Thomas Range or still farther to the west. One possible explanation for this, if it is assumed that the breccia came from the same centers as the flows, is that the explosions were powerful and blew out to the west. Another, which appears more likely, is that the sources of the breccia lay considerably to the west of most of the sources of flows, which may also have erupted much of the vitric tuff. Powers (1932, p. 281–282) and Anderson (1941, p. 367–382) have shown that in the Modoc Lava Bed quadrangle, California, explosive eruptions and lava flows came from separate sources.

This volcanic breccia is rather friable, and where not exposed on steep slopes it is covered either with talus from the overlying rhyolite or with fragments of rhyolite and obsidian that have weathered out of the breccia itself. There are many excellent exposures of the breccia, however, on steep slopes protected by thick overlying flows of resistant rhyolite.

The volcanic breccia is most commonly underlain by vitric tuff and overlain by obsidian. In a number of places, however, the pyroclastic layer consists wholly of breccia, as it does for example, below the uppermost two flows on Antelope Ridge, in certain places near the northeast end of The Dell, and around Pyramid Peak. In a reversal of the general order of deposition, volcanic breccia underlies vitric tuff in a small area in the southern part of Dugway Range. Whether breccia or tuff is deposited first probably depends mainly on whether the eruption began with a violent explosion or began quietly and then increased in violence.

Not only is the breccia confined to certain areas, but its present distribution within these areas is erratic. Part of its erratic distribution is due to it being deposited locally, and part is due to it being removed by later erosion. Along the east side of Pyramid Peak the breccia is scarce or absent, but on the west side several hundred feet of breccia is exposed, its thickness there being near the maximum fig. 27). In other areas, the breccia may pinch out completely against the flank of a buried hill. Vitric tuff and breccia are found along the sides, but not on the top, of a buried rhyolite hill on the eastern side of The Dell (fig. 30).

Lithology.—The volcanic breccia consists of poorly sorted angular fragments in a matrix of ash. It varies widely in color, through black, gray, white, greenish white, grayish pink, tan, reddish brown, and orange. The color changes both from one layer to the next and laterally within individual layers.

Fragments make up from about 25 to 85 percent of the breccia and are most abundant in the coarser layers. They have a wide range in size. In some layers of breccia they are little larger than those in the tuffs (less than 1¼ inches in diameter), but in other layers there are fragments as much as 3 feet in diameter. The fragments in the breccia consist almost entirely of volcanic material, and most are glassy (fig. 32). They are commonly obsidian, gray glass, pumice, gray rhyolite, reddish gray rhyolite, and brown porphyritic rhyolite. Pieces of limestone, dolomite, and quartzite are rare and generally less than an inch in diameter. Some of the fragments, especially the smaller ones, are subangular; most, however, are angular blocks of material believed to have been consolidated before the explosions that formed the breccia. No bombs have been found, nor any other evidence that the blocks forming the breccia were in a molten condition when flying through the air. For this reason the rock was called a volcanic breccia rather than an agglomerate, in accordance with the usage of Wentworth and Williams (1932, p. 45–46, 51).

The matrix of the breccia is a compact ash. The mineral grains in it are mostly too small to be visible in hand specimens, but in thin sections they are seen to make up as much as 35 percent of the matrix. They are chiefly anhedral to subhedral crystals of sanidine and quartz. Subhedral plagioclase (oligoclase to andesine) is probably next in quantity. All specimens contain small amounts of anhedral biotite and magnetite. Apatite, sphene, hornblende, and pyroxene were noted in individual specimens. Shards of glass are numerous in some specimens and absent in others. In some places there are many small cavities, some of which contain minute crystals of tridymite or cristobalite, or both. In a few places fractures in the breccia are filled with clay minerals and calcite.

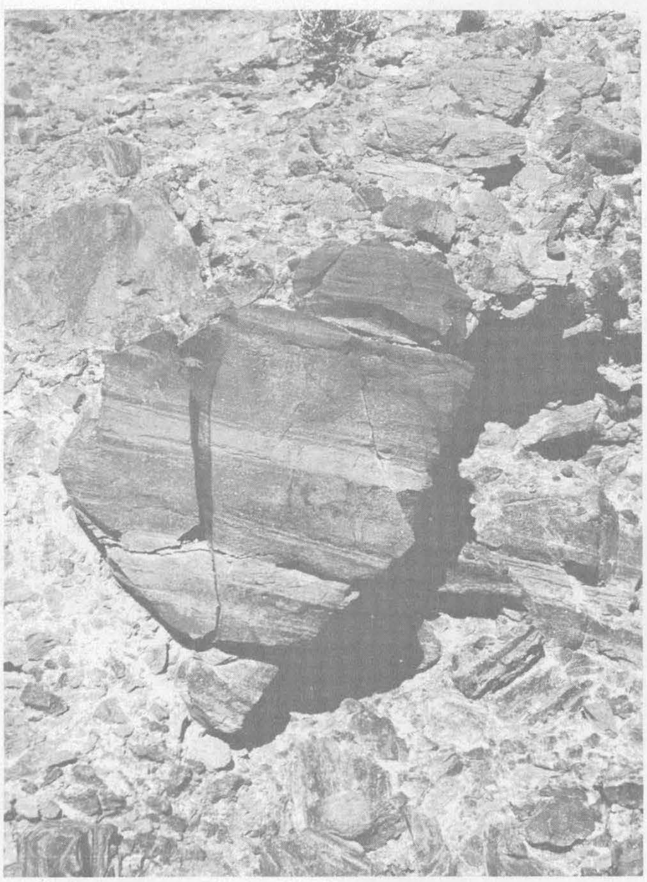


FIGURE 32.—Volcanic breccia. Details of glass breccia containing a block of streaked obsidian 2 feet across. The breccia is well indurated and has a matrix of pinkish-brown ash. One mile east of the south end of Spor Mountain.

One of the commonest types of breccia consists almost entirely of large jumbled blocks of obsidian. In some places, for example, in an outcrop half a mile east of the Bell Hill mine (pl. 1), the matrix is ashy, but in other places it contains varying amounts of black glass. At the bases of some rhyolite flows, obsidian explosion breccia grades into obsidian flow breccia. (See p. 95.)

RHYOLITE

Occurrence, relations, and facies.—Rhyolite is found throughout the eastern part of the Thomas Range, and makes up at least 95 percent of the younger volcanic group. Outside the area mapped, it occurs in the Drum Mountains to the south and makes up a large part of the Keg Mountains to the east. Similar rhyolite is also found in the Honeycomb Hills, which lie about 3 miles west of the Fish Springs Range.

The rhyolite is highly resistant to erosion, and along the east side of The Dell and around Topaz Mountain it forms cliffs as much as 800 feet high (fig. 18*B*). There is little soil on this rock, and much of it is almost devoid of vegetation.

Rhyolite forms the main part of each of the five major subgroups in the younger volcanic group. A layer of rhyolite usually rests conformably on either vitric tuff or volcanic breccia. It is usually at the top of an eruptive sequence, but in some places the uppermost part of the sequence consists of vitric tuff or breccia. The surface of the rhyolite beneath these pyroclastic rocks is almost unmodified in some places, but in other places it is more or less eroded. Rhyolite of the younger volcanic group is not often found in contact with either the older volcanic rocks or the Paleozoic rocks, but in several places it overlies porphyritic rhyolite of the older group, and along the northeast side of the main volcanic area in the Dugway Range it rests on the upturned edges of the Paleozoic rocks.

Lithology.—The rhyolite varies from place to place in color, texture, abundance of phenocrysts, degree of layering, and presence or absence of spherulites. The variations are gradational, and there may be as many differences between parts of a single flow as between two separate flows; it is rarely possible to determine, by inspection or even by microscopic study, what flow a given specimen of rhyolite came from. Two rhyolite flows in the northwestern part of the Thomas Range, however, can be distinguished in places by the presence of copper-colored biotite flakes in the older flow.

The rhyolite is divisible into three facies: obsidian, red spherulitic rhyolite, and gray rhyolite. A thin layer of obsidian, formed by rapid cooling, is generally formed at the base of a thick flow of rhyolite (fig. 28). Obsidian has also been found within or beneath layers of volcanic breccia in the northwestern part of the Thomas Range and about a mile northwest of the north end of Antelope Ridge. Discontinuous layers of obsidian occur, also, within other bodies of rhyolitic lava south of Dugway Pass, where they probably mark chilled surfaces of flows. The red spherulitic rhyolite is almost always found just above the obsidian near the base of a flow, but in a few places, notably in the northeastern part of the Thomas Range, it occurs considerably above the base. Whether in these places the red layers mark pauses in the outpouring of the lava is not known. Red spherulitic rhyolite resting on obsidian forms extremely irregular layers, which may vary laterally in thickness from less than an inch to 200 feet within a distance of 600 or 700 feet. The spherulitic rhyolite was found in all the subgroups except the lowest, in which only the top of the flow is exposed. The red rhyolite usually grades into gray rhyolite, through rock consisting of red spherulites in a gray matrix, but in some places the contact between the two facies is fairly sharp. The gray rhyolite makes up about 95 percent of all the rhyolite in the younger volcanic group.

Because the obsidian facies has sharp boundaries and is useful in distinguishing main subgroups from one another where pyroclastics are absent, it was mapped separately, but the gray and red rhyolites are represented by a single color symbol.

Associated with these three facies of rhyolite is a minor quantity of rhyolitic flow breccia. This is mostly in discontinuous zones near the bases of the flows, just above the obsidian, but in a few places it is at the tops of flows. Most of the flow breccia is in bodies no more than a few hundred feet long that grade laterally into massive rhyolite; these layers are as much as 200 feet thick in some places, but for the most part they are much thinner. Because of its similarity to the rhyolite, the small size of its individual exposures, and its erratic and gradational contacts, the flow breccia is mapped with the rhyolite.

Obsidian facies

Lithology.—The obsidian in most places consists mainly of a black spherulitic glass with a conchoidal fracture, but this rock varies considerably in texture and color within short distances. In some places it has a distinct slabby parting (fig. 33). Some of it is dark gray, and it contains brown, reddish-brown, and light-gray layers and lenses. Lenses, streaks, or matrix of brown glass around black glass spherulites are common. The spherulites noted in the obsidian are of two types. The most common are black and brown glassy spherulites, 1 to 2 mm in diameter, which make up much of the obsidian. Less common are brown aphanitic to porphyritic spherulites from about ¼ to 6 inches in diameter; these commonly occur in irregular pockets of brown aphanitic rock similar in composition to the spherulites, mostly in the upper 10 feet of an obsidian layer.

Most of the spherulites are incompletely formed; their bases merging with the surrounding rock. Those that are completely formed superficially resemble the concretions in sedimentary rocks. The spherulites are generally solid, but a few are hollow, and some former cavities are filled with chalcedony and opal. At one place a little fluorite was noted in a cavity. In some places, at the south end of the Thomas Range for example, obsidian layers enclose small irregular lenses of red spherulitic rhyolite.

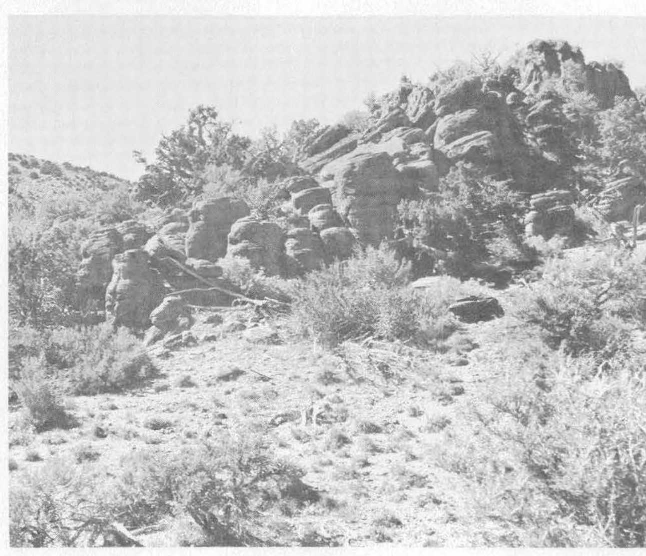


FIGURE 33.—Slabby structure in obsidian layer, north-central Thomas Range.

Some of the obsidian is porphyritic, but phenocrysts rarely make up more than 4 to 5 percent of the rock. The most common phenocrysts are clear to white rectangular crystals of sanidine; quartz is less abundant and plagioclase even less so. In the two specimens in which the maximum extinction angle was measured, the plagioclase was andesine. Trace quantities of biotite and magnetite are found in a few places.

As seen in thin section, the glass in the obsidian is generally clear and light to medium brown and commonly contains perlitic cracks. In most places it has a well-developed flow structure brought out by differences in the color and texture of the glass and by small oriented microlites and crystallites. In some areas crystallites are abundant; most are trichytes, but in some places they include belonites and globulites. Cavities in the glass are scarce; a few are lined with small crystals of tridymite.

In a few places the obsidian grades into a flow breccia that is of two types, one consisting of angular blocks of black obsidian in a black glass matrix and the other of lenticular black obsidian blebs in a brown glass matrix. The first type is fairly common in some areas, such as the southeastern part of the Thomas Range. Some obsidian layers grade downward into thin layers of flow breccia consisting of blocks of obsidian in an obsidian matrix, and in a few places, one of them 0.8 mile east of the mouth of Topaz Valley, an obsidian layer grades laterally into a flow breccia. Most of the flow breccia is confined to the basal parts of the obsidian layer and was probably formed by the breaking up of an original chilled crust by continued movement of lava in the overlying flow.

In a few areas, especially west of the Autunite No. 8 prospect, the glass layer consists of numerous elongate fragments of dark-gray or black obsidian in a brown glass matrix; this material closely resembles welded tuff (fig. 34). The matrix of this rock, however, has a conspicuous flow structure and contains unbroken spherulites and no shards. Along strike this rock grades into normal obsidian. How the elongate fragments were formed is not known. Perhaps they were originally part of a thin crust which was broken up and carried along in the moving flow, or perhaps they represent blobs of viscous glass that were thrown upward by explosion, fell back into the still molten glass, and were stretched by flowage.

Chemical composition.—A chemical analysis was made of black obsidian collected on the west side of the Thomas Range, 1.8 miles north of Wildhorse Spring (table 15, no. 8). This rock was very similar in composition to analyzed specimens of other facies of the rhyolite, especially to the red spherulitic rhyolite (table 15, no. 9) that commonly overlies the obsidian layer from which the sample came, and to a gray rhyolite from the uppermost flow (table 15, no. 11). The greatest difference in composition between the obsidian and the rhyolites is that the obsidian contains about 4 times as much H_2O as any of the rhyolites. This is not surprising because glass is known for its high water content. A compilation of analyses published in U.S.G.S. Professional Paper 99 (Washington, 1917, p. 56–233) shows that 35 samples of obsidians, presumably rhyolitic, averaged 1.44 percent water. The norm of the obsidian (table 15, no. 8) is almost identical with the norm of the gray rhyolite No. 10. Both rocks would be classified by Rittmann (1952, p. 95) as alkali-rhyolite.

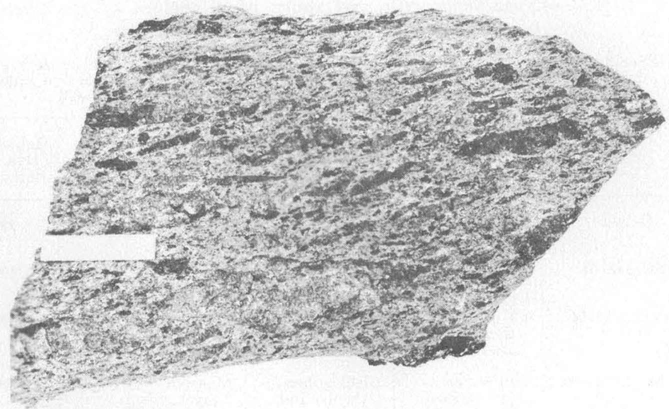


FIGURE 34.—Specimen from the base of an obsidian layer showing lenticular black obsidian fragments in a brown glass matrix from west of the Autunite No. 8 claim. White bar is 1 inch long.

George (1924, p. 353–372) has shown that the indices of refraction and the specific gravities of natural glass are closely related to its chemical composition; he made graphs indicating roughly the amount of SiO_2, H_2O, K_2O, MgO, and CaO, and total iron oxides corresponding to various specific gravities and indices of refraction. Ross and Smith (1955, p. 1071–1089) have also shown that the indices of refraction of rhyolitic glass is related to and varies with the amount of H_2O present. In order to have a comparison of the chemical composition of other obsidians with that of the analyzed specimen, the index of refraction and the specific gravity of the analyzed specimen and of three other specimens were determined (table 9). To determine how much difference in composition there may be between the spherulitic and nonspherulitic varieties of obsidian, the analyzed specimen (SC–14–54) was divided into two parts. Specimens used were selected fragments of fresh unaltered glass free of phenocrysts.

TABLE 9.—*Specific gravity and index of refraction of specimens of obsidian from the Thomas Range, Utah*

[Specific gravity determinations were made on Berman balance and are average measurements on three fragments from the same specimen. Refractive index determinations were made in white light and have an accuracy of ±0.003]

Specimen	Location	Description	Occurrence	Specific gravity	Refractive index
SC-14-54	1.8 miles north of Wildhorse Spring.	Black nonspherulitic obsidian.	Massive layer.	2.36	1.495
SC-14S-54	1.8 miles north of Wildhorse Spring.	Black spherulitic obsidian.	Massive layer.	2.36	1.492
MHS-30-54	0.3 mile southwest of Colored Pass.	Black nonspherulitic obsidian.	Block from obsidian flow breccia.	2.35	1.498
MHS-117-54	2 miles northeast of Lost Sheep mine.	Black spherulitic obsidian.	Massive layer.	2.37	1.500
MHS-125-54	1 mile due north of Wildhorse Spring.	Black nonspherulitic obsidian.	Block from volcanic breccia.	2.33	1.498

The values in the table indicate that there is not much difference in composition between the spherulitic and the nonspherulitic obsidian, and the specimens all contain about the same proportion of H_2O. They thus suggest that the various layers of obsidian do not differ more widely in composition than the various overlying rhyolites.

Red spherulitic facies

Lithology.—The red spherulitic facies of the rhyolite is made up of numerous small spherulites set in an aphanitic or glassy groundmass (fig. 35). Its color is mostly hematitic red but varies to gray, purplish gray, pale red, and reddish brown. Most of the spherulites are easily visible in hand specimen, although in a few places none were noted except under the microscope.

The spherulites range from less than ½ mm to about 10 mm in diameter. The larger ones, which generally have hollow centers, are found only in certain small areas, one of which is near the south end of Antelope Ridge and another on the south side of a small ridge 1½ miles northwest of the Autunite No. 8 prospect. Abundant spherulites commonly occur in layers separated by layers that contain relatively few. The spherulites consist mainly of radiating fibers of potassium feldspar and quartz, together with some glass. The radiating fibers may show a black extinction cross when viewed between crossed nicols. The fibers do not generally form complete spherulites; they are commonly in sheaves or bundles that, in cross section, fill only a half or a third of a circle. Spherulites appear to have formed late during the crystallization, for they commonly surround or partly surround phenocrysts. They are also common in the matrix, where they are superimposed in some places upon a preexisting flow structure (fig. 38). Flow structure is common in the red spherulitic rhyolite. The individual laminae have an average thickness of about 0.25 mm. The flow lines bend around the phenocrysts, and in some places, particularly just above the obsidian layer, they are highly contorted.

Most of the red spherulitic rhyolite contains few phenocrysts that are visible in hand specimens, and even in some thin sections there are none. In some specimens, however, they make up as much as 30 percent of the rock. On the average they make up about 10 percent of the rock—slightly less than in the gray facies. They are euhedral to subhedral crystals that range in length from 0.10 to 3.25 mm. They consist mainly of sanidine and quartz; these minerals vary widely in relative abundance, but sanidine generally predominates. Plagioclase, when present, is third in abundance and may constitute as much as 3 percent of the rock. It occurs in small subhedral to euhedral crystals whose average composition ranges from An_{15} to An_{35}.

The chief dark minerals are biotite and magnetite, but the amount of each nowhere exceeds 1 percent. A very little hornblende is present in some specimens, and a few minute grains of zircon were identified.

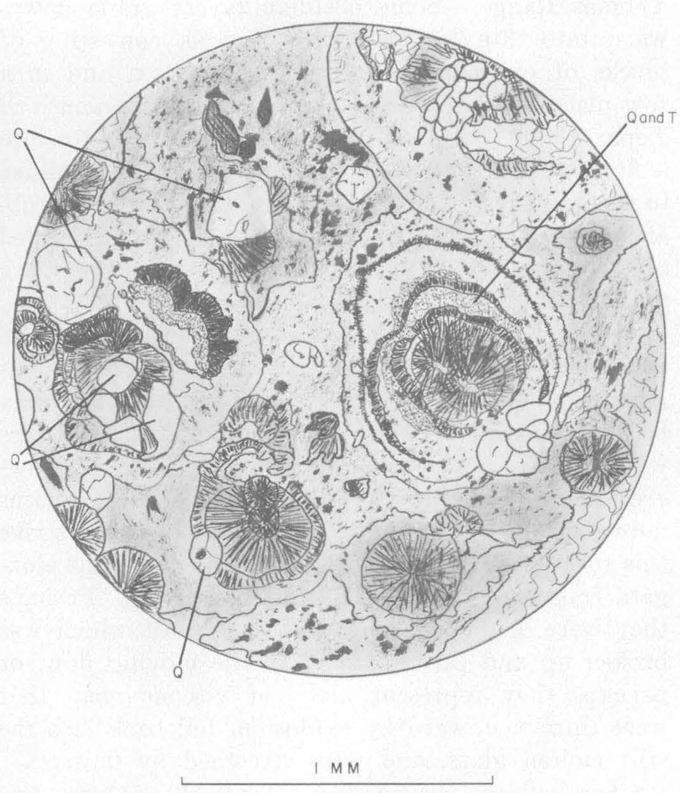


FIGURE 35.—Camera-lucida drawing of spherulitic rhyolite showing tridymite rings in spherulites. Radially fibrous areas are brown partially devitrified glass containing crystallites. Stippled areas are tridymite (t) and quartz (q). Outer rings of spherulites and area between spherulites are devitrified glass. Southwest side of Antelope Ridge.

The groundmass of most specimens is made up of (1) spherulites enclosed in a matrix that consists of glass containing some microlites and crystallites and (2) mosaics of interlocking crystals with low birefringence. The crystal mosaics generally form eye-shaped pockets that in places form as much as 20 percent of the rock interlayered with spherulitic rock. The mosaics consist chiefly of quartz and sanidine, but most of them also contain tridymite, cristobalite, or both. Other minerals noted in the groundmass include topaz in a specimen from the southern tip of Antelope Ridge and fluorite in a specimen from a small hill just north of Spor Mountain.

Chemical composition.—A chemical analysis was made of a specimen of red spherulitic rhyolite from the east side of the Thomas Range, 2.5 miles south-southeast of Dugway Pass (table 15, no. 9). This analysis reveals no significant differences in composition between the red rhyolite and the analyzed specimens of the gray rhyolite (table 15, nos. 10–13).

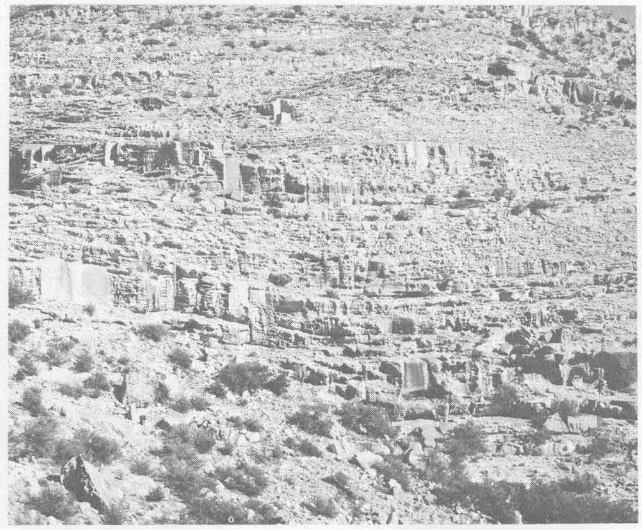
Gray facies

Lithology.—The gray facies of the rhyolite is generally a dense aphanitic rock containing some spherulites and a few visible phenocrysts of quartz and sanidine in a glassy matrix. Its color in most places is light gray, but in some places it is pinkish gray, medium yellowish brown, and light brownish gray. The exposed surfaces of this rhyolite have a characteristic honeycomb appearance, which is due to the weathering out of pockets along certain layers, especially those that contain lithophysae (fig. 36). In some areas this rhyolite is broken into crude steps whose risers are vertical joints.

Flow layers are common in some places in the gray rhyolite, although not everywhere; they are commonly folded into anticlines or synclines. Some of these folds are several hundred feet across, but they tend to become smaller and more contorted near the tops or bottoms of flows.

The tops of these rhyolite flows commonly consist of olive-green to brown glass containing numerous small cavities elongated parallel to the flow structure. In some places normal gray aphanitic rhyolite may be traced upward through partly glassy rock to nearly all glass at the top of the flow (fig. 29).

Some of the gray rhyolite contains no spherulites, but about half of it contains at least a few; on the whole, spherulites are not nearly as common in this rock as in the red facies. The spherulites are mostly too small to be readily seen in hand specimens. Lithophysae, from about 1/4 to 8 inches in diameter, are locally abundant, particularly in Topaz Valley. The



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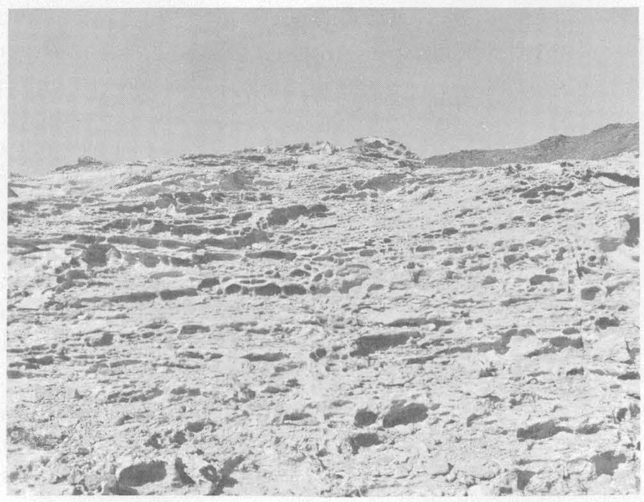


B

FIGURE 36.—Weathering of rhyolite. *A*, Rhyolite of the uppermost subgroup, north-central Thomas Range, showing vertical joints and "honeycomb" weathering. Field of view is several hundred feet across. *B*, Details of "honeycomb" weathering in rhyolite. Lineation of holes results from orientation of lithophysae parallel to flow lines. Field of view is about 15 feet across.

lithophysae are spherical and consist of a series of thin concentric shells of rhyolite separated by hollow spaces. The shells are mostly incomplete and tend to coalesce at one end. Some of the lithophysae have hollow centers. Small crystals of topaz, quartz, or sanidine commonly protrude into the hollow spaces at the center and between the shells. Some authors (Tyrrell, 1948, p. 98; Grout, 1932, p. 41) consider lithophysae to be large spherulites, but this view is open to question because spherulites are generally made up of radiating fibers and lithophysae of concentric shells.

Locally, and especially in Topaz Valley, the rhyolite contains small cavities or vugs as much as 1½ inches in diameter, which contain well-developed crystals of topaz, specularite, quartz, pink beryl, bixbyite, garnet, and pseudobrookite that have aroused the interest of mineralogists and mineral collectors (p. 102 to 108).

In most places the gray facies contains only a few small phenocrysts that are visible in the hand specimen. In a few places, however, as in an area at the north end of the Thomas Range, 1 to 2 miles west of Dugway Pass, and in another area on the east side of the Thomas Range, 1½ miles northeast of Colored Pass, phenocrysts are about as abundant in this rock as in the porphyritic rhyolite of the older volcanic group. In thin sections the phenocrysts, mostly of microscopic size, are seen to make up as much as 35 percent of the rock in some places but to be almost absent in others; the average is about 14 percent. The phenocrysts are chiefly of sanidine and quartz. Sanidine occurs in subhedral to euhedral crystals from 0.05 to 3.5 mm in diameter, and quartz (which is somewhat less abundant) in anhedral to subhedral crystals from 0.10 to 3.5 mm in diameter. Plagioclase is much less abundant than quartz and is not everywhere present, but in places it makes up as much as 3 percent of the rock. It occurs in subhedral to euhedral crystals, which range from 0.15 mm to 2.5 mm in length. Because of its scarcity, a maximum extinction angle measurement was difficult to obtain in many specimens, but the extinction angles measured indicate that it ranges from about An_{20} to An_{53}. Biotite and magnetite are the principal dark minerals, but neither is present in all thin sections, and neither forms more than 1 percent of any section. Biotite occurs in small euhedral crystals, which in some places are partly altered; its usual color is copper brown. Magnetite occurs in small rounded grains.

In addition to the above minerals, from a trace to less than 1 percent of the following minerals have been noted in from one to six specimens: zircon, hematite, hornblende, sphene, augite, garnet, topaz, and dark-purple fluorite. Of these minerals, topaz and fluorite have a special interest because of their apparent lack of relation to the total fluorine content of the rhyolite. Topaz was noted in only 3 of the 76 thin sections of this rock, in which it forms small anhedral grains or rosettes in the groundmass. A chemical analysis of one of the specimens thus found to contain topaz (table 15, no. 10) shows a fluorine content of 0.14 percent. If the fluorine were all in topaz, the topaz content of this rock would be roughly 0.9 percent, considerably more than the few small grains found would indicate. Some of this excess fluorine could be in fluorite, but fluorite was found in only one specimen from the north end of Spor Mountain, where it was very scarce (fig. 37). In thin sections from other analyzed specimens of this rhyolite, in all of which there was considerable fluorine, neither topaz nor fluorite was found.

The glass which generally makes up most of the groundmass appears colorless to light or medium brown in thin section. Some of it contains microlites and crystallites, and perlitic cracks have been noted in specimens from the northeastern part of the Thomas Range. In some thin sections most of the groundmass consists of devitrified glass containing only very minute crystals; in others it is a mosaic of interlocking larger crystals, chiefly of quartz and feldspar, with minor amounts of biotite, magnetite, tridymite, and cristobalite.

There are also small pockets or eyes of clear material, made up chiefly of quartz and sanidine crystals, commonly associated with tridymite or, locally, with cristobalite. The tridymite is mostly in small rectangular crystals, but in a few places it forms wedge-shaped twins or is anhedral. Most of the cristobalite shows no crystal form, although in places it forms small rosettes. Where both of these minerals are anhedral they are almost indistinguishable.

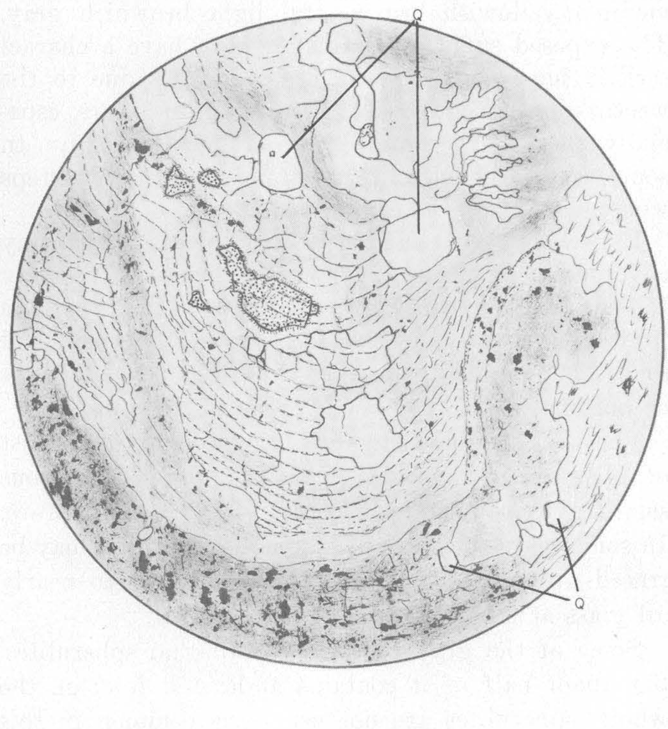


FIGURE 37.—Camera-lucida drawing of rhyolite showing fluorite (stippled) and quartz (q) in lithophysae. Rings in lithophysae are marked by trains of magnetite dust. North end of Spor Mountain.

Chemical composition.—Chemical analyses were made of three specimens of rhyolite of the gray facies collected at three widely separated localities: (1) 1.9 miles southwest of Dugway Pass, (2) 3.1 miles east-northeast of Wildhorse Spring, and (3) near the center of Topaz Valley (table 15, nos. 10–12). An analysis of a fourth specimen described by Cross (1886, p. 67–69) is available (table 15, no. 13); its locality is not given. The four chemical analyses are all similar, and according to Rittmann (1952, p. 95) nos. 10, 11, and 13 would be classified as rhyolites and no. 12 as an alkali rhyolite.

The beryllium content of three specimens of rhyolite, collected in the northeastern part of the Thomas Range and determined spectrographically by P. R. Barnett was 0.002, 0.0015, and 0.003 percent. Seven other samples of rhyolite collected by J. C. Olson (Warner, Holser, Wilmarth, and Cameron, 1959, p. 145) from various places in the Topaz Valley were analyzed spectrographically. Some of these samples are from areas where rose-colored beryl was found. These seven samples ranged from 0.0011 to 0.0039 percent beryllium and averaged 0.0020 percent.

The beryllium content of rhyolite in the Thomas Range is difficult to compare with that of rhyolite in other regions because of the lack of published data. A general average beryllium content for rhyolite and rhyolitic glass in western United States was obtained by compiling 68 spectrographic analyses of samples collected by R. R. Coats of the U.S. Geological Survey in Nevada, Oregon, Idaho, Wyoming, Montana, Washington, California, Arizona, Colorado, and Utah. The beryllium content of these rhyolitic rocks ranged from 0 to 0.01 percent, and averaged 0.0005 percent. The beryllium content of rhyolite from the Thomas Range is roughly four times this average, and may be due either to occult beryl or to a general enrichment of beryllium in small amounts in minerals such as feldspar.

Flow breccia facies

The rhyolite flow breccia is light gray, light brown, purplish gray, or hematitic red, and consists of angular fragments of red and gray rhyolite, from less than 1/8 to more than 6 inches in diameter, in a red or gray rhyolitic matrix. Phenocrysts are scarce in both the matrix and the fragments, making up less than 1 percent to about 8 percent of the rock, and are generally not visible in hand specimen. They consist chiefly of sanidine and quartz but commonly include a little plagioclase and in some specimens trace amounts of magnetite and biotite. The matrix is mainly made up of pieces of glass, some of which are partly devitrified. Microlites and crystallites are not uncommon. Tridymite was noted in several specimens, and both calcite and chalcedony have been found in the matrix in a few places.

GREEN GLASS

Occurrence and relations.—Throughout the main volcanic mass in the Thomas and Dugway Ranges there are widely scattered outcrops of what may briefly be called "green glass," for although it varies considerably in color, most of it is green or greenish gray. In its two largest areas, one of which is in the north-central part of the Thomas Range and the other about a mile east of Colored Pass, the green glass is in the upper part of the rhyolite of the third subgroup and in the overlying vitric tuff. Smaller exposures of this rock, ranging down to areas too small to show on plate 1, occur in parts of other subgroups or cut across them. The green glass is exposed in various places from the base of the mountains to an elevation of about 6,200 feet. Except in a narrow band on the crest of Antelope Ridge, it does not cap any of the ridges.

The green glass forms extremely irregular bodies, the thicknesses of which vary from a few feet to more than a thousand feet within short horizontal distances, as, for instance, on the south side of Pyramid Peak, Dugway Range (pl. 1).

The green glass is less resistant than most of the lavas, and many of the areas underlain by it are grassy swales. Its exposures are generally discontinuous and tend to form low rounded knobs.

Contacts of the green glass with other rocks, especially with other members of the younger volcanic group, are exposed in a number of places. On the west side of the mouth of Topaz Valley, green glass cuts the rhyolite and tuff of the fifth subgroup, which is the youngest in the area. In the central part of the Thomas Range the third and fourth subgroups are cut or replaced by this rock. In the Dugway Range, rhyolite of the first subgroup, rhyolite and tuff of the second, and breccia of the third are cut by green glass. The green glass is not necessarily all of the same age; where it cuts across a rock, as it does on the top of the Antelope Ridge and on the south side of Pyramid Peak, it is evidently younger than that rock, but the age relation is less clear where the green glass is conformable with the other members of a subgroup. Where it is conformable, the green glass forms a layer below the obsidian layer and occupies the position where tuff or breccia is commonly found. The lower boundary of the green glass may conform to what would be the lower boundary of the pyroclastic beds if they were present, or it may be found much lower in the underlying rhyolite. In places the green glass grades along strike into tuff. Its contacts generally cut the overlying and underlying volcanic rocks at a small angle. In some places the boundaries of the green glass are so sharp that they can be located within a few inches. In many places, on the other hand, green glass and some other rock are separated by a gradational zone several hundred feet wide. Gradation of white vitric tuff into green glass passes through the following stages: first, parts of the tuff take on a slightly greenish cast; then the greenish cast deepens and spreads all through the rock, whose texture becomes more uniform and less distinctly pyroclastic; and finally the rock is a pale-green glass with a spheroidal texture. The alteration of tuff appears to be partly a result of impregnation with silica. Similar changes take place in volcanic breccia. In rhyolitic lava, however, the changes are different. Gray aphanitic rhyolite changes first either to a gray porphyritic rhyolite or almost abruptly to a brown porphyritic rock with a groundmass containing varying amounts of dull-brown glass, which changes in turn to a porphyritic spherulitic rock and then to a green spherulitic glass. The transitions from one of these rocks to the next are generally abrupt and in some places there is much interlayering of the various rocks.

Because green glass cuts most of the rocks with which it is in contact, it might be regarded as the youngest rock in the younger volcanic group. Its relations to the other rocks appears, however, to be somewhat anomalous, inasmuch as it cuts sharply across other kinds of volcanic rock in some places and grades into them in others. Some of its characteristics appear to indicate that it was formed by replacement. The writers believe that the green glass may have formed, as suggested by T. A. Steven of the U.S. Geological Survey, in and near the vents and that it consists not only of the vent fillings but also of partially remelted adjacent wall rocks, with the possible addition of some new material. The generally steep dips of flow layers in the green glass, suggesting that its parent magma moved steeply upward, would be explained by this theory of origin. Some of the larger green glass bodies, moreover, such as those on Pyramid Peak and in the north-central part of the Thomas Range, occur in areas that probably contained vents.

The green glass is rarely seen in contact with the volcanic rocks of the older group or with the underlying Paleozoic sedimentary rocks, but at several places in the southern part of the Dugway Range, along the east flank of the volcanic rocks, it overlies upturned Cambrian rocks.

Lithology.—The material mapped as green glass includes not only the typical green spheroidal glass but also such gradational rocks as the brown porphyritic rock and the brown, gray, and greenish-gray spheroidal rocks, but no rocks in which a pyroclastic texture is visible. In short, it includes not only typical spheroidal green glass but all transitional material whose derivation is uncertain, and this transitional material covers a larger total area than the glass.

The material here called green glass is mostly dark greenish gray, but in some places it is grayish green, light gray, brownish gray, brown, or reddish brown. The greenish-gray rock appears, megascopically, to consist almost wholly of clear glass broken by numerous perlitic fractures (fig. 38). It is these fractures, rather than the presence of spherulites, that gives the rock is spheroidal texture. In some places, however, the rock contains many spherulites. Spherulites are in fact about as numerous, volume for volume, in the green glass unit as a whole as they are in any of the other volcanic rocks. The spherulites range in size from tiny pellets visible only under the microscope to large nodules 6 inches in diameter. In hand specimens they commonly appear to consist of light-brown or purplish-gray partly devit-

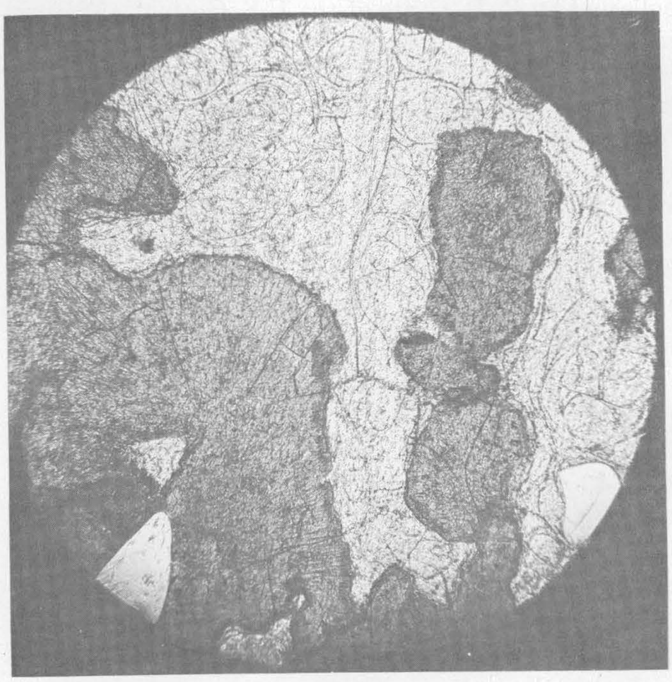


FIGURE 38.—Photomicrograph of a brown spherulitic glass of the green glass unit showing perlitic cracks. Darker areas are brown spherulites that have radial structures superimposed upon lineation shown by alined crystallites and microlites in the clear glass.

rified glass, and are darker colored than the glass that surrounds them. In some thin sections the glass in the spherulites is light brown and is surrounded by clear glass (fig. 38), in others it is medium brown and is surrounded by a light-brown glass. Under the microscope the spherulites are seen to consist of radiating fibers that mostly have a lower refractive index than balsam; they are presumed to be mainly potassium feldspar, although some quartz is present. Spherulites or parts of spherulites commonly form on or around earlier formed phenocrysts. The larger ones (over half an inch in diameter) commonly have hollow centers. These cavities may be lined with quartz crystals, minute calcite crystals, or botryoidal masses of opal and chalcedony (fig. 39). Agate, the banded form of chalcedony, is rare, although it is found in a few localities. It is most common on the flats about 1 mile north of the northern end of the Thomas Range. Collectors have dug a number of pits in this area (see prospect symbols on plate 1), and a brief article on collecting has been written by Ives (1946b, p. 411–415).

In some parts of the glass, conspicuous flow structures are brought out by the alinement of microlites or crystallites or by color-layering in the glass (fig. 40). The color layers range from microscopic size to several feet in width. Some bands may be entirely spherulitic material, and in others spherulites are absent.

Small open pockets or cavities, as much as 4 inches across, are plentiful and commonly contain rectangular crystals of tridymite or, in a few places, wedge-shaped twins. Cristobalite is also found in some of the cavities.

Few phenocrysts are visible in hand specimens, but in thin sections (fig. 40) it can be seen that small phenocrysts of quartz and sanidine commonly make up from 10 to 25 percent of the rock. Some of this rock contains larger and more conspicuous phenocrysts than the typical green glass, though the phenocrysts are of the same kinds and about equal in average abundance in the two kinds of rock. Quartz in subhedral to euhedral crystals, from 0.08 to 1.5 mm across, is very scarce in some specimens but makes up as much as 20 percent of others. Sanidine in subhedral to euhedral crystals, from 0.2 to 2.25 mm long, has about the same range in abundance. The embayment of both quartz and sanidine crystals in places by glass shows that they were formed before the glass solidified. Plagioclase phenocrysts form at most about 3 percent of the rock. They are generally smaller than those of quartz or sanidine, and some are enclosed in sanidine. Their composition ranges from An_{20} to An_{33} and averages about An_{26}. Small more or less ragged crystals of biotite occur in almost every specimen, but nowhere make up more than 1 percent of the rock. Magnetite, in small rounded anhedra, generally occurs only in minute quantity. Some thin sections contain a very few small euhedral crystals of sphene and zircon.

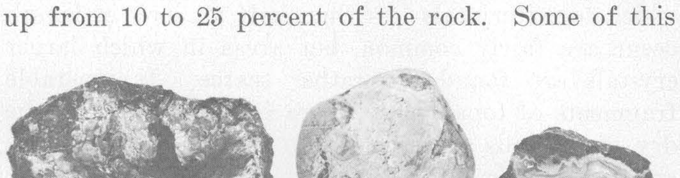


FIGURE 39.—Types of silicalined geodes fromh green glass. Left, geode lined with botryoidal opal and chalcedony; center, "Dugway geode" weathered from green glass and rounded by rolling on beaches of Lake Bonneville; right, interior of a "Dugway geode" showing outer rim of banded agate and hollow center lined with drusy quartz crystals. Black bar on center specimen is 1 inch long.

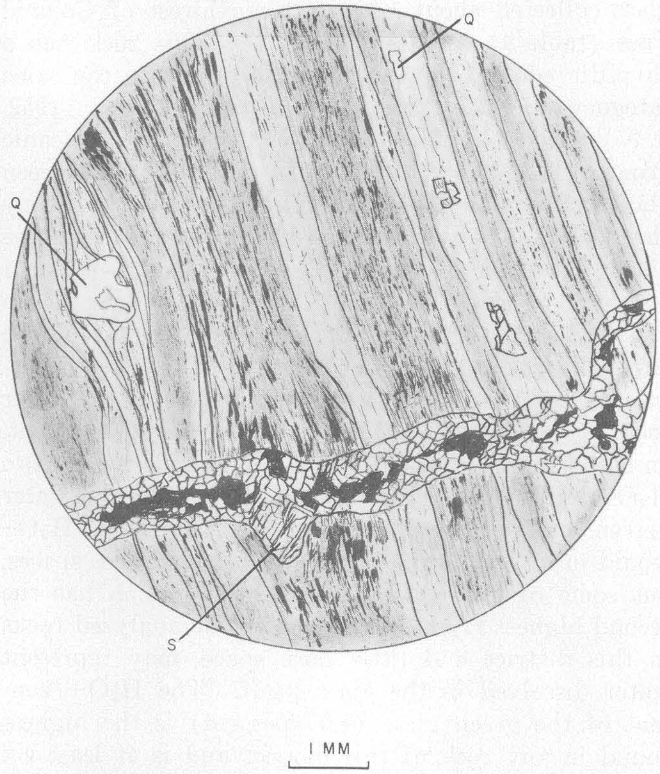


FIGURE 40.—Camera-lucida drawing of flow-banded green glass cut by a veinlet of chalcedonic quartz. Lighter colored bands are chiefly tridymite, quartz, and orthoclase; darker bands are partly divitrified glass. q, quartz, s, sanidine. Specimen collected 3.6 miles southwest of Dugway Pass.

Chemical composition.—A chemical analysis of one specimen of typical dark greenish-gray spheroidal glass collected about 1,000 feet northwest of Colored Pass (table 15, no. 14) shows that this rock has a rhyolitic composition and that it falls into the same category in Rittmann's chemical classification (1952, p. 95) as most of the rhyolites of the younger volcanic group. The analysis reveals, however, that the green glass is lower in SiO_2, Al_2O_3, and Na_2O than any rhyolite of the younger group. Nevertheless, the norm of the green glass is higher in quartz than that of about half of the rhyolites of the younger group and higher in albite than the norms of most of the rhyolitic rocks in the older group. The biggest difference in composition between this rock and the other rocks of rhyolitic composition is in the water content. In chemical analyses the water content is divided into H_2O- and H_2O+ with H_2O- representing the water driven off by heating the rock to about 105°. H_2O- would ordinarily represent water held in pore spaces, but some of the H_2O- in this glass, which has the second highest H_2O- content of all the analyzed rocks in this district and little pore space, may represent water dissolved in the glass itself. The H_2O+ content of the green glass (4.05 percent) is the highest found in any rock of this district and is at least six times as great as that found in any of the rhyolites except the obsidian (2.34 percent) (table 15, no. 8).

The specific gravity and index of refraction of two selected specimens of clean dark greenish-gray spheroidal glass of similar appearance, in which some crystallites were visible, were determined, with the results shown in table 10.

TABLE 10.—*Specific gravity and index of refraction of two specimens of green glass from the Thomas Range, Utah*

[Specific gravity determinations were made on a Berman balance and are the average of three fragments from the same specimen. Refractive index determinations were made in white light and have an accuracy of ±0.003]

Specimen	Location	Description	Specific gravity	Refractive index
MHS-8-54	1,000 feet north of Colored Pass.	Dark greenish-gray glass containing some crystallites.	2.30	1.485
WJC-12-54	Top of south end of Antelope Ridge.	Dark greenish-gray glass containing abundant crystallites.	2.36	1.50

The specimen from north of Colored Pass (MHS-8-54) is from the sample on which the chemical analysis (table 15, no. 14) was made. Inasmuch as the refractive indices of these two specimens of green glass are similar, the difference in specific gravity is probably due to the presence of compounds other than H_2O. The difference in specific gravity is considerably greater than that found between any two specimens of obsidian (table 9). The second specimen of green glass (WJC-12-54) is similar in specific gravity and refractive index to some of the obsidian specimens, and therefore presumably resembles them in chemical composition. If it does, both specimens of green glass are rhyolitic but differ considerably in composition. This difference may be due either to differences in their parent magmas or to the incorporation and remelting of chemically different wall rocks.

MINERALS OCCURRING IN CAVITIES IN THE RHYOLITIC ROCKS OF THE YOUNGER VOLCANIC GROUP

The Thomas Range is a well-known collecting locality for a number of minerals which occur in cavities in the gray facies of the rhyolite (fig. 41) and for silica minerals found in several volcanic rocks. Topaz, red beryl, and bixbyite are the minerals of chief interest in the cavities, and quartz, specularite, pseudobrookite, and garnet are of secondary interest. Although rhyolite flows extend well into the Dugway Range, these minerals are very rare in that area. These minerals first attracted scientific interest to the Thomas Range and have been described by Alling (1887), Buranek (1947), Cross (1886), Hillebrand (1905), Jones (1895), Montgomery (1934; 1935), Pabst (1938), Palache (1934), Patton (1908), and Penfield and Foote (1897). In the rocks of the younger volcanic group, the silica minerals opal, chalcedony, and the banded variety called agate are commonly found. Not only have the silica minerals, as well as the minerals in cavities in the rhyolite, been of scientific interest but they are in demand as collector's items. These minerals are discussed separately.

TOPAZ

Topaz crystals are found in all rhyolite flows of the younger volcanic group. Distribution within the flows, however, is quite local and generally does not exceed several hundred square feet in any one area. Areas in which topaz crystals less than half an inch in length occur are fairly common, but areas in which larger crystals are found are rather scarce. Innumerable fragments of topaz crystals are found in many of the dry streambeds which head in the rhyolite. Topaz crystals are found in greatest abundance in Topaz Valley, and, in spite of all the collecting that has taken place, it is still one of the best sources of good specimens.

The occurrence of topaz crystals in rhyolites is not unique to the Thomas Range and similar occurrences have been reported in North America at (1) Guanajunto, Zacatecas, and Durango, Mexico, (2) Lander County, Nevada, (3) the Black Range, New Mexico (Fries, Schaller, and Glass, 1942, p. 318), (4) Honeycomb Hills, western Utah, (5) Chalk Mountain near

Fremont Pass, Colorado, and (6) Nathrop, Colorado (Cross, 1886, p. 435–436).

Both clear and opaque crystals are found in the Thomas Range. The clear variety occurs singly or in clusters in small cavities, some of which are found in the hollow centers of lithophysae. These crystals are generally attached at one end, the other end being well terminated. Doubly terminated crystals attached in the middle were found in a few places. Crystal faces are well developed, and Alling (1887, p. 146–147) measured and described two pinacoids, b(010), c(001); two prisms, m(110), l(120); a macrodome, d(201); two brachydomes, f(021), y(041); and four pyramids, i(223), u(111), o(221), e(441), on topaz from the Thomas Range.

Many clear crystals, when broken out of the rhyolite, are pale amber, but on exposure to sunlight fade and become colorless. A few rose and amber topaz crystals, which had not faded, were found at the north end and on the east side of the Thomas Range. Similar rose topaz is reported (Montgomery, 1934, p. 87) from the east side of the Thomas Range just north of Pismire Wash. The topaz crystals vary in size but most of them are half an inch or less in length (along c axis). The largest clear crystal known measured 2 inches in length and five-eighths of an inch across its greatest width; it was collected from near the center of Topaz Valley (Buranek, 1947, p. 38).

The opaque topaz is light gray to nearly black. Some of the crystals are in solid rhyolite, others are partly in cavities. The crystals appear to have grown in the rhyolite and to have incorporated parts of the rhyolite as they grew. Patton (1908, p. 185) investigated these crystals in thin section; he noted that the interiors are crowded with quartz grains averaging 0.05 mm in diameter and that the feldspar so common in the surrounding rhyolite is missing. Patton's findings suggest that a reaction of fluorine-rich fluids with the feldspar formed topaz and quartz in some manner similar to the formula:

$$\underset{\text{(sanidine)}}{8KAlSi_3O_8}+2F_2+2H_2O\rightarrow\underset{\text{(topaz)}}{4[Al_2(F,OH)_2SiO_4]}+\underset{\text{(quartz)}}{20SiO_2}+4K_2O+O_2$$

All gradations occur between clear and opaque crystals, and some crystals are clear at the ends that protrude into cavities but are opaque where they are attached to the sides of the cavities. In general, opaque crystals are larger than clear crystals and are commonly

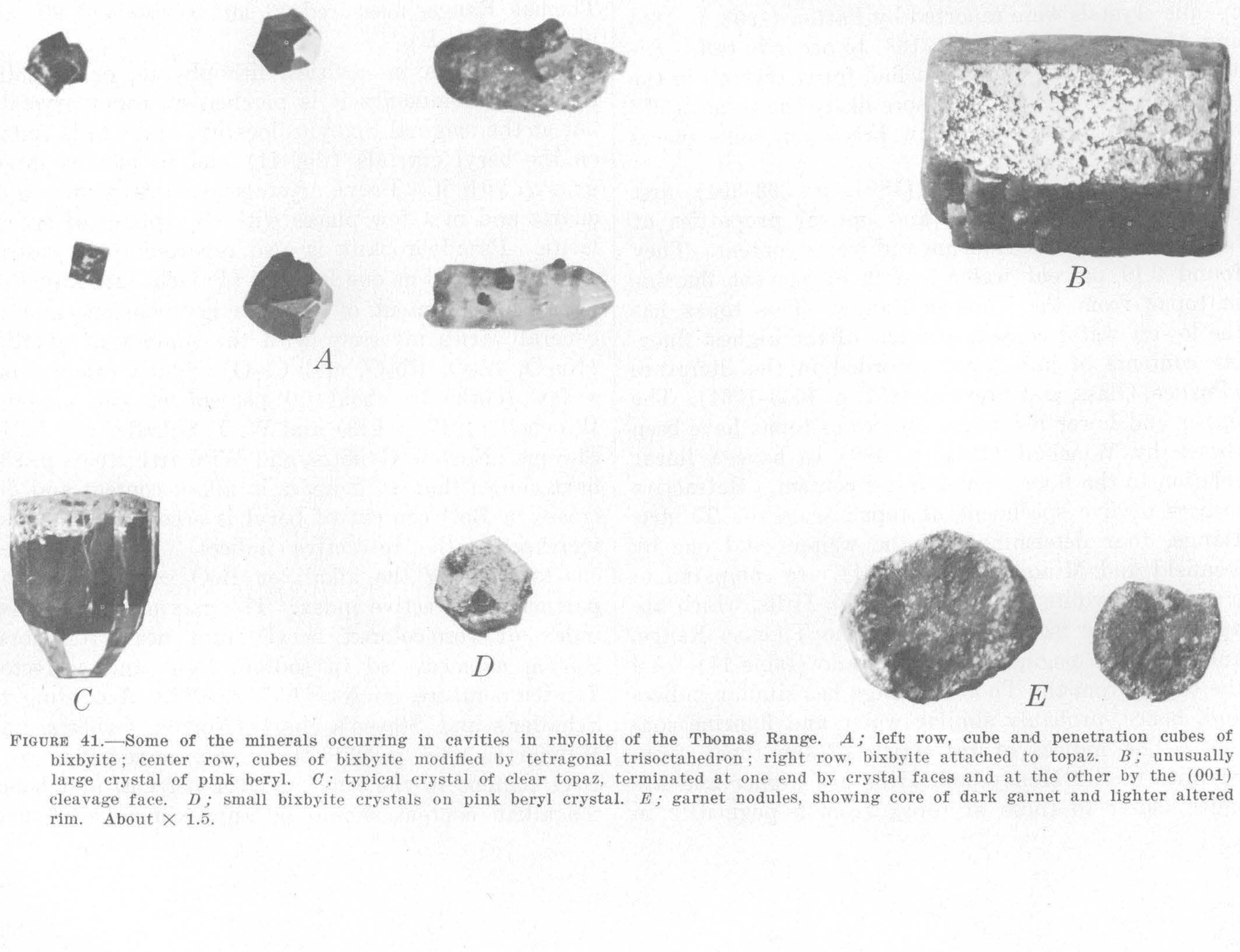


FIGURE 41.—Some of the minerals occurring in cavities in rhyolite of the Thomas Range. *A*; left row, cube and penetration cubes of bixbyite; center row, cubes of bixbyite modified by tetragonal trisoctahedron; right row, bixbyite attached to topaz. *B*; unusually large crystal of pink beryl. *C*; typical crystal of clear topaz, terminated at one end by crystal faces and at the other by the (001) cleavage face. *D*; small bixbyite crystals on pink beryl crystal. *E*; garnet nodules, showing core of dark garnet and lighter altered rim. About × 1.5.

TABLE 11.—*Indices of refraction of topaz from the Thomas Range, Utah, and other areas*

[Index determinations were made using a sodium light]

Specimen	Location	Description	Country rock	Indices of refraction	
				N_α	N_γ
A	Topaz Valley, Thomas Range.	Clear colorless well-formed crystal.	Rhyolite	1.608	1.618
B	do	do	do	1.608	1.618
C	do	do	do	1.608	1.6185
D	2½ miles northeast of Bell Hill mine, Thomas Range.	do	do	1.605	1.618
E [1]	Thomas Range	do	do	1.607	1.618
F	Honeycomb Hills western Utah.	Clear yellow crystal.	do	1.610	1.622
G	Crystal Rock area, El Paso County, Colo.	Piece of a clear pale brown crystal.	Pegmatite	1.610	1.620
H [2]	Brown Derby mine, Gunnison County, Colo.	Piece of white opaque crystal.	do	1.617	--------

[1] Data from Penfield and Minor (1894, p. 394).
[2] Data from Staatz and Trites (1955, p. 43).

an inch or more in length. Opaque crystals tend to have simpler forms, and the prism, m(110), is the most common. In some specimens a second prism, l(120), is present, and if terminated, the form is generally a simple pyramid, u(111). The opaque crystals occur in certain localities, just as the clear crystals do, and in some places the two are found together. Smooth opaque crystals were reported by Patton (1908, p. 186) and Montgomery (1935, p. 163) to occur in tuff. Inasmuch as the writers did not find topaz crystals in the tuff in the Thomas Range, more likely the term "tuff" was used to describe the flow breccia in some places near the base of the rhyolite.

As Penfield and Minor (1894, p. 393–394) first pointed out, the physical and optical properties of topaz vary with the fluorine and water content. They found 0.19 percent water and 20.37 percent fluorine in topaz from the Thomas Range. This topaz has the lowest water content and one of the highest fluorine contents of any topaz recorded in the literature (Pardee, Glass, and Stevens, 1937, p. 1063–1064). The upper and lower refractive indices of topaz have been shown by Winchell (1947, p. 199) to have a linear relation to the fluorine and water content. Refractive indices of five specimens of topaz from the Thomas Range, four determined by the writers and one by Penfield and Minor (1894, p. 394), are compared to one from rhyolite in the Honeycomb Hills, which are approximately 22 miles west of the Thomas Range, and two from pegmatites in Colorado (table 11). All the topaz from the Thomas Range has similar indices and, hence, probably similar water and fluorine content. The indices of refraction of the topaz from rhyolite in the Honeycomb Hills are higher and are much closer to those of topaz from a pegmatite in El Paso County, Colo. This suggests that origin may not be the most important factor in determining the final composition of the topaz.

BERYL

Although beryl is not a common mineral in the Thomas Range, it has been found with bixbyite at the original bixbyite locality on the east side of the range (Hillebrand, 1905, p. 330–331), at several places in Topaz Valley (Montgomery, 1935, p. 167; Buranek, 1947, p. 40), and in an area close to Wildhorse Spring. To our knowledge the occurrence of beryl in rhyolite in the Thomas Range is unique in the United States.

The beryl occurs in small rose-red crystals whose only developed faces are the basal pinacoid and the prism (fig. 41). In all localities in the Thomas Range except one, the beryl occurs in tabular crystals which may be as large as 6 mm across and 3 mm high. Such beryl, shorter in the direction of the c axis, is rare; generally crystals are elongated in the direction of the c axis. Near Wildhorse Spring, however, beryl elongated in the direction of the c axis was found. Most of these crystals were less than 7 mm across and 8 mm high, but one crystal, the largest known from the Thomas Range, measured 13 mm across and 20 mm high (fig. 41, B).

Beryl occurs in cavities, lithophysae, or in solid rhyolite. Commonly it is perched on topaz crystals, but at the original bixbyite locality, bixbyite is found on the beryl crystals (fig. 41) and in part is intergrown with it. Beryl crystals are intergrown with quartz and in a few places with thin plates of specularite. Pseudobrookite is also reported to be associated with beryl at one locality (Palache, 1934, p. 15).

The BeO content of beryl is not constant and in general varies inversely with the content of alkalies (Na_2O, Li_2O, Rb_2O, and Cs_2O), which range from a few tenths to about 10 percent of the mineral. Winchell (1947, p. 213) and W. T. Schaller and R. E. Stevens (Norton, Griffitts, and Wilmarth, 1958, p. 23) have shown that an increase in alkali content and decrease in BeO content of beryl is accompanied by an increase in the refractive indices. They compiled charts showing the alkali or BeO content for any particular refractive index. The maximum refractive index of rose-colored beryl from near Wildhorse Spring as measured in sodium light and corrected for temperature is: $N_\omega = 1.576 \pm 0.001$. According to Schaller's and Steven's chart (Norton, Griffitts, and Wilmarth, 1958, p. 23), this index corresponds to a BeO content in the beryl of 13.4 percent, and hence the alkali content should be approximately 0.6 per-

TABLE 12.—*Quantitative and semiquantitative spectrographic analysis of the minor elements in beryl from the Thomas Range*

[Analyst, J. C. Hamilton. Semiquantitative analyses in italics]

Cs	Rb	Na	K	Li	Ca	Fe	Mg	Ti	Mn	Sc	Zn	Sn	Ba	Cu	Ga	Zr	As	B	Nb	Ta	Y	Yb
0.9	0.35	*0.3*	0.5	0.05	0.07	1.6	*0.007*	0.2	0.2	0.001	0.2	0.08	0.0023	0.007	0.006	0.02	0.26	0.02	0.01	*0*	0.009	0.0008

cent. According to Winchell's chart (1947, p. 213), this index would correspond to a total alkali content of 0.8 percent. A quantitative and semiquantitative spectrographic analysis made on the minor elements in beryl (table 12) indicates, however, that the total effective alkali content is actually 1.6 percent. (The effective alkali content includes Na, Ca, Rb, and Li; it does not include K because K content of beryl does not affect the index of refraction.) Thus, these charts are not applicable for this particular beryl, and are probably not applicable to any beryl formed in rhyolite.

The spectrographic analysis (table 12) of the minor element content of this beryl is distinctive from beryl found in other environments, and its content of a number of the minor elements is unique. This beryl in comparison to beryl from pegmatites, has a relatively low content of titanium, sodium, magnesium, and scandium; a relatively high content of barium and cesium; and one of the highest contents known of rubidium, iron, titanium, zinc, manganese, arsenic, boron, gallium, niobium, tin, yttrium, ytterbium, and zirconium. In contrast, beryl from pegmatites rarely contains any arsenic, boron, niobium, tin, yttrium, ytterbium, and zirconium; iron rarely exceeds 0.4 percent of the mineral; titanium makes up 0.003 percent or less; and zinc does not exceed 0.1 percent. The amount of rubidium in this beryl compares to the amount in beryl from lithium-rich cores of pegmatites.

Beryl in granite commonly is comparable in iron content, and beryl from granite on Mount Antero, Colo., and Sheeprock Mountains, Utah, and at Lone Pine, Calif., and Aqua Verde, Ariz., contains as much as 1.5 percent iron. The presence of abnormally high quantities of titanium, arsenic, manganese, zinc, iron, and rubidium probably reflects the difference in composition of the original material in which the beryl was formed. The composition of granitic pegmatites is generally quite low in titanium, arsenic, manganese, zinc, and iron, and what little is present generally occurs in tourmaline, garnet, and gahnite. Rhyolite from the Thomas Range contains more of these elements as indicated by six analyses (table 15, nos. 8–13) made on the rhyolite of the younger volcanic group, which contained on the average 0.06 percent titanium, 0.02 percent manganese, and 0.77 percent iron; the rhyolite (analysis no. 12) with the maximum amount of these elements contained 0.08 percent titanium, 0.04 percent manganese, and 0.97 percent iron.

BIXBYITE

Bixbyite was first described by Penfield and Foote (1897, p. 105–108) from original material found by Maynard Bixby. Bixbyite is much less common in the Thomas Range than topaz, and known localities are generally restricted to a few small areas (1) on the east side of the Thomas Range less than a mile north of Pismire Wash, which is probably the location of Maynard Bixby's original discovery, (2) at the north end of the Thomas Range over an area of about 1 square mile, (3) at the south end of the Thomas Range in Topaz Valley (Buranek, 1947, p. 40), and (4) along the west side of the Thomas Range (Montgomery, 1935, p. 168).

Bixbyite is a rare mineral and has been described from only two other localities, (1) Ville de las Plumas, northern Patagonia (Cortellezzi, Himmel, and Schroeder, 1934, p. 129–135), and (2) the Black Range, New Mexico (Fries, Schaller, and Glass, 1942, p. 305–322). In both of these other areas it is associated with silicic volcanic rocks. The type of occurrence in the Black Range is almost identical to that in the Thomas Range.

Bixbyite $(Mn, Fe)_2O_3$ is one of the few easily recognizable manganese oxide minerals. It is isometric and forms simple cubes with a metallic luster in most areas (fig. 41), but in the northern part of the Thomas Range these cubes are commonly modified by the tetragonal trisoctahedron, n(211), and in a few places by an octahedron, o(111), which forms tiny faces beveling the tetragonal trisoctahedron. Although the bixbyite cubes are commonly less than 1 mm across, crystals as large as 6 mm across have been noted along the east side of the Thomas Range (Montgomery, 1934, p. 84), and as large as 12 mm in the northern part of the Thomas Range.

Bixbyite occurs in cavities, lithophysae, and along fractures. It has been found perched on crystals of topaz, garnet, rose beryl, and quartz. Although in part younger than the topaz, in the northern part of the Thomas Range it is intergrown with topaz.

A semiquantitative spectrographic analysis (table 13) was made on a specimen of bixbyite from the north end of the Thomas Range. The amounts of the

TABLE 13.—*Semiquantitative spectrographic analysis of bixbyite from the Thomas Range*

[Analyst, R. G. Havens]

Si	Al	Fe	Ti	Mn	Ca	Mg	Be	Cu	Ga	Nb	Sc	Sn	Yb	Zn	Zr
0.x	x	xx	0.x+	xx	<0.02	0.x−	0.00x−	0.00x+	0.0x	0.00x	0.0x	0.0x+	<0.001	0.x−	0.0x−

Looked for but not detected: P, K, Na, Ag, As, Au, B, Bi, Cd, Ce, Co, Dy, Er, Gd, Hf, Hg, Ge, In, Ir, La, Li, Mo, Nd, Ni, Os, Pb, Pd, Pt, Re, Rh, Ru, Sb, Sr, Sm, Ta, Th, Tl, Te, U, V, Y, and W.

Key to semiquantitative determinations: 0.000x+, from about 0.0005 to about 0.001 percent; 0.00x−, from about 0.001 to about 0.002 percent; 0.00x, from about 0.002 to about 0.005 percent; 0.00x+ from about 0.005 to about 0.01 percent; 0.0x−, from about 0.01 to about 0.02 percent; 0.0x, from about 0.02 to about 0.05 percent; 0.0x+, from about 0.05 to about 0.1 percent; 0.x−, from about 0.1 to about 0.2 percent; 0.x, from about 0.2 to about 0.5 percent; 0.x+, from about 0.5 to about 1 percent; x.−, from about 1 to about 2 percent; x., from about 2 to about 5 percent; x.+, from about 5.0 to about 10 percent; and xx., above 10 percent.

principal elements, as well as the amounts of silicon and aluminum, are similar to those obtained by Foote (Penfield and Foote, 1897, p. 106) in a chemical analysis of bixbyite from the Thomas Range. The silicon and aluminum were believed present in impurities by Penfield and Foote (1897, p. 106) and by Fries, Schaller, and Glass (1942, p. 314), who made an analysis of bixbyite from the Black Range, New Mexico. The bixbyite used in the semiquantitative spectrographic analysis (table 13) was carefully hand picked under the microscope and is reasonably free of adhering impurities. The silicon and aluminum are believed by the writers to be part of the bixbyite and may substitute in minor amounts for some of the other elements.

Although the presence of the manganese-bearing mineral bixbyite might suggest that the rhyolite is manganese-rich, chemical analyses of four specimens (table 15, nos. 9–12) of the containing rhyolite show a manganese content of only 0.03 to 0.05 percent. This amount of manganese is a little less than that of the average rhyolite (Washington, 1917, p. 114–141). Inasmuch as bixbyite occurs in cavities and along fractures, it may have been formed by late-stage manganese-rich fluids.

QUARTZ

Quartz, in addition to being an essential mineral in the rhyolite, lines the sides of some of the cavities and lithophysae in this rock. Quartz is perhaps equally as common in cavities as topaz, but because its crystals are small and clear it is easily overlooked or is mistaken for the associated topaz. Quartz is generally found as clear bipyramidal crystals as much as 1 mm across and locally as much as 5 mm across. At a few localities, such as near Wildhorse Spring, half a mile south of Colored Pass, and near the upper part of the north fork of Pismire Wash, the quartz occurs in crystals that have a distinctive pale blue or purple color.

SPECULARITE

Specularite is perhaps as widely distributed throughout the range as the topaz with which it is commonly closely associated. The specularite is shiny, steely black, and its crystals occur in paper-thin plates averaging about 1 mm in diameter. The crystals are hexagonal and are flattened parallel to the basal pinacoid. Specularite occurs in lithophysae and cavities, and commonly is found perched on topaz crystals, although in some places the specularite is included in the topaz crystals.

PSEUDOBROOKITE

Pseudobrookite is one of the rarest minerals occurring in the cavities. We did not see this mineral in place, but found several pieces in float near Wildhorse Spring and at the bixbyite locality on the east side of the Thomas Range. Pseudobrookite has been found in place, however, in Topaz Valley (Buranek, 1947, p. 39) and on the east side of the Thomas Range south of Pismire Wash (Montgomery, 1935, p. 165). Pseudobrookite was first found in the Thomas Range in 1934 by Edwin Over, and first described by Charles Palache (1934, p. 15). This mineral is known in but a few other localities. Fries, Schaller, and Glass (1942, p. 317–318) listed 15 areas in which the mineral occurs, of which only four are in the United States.

Pseudobrookite ($Fe_2O_3 \cdot TiO_2$) occurs in black submetallic acicular crystals, which form radiating clusters. Most of the crystals are less than one-quarter of an inch long, but some as long as an inch have been reported (Montgomery, 1935, p. 166). Pseudobrookite lines cavities, particularly along fracture zones; it is commonly associated with specularite and less commonly with topaz and beryl (Buranek, 1947, p. 39; Palache, 1934, p. 15).

Pseudobrookite may be formed by sublimation, inasmuch as it has been found in the flues of furnaces in a soda factory (Doss, 1892, p. 569–584). This mineral is reported near conspicuous fractures in Topaz Valley (Buranek, 1947, p. 39) and along the east side of the Thomas Range (Edwin Over, Jr., 1954, oral communication), and fractures may have served as channels for iron- and titanium-bearing fluids. Possibly pseudobrookite was precipitated from vapors escaping from bodies of cooling lava and rising along fractures.

GARNET

Garnet is not common in the Thomas Range, although we have found it (1) on the east side of the Thomas Range, 1/4 mile east of the original bixbyite locality, (2) on the east side of the Thomas Range about 1 1/4 miles southwest of the mouth of Pismire Wash, (3) in the north end of the Thomas Range approximately 1 1/2 miles south of the Dugway Pass road, (4) on the steep rhyolite cliffs, 1 mile east-northeast of the Bell Hill mine, and (5) on the top of a mountain, 1 1/4 miles north of Topaz Mountain. Garnet has also been reported from Topaz Valley (Patton, 1908, p. 190). At all these places the garnet occurs in rhyolite of the third, fourth, and fifth subgroups; it is much less plentiful than quartz or hematite and about as common as bixbyite.

Garnet crystals are locally common in rhyolite flows in other regions. Such occurrences are known in the following localities: (1) Garnet Hill, 5 miles east of Ely, Nev., (2) near Gold Spring, Lincoln County, Nev., a few miles west of the Utah border, (Patton, 1908, p. 191), (3) Nathrop, Colo. (Cross, 1886, p. 64–65), (4) Lander County, Nev. (Fries, Schaller, and Glass, 1942, p. 318), and (5) the Black Range, New Mexico (Fries, Schaller, and Glass, 1942, p. 318).

Garnet in rhyolite in the Thomas Range forms small rounded crystals with poorly developed crystal faces. Where recognizable, the trapezohedron is the common form. The garnet crystals are generally a quarter to a half inch in diameter. The largest single crystal measured 1 inch in diameter, and was found about 1 mile east-northeast of the Bell Hill mine, but a penetration group of crystals measuring 2 inches across was found in rhyolite about 1 1/4 miles north of Topaz Mountain. The garnet is deep reddish brown and locally contains many inclusions of quartz and, less commonly, of topaz.

The garnet is commonly encased in a thick black crust (fig. 41) made of a mixture of quartz, hematite, manganese oxides, and in some places topaz. In a few localities only a tiny center of garnet remains within the thick crust, which appears to have formed by alteration of the outer parts of the garnet, probably before the volcanic rocks were completely cooled.

The composition of most garnets can be broken down into percentages of component end members (almandite, spessartite, pyrope, grossularite, and andradite) by determining the specific gravity and the index of refraction and referring to graphs compiled by Ford (1915, p. 41–44). Refractive index measurements were made on four specimens of garnet from the Thomas Range and one specimen of garnet from the rhyolite at Garnet Hill near Ely, Nev. (table 14). These measurements were made in sodium vapor light and were corrected for temperature. Accurate specific gravity determinations were difficult to obtain on most garnet from the Thomas Range because of minute inclusions. Only one specimen (WJC–151–55) was free enough of inclusions to obtain an accurate specific gravity; on this garnet it is 4.20±0.03. In order to obtain further data, quantitative spectrographic analyses were made for iron and manganese, and semiquantitative spectrographic analyses were made for calcium, magnesium, aluminum, silicon, chromium, and titanium on four specimens of garnet (table 14). Iron, manganese, aluminum, and silicon were the only elements found in major amounts. All the garnets consist chiefly of almandite and spessartite; the combined grossularite, andradite, and pyrope content amounts to only 1 to 3 percent of the garnets. The three specimens from the Thomas Range were similar and contained approximately equal amounts of spessartite and almandite; in the one specimen from Garnet Hill, Nevada, two-thirds of the garnet was almandite.

Wright (1938, p. 444) stated that "spessartite and almandite constitute 85–90 percent of the molecules of garnets from pegmatites and granites." The composition of the garnet from these two localities is

TABLE 14.—*Index of refraction and spectrographic analyses of garnet from the Thomas Range, Utah, and Garnet Hill, Nevada*

[Spectrographic analyses by P. J. Dunton. Index of refraction determinations are accurate to within +0.005. Mn and Fe determinations accurate to approximately 3 percent. Key to semiquantitative determinations is as follows: 0.00x, from about 0.002 to about 0.005 percent; .00x+, from about 0.005 to about 0.01 percent; 0.0x−, from about 0.01 to about 0.02 percent; 0.0x, from about 0.02 to about 0.05 percent; 0.0x+, from about 0.05 to about 0.1 percent; 0.x−, from about 0.1 to about 0.2 percent and xx, from about 10 to 100 percent]

Specimen field number	Location	Index of refraction	Composition, in percent							
			Mn	Fe	Ca	Mg	Al	Si	Cr	Ti
WJC-106-55	North end of Thomas Range 1 1/2 miles south of the Dugway Pass road.	1.818	--------	--------	--------	--------	--------	--------	--------	--------
WJC-151-55	1 mile east-northeast of the Bell Hill mine	1.815	15	15	0.x−	0.x−	xx.	xx.	0.0x	0.0x+
WJC-174A-55	Top of mountain 1 1/4 miles north of Topaz Mountain; outer part of garnet.	1.818	15	15	.x−	.0x+	xx.	xx.	.00x	.x
WJC-174B-55	Top of mountain, 1 1/4 miles north of Topaz Mountain; inner part of garnet.	1.815	15	15	.x−	.0x+	xx.	xx.	.0x−	.x
WJC-200-55	Garnet Hill, 5 miles west of Ely, Nev	1.820	10	20	.x−	.x−	xx.	xx.	.00x+	.0x

similar to that of garnet in granite and pegmatites; this similarity suggests that garnet from rhyolites might also be included under Wright's generality. Data on garnet from other rhyolites would be needed, however, to substantiate this statement.

OPAL, CHALCEDONY, AND AGATE

Opal, chalcedony, and agate are widespread in the Thomas and Dugway Ranges, although they occur abundantly in only a few small areas. Opal is amorphous hydrous silica, chalcedony is cryptocrystalline quartz, and agate is banded chalcedony.

Several varieties of opal occur in the area, chiefly as botryoidal coatings on the inside of spherulites and along fractures. Common translucent opal occurs at many places, particularly in the geodes in the obsidian and green glass. Locally, large irregular masses of opalized material are found along the contact between green glass and tuff layers. One such locality is about 3 miles south-southwest of Dugway Pass in the NE¼ sec. 5, T. 12 S., R. 11 W. Milk opal, a pure white, nearly opaque variety, fills geodes in green glass in a basin about 1¼ miles north of Colored Pass, SW¼ sec. 18, T. 12 S., R. 11 E. Pale-green fluorescent hyalite opal forms veins at several localities, and is associated with uranium minerals at the Autunite No. 8 and Buena No. 1 properties.

Most of the opal seen in the Thomas and Dugway Ranges is of poor quality as a collector's item; except for the hyalite opal, it is badly fractured or checked.

Chalcedony is so widely distributed that brief mention is made here of only a few of the areas where the agate, or banded variety, may be found. As with opal, chalcedony occurs most commonly in geodes in the glassy rocks (fig. 39), although locally it fills fractures. The "Dugway geode" area, well known to many Utah collectors, has been described by Ives (1946b, p. 411–415). The source of these geodes is spherulitic green glass which crops out in isolated patches in an area of several square miles at the north end of the Thomas Range about 4 miles northwest of Dugway Pass. The geodes were scattered over a wide area by wave action in Lake Bonneville. The typical Dugway geode is about 3 or 4 inches in diameter, has an outer layer of dark-purpish-gray banded rhyolite, an inner layer, generally less than ½ inch thick, of translucent agate, and a hollow center which in some places is lined with small quartz crystals.

Agate occurs in other areas including a locality about 1 mile southwest of the mouth of Pismire Wash in NW¼SW¼, sec. 28, T. 12 S., R. 11 W., where it is found in geodes in the green glass.

TUFFACEOUS SANDSTONES

Three sandstones associated with or derived from the neighboring volcanic rocks are found in the Thomas Range. All three are of limited extent, the largest being exposed over an area of only 3,400 by 2,000 feet. The rocks are of three different ages and were probably deposited in small lakes formed by damming of streams by flows or ash falls. Two of the three sandstones are formed of materials derived from rhyolitic rocks and one from material derived from a rhyodacite. The oldest one is a pyroxene-plagioclase sandstone, the next a quartz-sanidine sandstone, and the youngest a calcareous sandstone. In addition, a red sandstone and conglomerate occur in the southwestern part of the Dugway Range, but, because this unit grades westward into and is largely red vitric tuff, it is described in the section on "Older volcanic group."

Occurrence and relations.—Pyroxene-plagioclase sandstone is limited to one small area on the western border of the map area in the central part of the Black Rock Hills; quartz-sanidine sandstone is exposed only in the central part of The Dell in the vicinity of the Good Will mine; calcareous sandstone is limited to an area along the west side of the Thomas Range, approximately 1 mile north of Wildhorse Spring.

Outcrops of tuffaceous sandstone are in general poorly exposed because the rock is friable and easily weathered. The pyroxene-plagioclase sandstone was deposited upon hills of rhyodacite and then was cut by a 4- to 5-foot dike of rhyodacite. The quartz-sanidine sandstone is underlain by quartz-sanidine crystal tuff and overlain by thin limestone conglomerate and vitric tuff, all belonging to the older volcanic group. The calcareous sandstone grades laterally into vitric tuff of the younger volcanic group but thins rapidly as it becomes more tuffaceous. South of the main exposure of sandstone the tuff is only a few feet thick and north of it, 20 to 50 feet thick; the sandstone near its center is at least 200 feet thick. The calcareous sandstone is overlain by volcanic breccia from which it is separated by a pronounced angular unconformity. These sandstone beds show a moderate dip to the west and are believed to have formed as foreset beds of a stream delta.

Lithology.—The plagioclase-pyroxene sandstone is a light to medium dark gray; the darker shades have a salt-and-pepper appearance. This rock forms distinct compact well-sorted layers. Individual layers vary in grain size: some have silt-size grains and others have grains as coarse as 2 mm in diameter.

Layers are from ¼ inch to 2 feet thick and have a dip as high as 9°. The strike and dip show considerable local variation and probably represent the initial attitude of the beds.

The sandstone is made up of angular to subrounded fragments, about half of which are of clear to brown glass. Some of the glass contains numerous small plagioclase microlites. Crystal fragments which make up the other half of the rock include: hypersthene (15 percent), augite (10 percent), plagioclase (23 percent), and magnetite (2 percent). Although the plagioclase may have come from several sources and thus may have a variable anorthite content, most of the plagioclase has a fairly large extinction angle, and is probably similar in composition. Maximum extinction angles of 28°, which correspond to that of labradorite (An_{54}), have been measured. The minerals and glass that make up this sandstone are identical to those found in the rhyodacite on which it is deposited. The sandstone was probably formed by erosion of the rhyodacite on the mountain above the present 5,250-foot level, and the deposition of the sand in a lake lying along its eastern side below the 5,250-foot level.

The quartz-sanidine sandstone is a white, light-gray, and yellowish-green friable rock with an average grain size of about 0.4 mm. Stratification is poor. The sand grains are angular to subrounded and consist chiefly of quartz and sanidine with minor amounts of plagioclase, biotite, and magnetite. A few lithic fragments of rhyodacite or porphyritic rhyolite are found. The matrix is chiefly clay with a little fine-grained calcite.

A more detailed description of this sandstone is given in the section on the Good Will property.

The calcareous sandstone is a friable grayish-orange to brown rock which consists of about 90 percent very fine sand-size particles. Although the rock is mainly sandstone, it contains a few small conglomeratic layers 1 to 8 inches thick. These layers contain subrounded to rounded pebbles, ¼ to 2 inches in diameter, of rhyodacite, porphyritic rhyolite, obsidian, pumice, an aphanitic dark-gray volcanic rock, vitric tuff, and quartzite.

The sandstone is made up of about 37 percent mineral fragments, 20 percent glass, and 43 percent calcite. Angular to subrounded mineral fragments are quartz (15 percent), plagioclase (10 percent), potassium feldspar (5 percent), biotite (1 percent), and magnetite (1 percent), and less than 1 percent hornblende, augite, sphene, and zircon. The plagioclase probably came from more than one source, as it has a variable anorthite content.

Glass is found in a variety of fragments ranging from clear through light brown to dark brown in color and from subrounded to angular in shape. Slender delicate Y-shaped shards are present in some places.

Irregular-shaped calcite grains make up much of the matrix of this rock. Calcite is not found in the matrix of the vitric tuffs that grade into the sandstone on the north and south; hence, the calcite was probably deposited from the lake water in which the sandstone was laid down.

CHEMICAL RELATIONS

Thirteen rock analyses of the volcanic rocks of the Thomas Range, have been made in the laboratories of the U.S. Geological Survey by L. M. Kehl, E. J. Tomasi, and M. K. Balazs, are given in table 15, which also includes one previous analysis (Cross, 1886, p. 438) and the norms of all the analyzed rocks.

The volcanic rocks of the Thomas Range have a small range in chemical composition as compared with those of most other volcanic areas. All the rocks of the younger volcanic group, which makes up the greater part of the exposed volcanic material, contain between 69.79 and 76.54 percent silica and are rhyolitic in composition. In the rocks of the older volcanic group, the silica percentage ranges more widely—from 58.86 to 77.24 percent.

The chemical variations of individual volcanic rocks or groups of volcanic rocks are best shown by diagrams. Because of the restricted range in composition of the rocks of the Thomas Range, however, it is especially difficult to represent their chemical differences graphically. For this reason several kinds of diagrams were used for illustrating several kinds of differences between the rocks in the Thomas Range and also for showing some of the broader differences between them and the volcanic rocks of neighboring regions. One kind of diagram may show how the percentage of each component of a rock varies as the magma differentiates. Other diagrams can show the differences in chemical composition between two groups of rocks as the magma differentiates, and still others consist of a series of points showing the spread of composition of the rocks under consideration.

All these diagrams are based on the assumption that the chemical analyses are accurate and that the chemical composition has not been changed by any secondary processes, such as silicification or weathering. Diagrams that show the change in chemical composition of rocks in one region as compared to those of another area are generally based on the assumption that all the rocks in one area are related.

TABLE 15.—*Chemical compositions and norms of volcanic rocks from the Thomas Range, Utah*

[Analysts; E. J. Tomasi (1–4, 6–8, 14; fluorine for 5, 12); L. M. Kehl (5, 12, except for fluorine); M. K. Balazs (9–11); L. G. Eakins (13); Analyses in weight percent]

Constituent	Older volcanic group						Younger volcanic group							
	Chemical compositions													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	58.86	63.68	63.24	73.48	73.30	77.24	69.79	74.67	74.90	75.81	76.05	76.54	74.49	72.92
Al_2O_3	13.36	14.79	14.94	12.39	14.27	10.81	12.20	12.26	12.48	12.18	12.38	12.16	14.51	11.97
Fe_2O_3	2.09	2.82	1.88	1.44	.34	1.66	.98	.71	.75	.98	.68	.92	.57	.70
FeO	4.78	1.82	2.71	.23	1.89	.27	.17	.27	.17	.00	.29	.37	.32	.27
MgO	7.01	3.34	3.51	.44	.13	.33	.79	.11	.17	.25	.29	.14	Tr.	.07
CaO	6.35	4.80	4.81	1.99	.34	1.48	1.82	.61	1.30	.94	.54	.78	1.03	.98
Na_2O	2.30	2.84	2.83	2.28	3.86	2.59	3.45	3.31	3.72	3.18	3.06	3.50	3.79	2.75
K_2O	2.51	3.00	3.05	5.88	4.76	4.12	4.35	5.05	4.89	5.08	5.27	4.97	4.64	4.95
H_2O-	.32	1.01	.35	.33	.11	.49	1.57	.13	.15	.40	.63	.05		.74
H_2O+	1.01	.58	1.51	.49	.39	.37	3.25	2.24	.12	.28	.34	.11	.64	4.05
TiO_2	.72	.68	.67	.23	.03	.20	.11	.14	.08	.12	.13	.09		.08
CO_2	.04	.21	.08	.18	.06	.13	.46	.01	.67	.34	.03	.16		.01
P_2O_5	.23	.15	.16	.06	.03	.06	.02	.01	.01	.01	.01	.02		.01
Cl	.02	.01	.03	.01		.01	.88	.10	.04	.07	.16			.11
F	.05	.07	.06	.47	.77	.04	.25	.26	.25	.14	.14	.27		.32
MnO	.12	.06	.07	.05	.07	.02	.06	.05	.05	.03	.04	.05	Tr.	.06
Less O	.02	.03	.03	.20	.32	.02	.31	.13	.12	.08	.09	.11		.16
Total	99.75	99.83	99.87	99.75	100.03	99.80	99.84	99.80	99.63	99.73	99.95	100.02	99.99	99.83
	Norms													
Quartz	12.30	21.72	19.32	33.96	30.96	43.14	34.74	35.16	33.84	36.48	38.46	36.42	32.58	35.82
Orthoclase	13.90	17.97	18.35	35.03	28.36	24.46	25.58	30.02	28.91	30.02	31.14	29.47	27.24	29.47
Albite	19.39	24.10	24.10	19.39	32.49	22.01	22.01	27.77	31.44	27.25	24.63	29.34	31.96	23.58
Anorthite	19.18	18.63	18.63	6.12		5.56	5.00	1.95	1.11	1.95	2.22	1.67	5.28	3.89
Diopside	10.01	2.81	3.99	.86		.86								
Hypersthene	18.78	7.10	9.28	.70	3.60	.40	2.00	.30	.40	.60	.70	.30		.20
Magnetite	3.02	3.71	2.78		.46	.23	.46	.46	.46		.46	1.39	.93	.93
Ilmenite	1.37	1.37	1.37	.46		.46		.30			.30			
Hematite		.32		1.44		1.60	.64	.32	.48	.96	.32			
Corundum					2.75		1.43	.71	.41	.71	1.12	.51	1.33	.61
Fluorite		.16	.16	.94	.47		.55	.55	.55	.31	.31	.31		.62
Halite							1.52				.23			
Unused fluorine					.30									
Calcite		.50		.40		.30	1.00		1.50	.80		.40		
Total	97.95	98.39	97.98	99.30	99.39	99.02	94.93	97.54	99.10	99.08	99.89	99.41	99.32	95.12

1. Dark labradorite rhyodacite, Harrisite mine, on the southern end of Spor Mountain.
2. Rhyodacite, southern end of Eagle Rock Ridge.
3. Rhyodacite, south end of the Thomas Range.
4. Quartz-sanidine crystal-tuff collected 0.4 mile northwest of Colored Pass.
5. Gray porphyritic rhyolite from small plug in saddle near north end of Eagle Rock Ridge.
6. Porphyritic rhyolite collected 0.3 mile east of the Autunite No. 8 prospect.
7. Vitric tuff collected 0.6 mile northeast of the Bell Hill mine.
8. Obsidian facies of the rhyolite from fourth subgroup collected 1.8 miles north of Wildhorse Spring.
9. Red facies of the rhyolite from the third subgroup collected 2.5 miles south-southeast of Dugway Pass.
10. Gray facies of the rhyolite from the third subgroup collected 1.9 miles southeast of Dugway Pass.
11. Gray facies of the rhyolite from the fourth subgroup collected 3.1 miles east-northeast of Wildhorse Spring.
12. Gray facies of the rhyolite from fifth subgroup collected in Topaz Valley.
13. Gray facies of the rhyolite, locality not specified.
14. Green glass collected 0.2 mile northwest of Colored Pass.

In these latter diagrams, it is also tacitly assumed that the rocks become younger as they become more silicic.

In many regions not all these assumptions are valid. Inasmuch as the older and younger groups of volcanic rocks in the Thomas Range are of different ages, they are considered separately.

One of the most practical of the two-component variation diagrams in common use is the silica-variation diagram (figs. 42, 43) of the form proposed and applied by Harker (1900, p. 390; 1909, p. 118–146, 333–350). This diagram has the advantages of ease of construction, simplicity of chemical relations, and straightforwardness in graphical addition or subtraction; the only calculation involved is in changing all the Fe_2O_3 to FeO, so that both iron oxides can be represented by a single curve. For some of the oxides, there is a scattering of points allowing some latitude in the drawing of the connecting curves. In the younger volcanic group this is true with CaO and Na_2O (fig. 43), but in general the position of the curves for these rocks is well controlled. In the older volcanic rocks a fairly wide scattering of points is noted at the silicic end, and the scarcity of points in this part of the graph does not allow for the accurate determination of the curve and for indicating how much any particular rock differs from the average.

A general comparison can be made, however, between the two sets of curves (figs. 42 and 43). Even assuming the widest variation possible in the curve for the older volcanic group, little similarity is noted. The curve for the Al_2O_3 in the younger group is almost flat, whereas for the Al_2O_3 in the older group it shows a steep drop toward the more siliceous end.

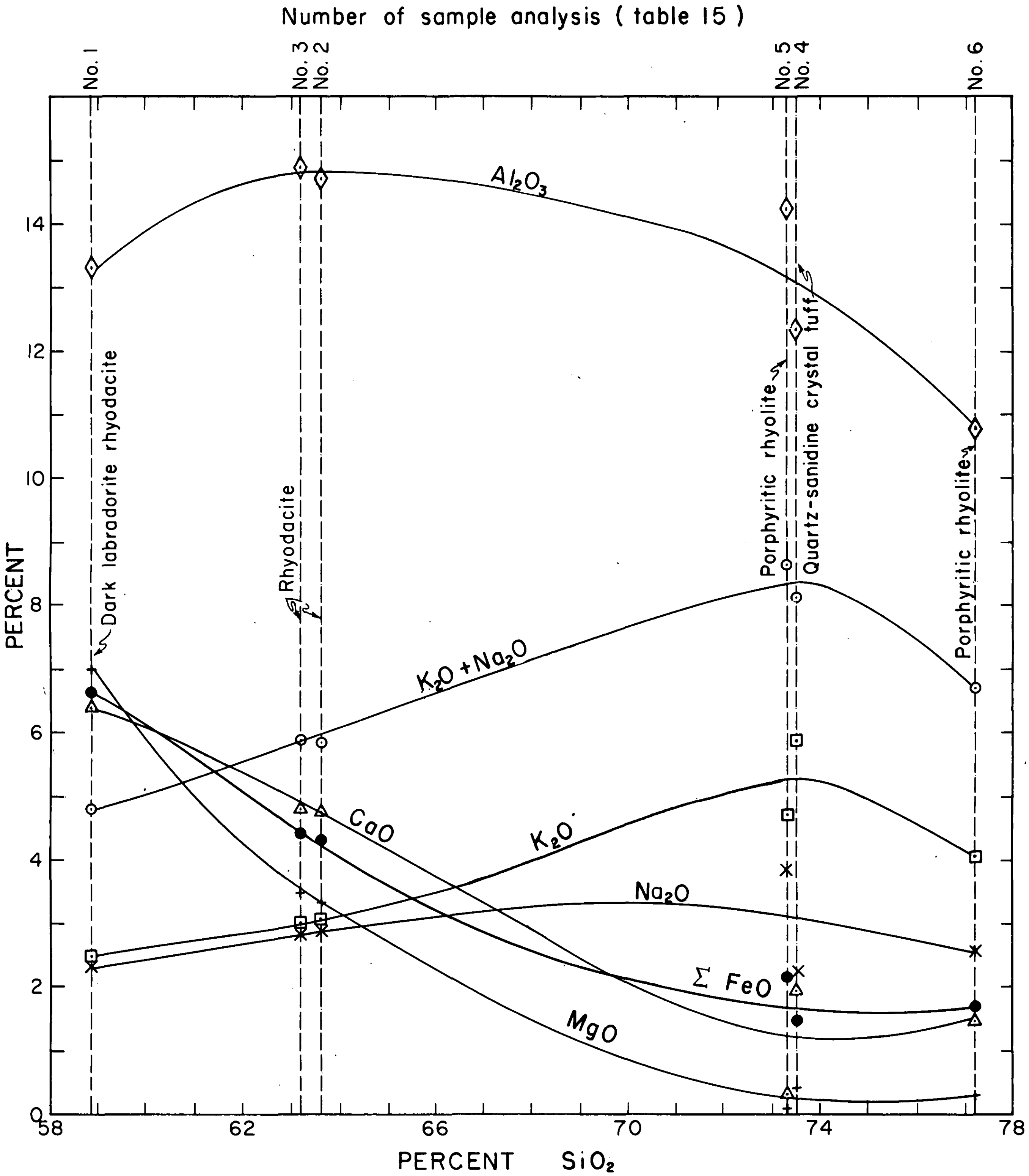


FIGURE 42.—Silica-variation diagram of the rocks of the older volcanic group from the Thomas Range.

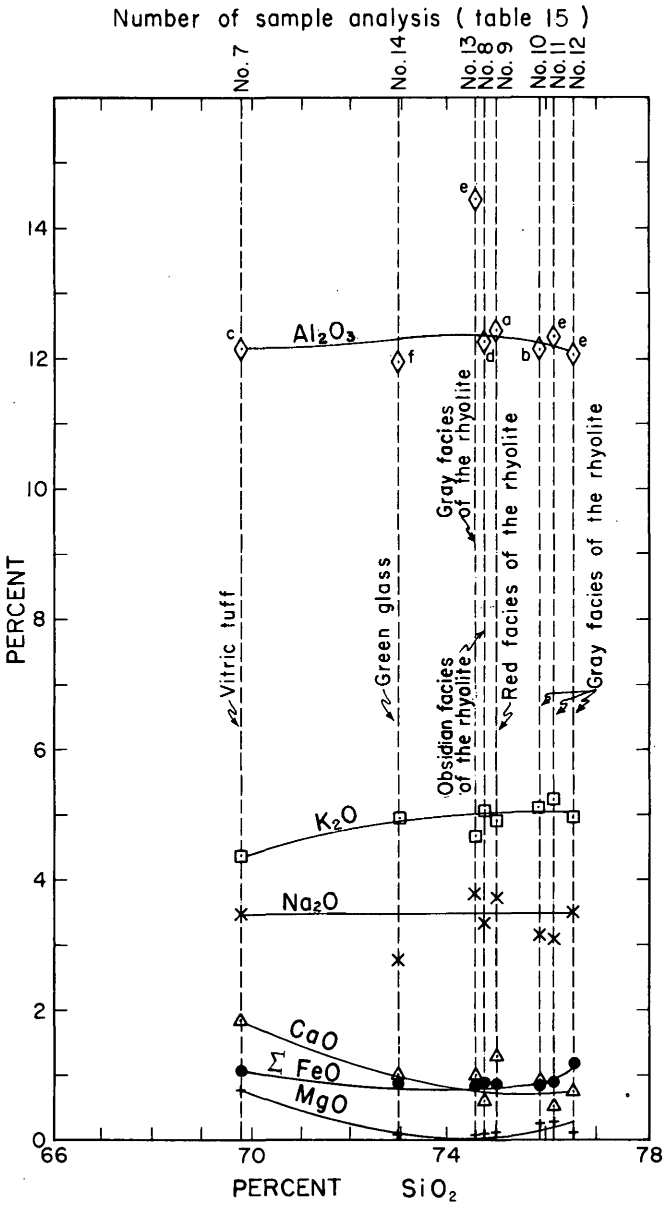


Figure 43.—Silica-variation diagram of the rocks of the younger volcanic group from the Thomas Range.

The curves for K_2O show little if any correlation, but the curves for Na_2O, and also for CaO, would be fairly similar if the curve for the older group were placed close to the value obtained for the quartz-sanidine crystal tuff. The curves for ΣFeO, although similar in slope, vary in magnitude because the ΣFeO values of the older volcanic group are all considerably higher than those of the younger volcanic group. The greatest similarity is found between the MgO curves of the two groups, but the percentage of MgO is so low in both groups that this agreement has little real significance. The differences between these two sets of curves, even with liberal interpretation of the position of the curve in the rocks of the older volcanic group, are so much greater than the similarities as to suggest that the two groups are not consanguineous.

The fourfold classification of rock sequences into alkalic, alkali-calcic, calc-alkalic, and calcic, as suggested by Peacock (1931, p. 54–67), is based on the silica-variation diagram. Peacock introduced the useful term "alkali-lime index," meaning the SiO_2 value at which the curves for Na_2O+K_2O and CaO intersect on the variation diagram (fig. 42). Indices below 51 percent SiO_2 belongs to the alkalic series; from 51 to 56, to alkali-calcic; from 56 to 61, to calc-alkalic; and above 61, to calcic series. The position of the intersection of the curves for rocks of the younger volcanic group cannot be obtained with any accuracy because no control points occur in its vicinity; its position could only be approximated by extending the curves at least their present length toward the less siliceous side of the graph. In the following discussion, therefore, only the rocks of the older volcanic group will be compared with volcanic rocks of other regions.

The alkali-lime index for the Thomas Range rocks of the older volcanic group is 61.6; its position being controlled by the three sets of analyses for the rhyodacites (fig. 42). The rocks from the older volcanic group belong to the calcic series, which includes the volcanic rocks of Katmai, Alaska (Peacock, 1931, p. 61), and of Lassen Peak and Mount Shasta (Williams, 1935, p. 297), which have indices of 63.8, 63.9, and 63.7, respectively. The indices for the rocks from the older volcanic group of the Thomas Range agree more closely, however, with those for the rocks of Parícutin volcano and of the region surrounding it (Wilcox, 1954, p. 315) and of those of Crater Lake (Williams, 1942, p. 153–154), which have indices of 61, 61.5, and 62, respectively. The rocks of these three regions, however, have little resemblance to those of the Thomas Range. The volcanic rocks at Crater Lake are mostly andesitic and dacitic, and those at Parícutin and the region surrounding it mostly basaltic and andesitic, whereas the volcanic rocks of the Thomas Range are mostly rhyolitic. These three groups of rock belong in the same rock suite, but the rocks from Crater Lake and Parícutin represent the less siliceous end of the suite, and those from the Thomas Range the more siliceous end.

In addition to the silica-variation diagrams two triangular diagrams were prepared (figs. 44 and 45). One (fig. 44) has as end members CaO, Na_2O, and K_2O; the other (fig. 45) MgO, the alkalies (Na_2O+K_2O), and the iron oxides ($FeO+0.9Fe_2O_3$). This latter diagram is similar to that originally proposed by Poldervaart (1949, p. 177–188), but has been modified according to Coats (1953, p. 18–19), who added to the original FeO the amount of FeO corresponding to the Fe_2O_3 in the analysis. This is done because of the widespread inconsistency in degree of oxidation of iron in volcanic rocks. Both diagrams include analyses of five samples of rocks from the East Tintic mining district, Utah, obtained through the courtesy of T. S. Lovering (1956, written communication), and seven analyses representing Daly's averages (1933, p. 9–30).

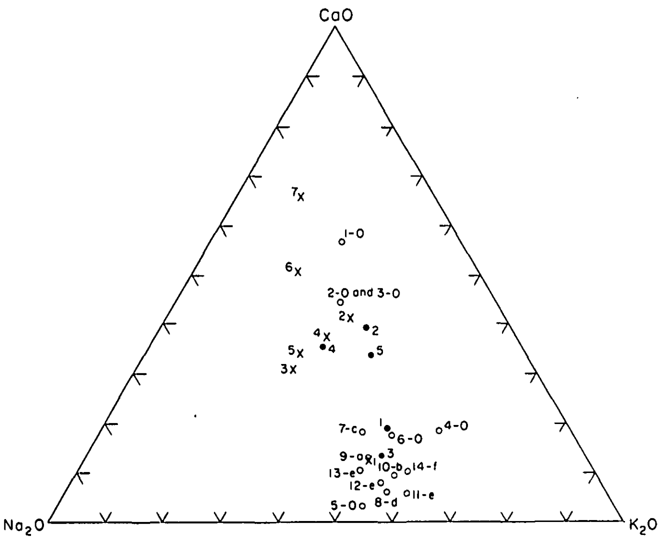


FIGURE 44.—Relations of K_2O, Na_2O, and CaO in the volcanic rocks of the Thomas Range and the East Tintic mining district.

⊙ Rocks from the Thomas Range:

1. Dark labradorite rhyodacite, Harrisite mine
2. Rhyodacite, Eagle Rock Ridge
3. Rhyodacite, south end of Thomas Range
4. Quartz-sanidine crystal tuff, Colored Pass
5. Porphyritic rhyolite, Eagle Rock Ridge
6. Porphyritic rhyolite, near Autunite No. 8
7. Vitric tuff, near Bell Hill mine
8. Obsidian, north of Wildhorse Spring
9. Red rhyolite, south-southeast of Dugway Pass
10. Gray rhyolite, southeast of Dugway Pass
11. Gray rhyolite, east-northeast of Wildhorse Spring
12. Gray rhyolite, Topaz Valley
13. Rhyolite, Thomas Range (Cross, 1886, p. 438)
14. Green glass, Colored Pass

× Average rock analysis compiled by Daly (1933, p. 9–17):

1. Rhyolite
2. Latite
3. Trachyandesite
4. Quartz latite
5. Dacite
6. Andesite
7. Basalt

● Rocks from East Tintic mining district, Utah:

1. Average of 3 analyses of quartz latite
2. Augite-biotite latite
3. Swansea quartz monzonite
4. Hornblende- biotite- quartz-monzonite, North Lily stock
5. Hornblende-biotite monzonite, Iron Duke mine

O Suffix on numeral indicates rock is a member of the older volcanic group.

a–f—Suffix on numeral indicates rock is a member of the younger volcanic group, a being the oldest and f the youngest.

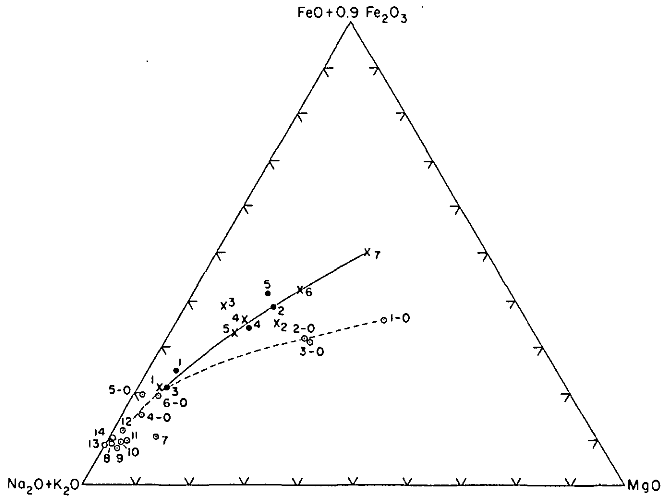


FIGURE 45.—Relations of magnesia (MgO), iron oxide (FeO), and alkalies (Na_2O+K_2O), in the volcanic rocks of the Thomas Range and the East Tintic mining district.

⊙ Rocks from the Thomas Range:

1. Dark labradorite-rhyodacite, Harrisite mine
2. Rhyodacite, Eagle Rock Ridge
3. Rhyodacite, south end of Thomas Range
4. Quartz-sanidine crystal tuff, Colored Pass
5. Porphyritic rhyolite, Eagle Rock Ridge
6. Porphyritic rhyolite, near Autunite No. 8
7. Vitric tuff near Bell Hill mine
8. Obsidian, north of Wildhorse Spring
9. Red rhyolite, south-southeast of Dugway Pass
10. Gray rhyolite, southeast of Dugway Pass
11. Gray rhyolite, east-northeast of Wildhorse Spring
12. Gray rhyolite, Topaz Valley
13. Rhyolite, Thomas Range (Cross, 1886, p. 438)
14. Green glass, Colored Pass

× Average rock analysis compiled by Daly (1933, p. 9–17):

1. Rhyolite
2. Latite
3. Trachyandesite
4. Quartz latite
5. Dacite
6. Andesite
7. Basalt

● Rocks from East Tintic mining district, Utah:

1. Average of 3 analyses of quartz latite
2. Biotite-augite latite
3. Swansea quartz monzonite
4. Hornblende - biotite - quartz monzonite, North Lily stock
5. Hornblende-biotite monzonite, Iron Duke mine

O Suffix on numeral indicates rock is a member of the older volcanic group.

Figure 44 shows a general decrease in CaO from the dark labradorite-rhyodacite (no. 1) to the porphyritic rhyolites (no. 5) in the older volcanic group; in the quartz-sanidine crystal tuff (no. 4) there is a significant variation from the general trend in the ratio between K_2O and Na_2O, probably because this tuff contains fragments of sedimentary rocks. The rocks of the younger volcanic group are bunched close to Daly's average rhyolite, but all except the vitric tuff contain the same or a less amount of CaO. The bunching of this group suggests that the original magma was little differentiated. Rocks from the East Tintic district show little relation to either group of volcanic rocks from the Thomas Range.

In figure 45 the symbols representing analyses of Daly's average rocks (1933, p. 9–17) and those from the East Tintic district fall on or near a smooth curve (solid) slightly convex toward the iron oxide corner. In a series where iron enrichment has taken place, the plotted points fall on a line above this curve and are more sharply convex toward the iron oxide corner. The symbols representing rocks of the younger volcanic group form a small cluster on this graph, but those representing rocks of the older volcanic group from a curve (dashed) that diverges considerably from the solid curve. This divergence is not due to an excess of MgO but rather to a deficiency of iron oxide.

Poldervaart (1949, p. 181) gave Daly's averages as an example of a more salic type of rock. The curve representing the older volcanic rocks of the Thomas Range, however, is similar to that representing Daly's averages, but falls below it and thus shows that the Thomas Range rocks are more salic than Daly's average rocks.

From these four variation diagrams (figs. 42, 43, 44, and 45), it is possible to compare the general order of crystallization in the various rocks of the Thomas Range. The suffix "O" is attached in figures 44 and 45 to the numbers or names of all the rocks belonging to the older volcanic group. The relative ages of most rocks in the older volcanic group are too uncertain to be discussed in relation to the chemical composition of those rocks. The rhyodacites, however, are known to be older than the porphyritic rhyolite, and the variation diagrams show that they contain considerably less SiO_2, Na_2O, K_2O and more CaO, FeO, and MgO than the porphyritic rhyolites.

The relative ages of the younger volcanic rocks are much better known, and are indicated in figures 43 and 44 by the letters "a" to "f," "a" representing the oldest rock and "f" the youngest. Three analyses of rocks that all came from a single flow are all marked "e." In the silica-variation diagram (fig. 43) the letters are plotted only on the Al_2O_3 curve, but the positions are the same on the other curves. In the K_2O–Na_2O–CaO diagram (fig. 44) the letters are used as suffixes to the locality number. The age relations between numbers of the younger group are not shown on the other triangular variation diagram, because most of the points representing analyses of the younger volcanic rocks are so close together that they are of no significance. On the other two variation diagrams, the random distribution, with respect to age, of the points marked by the letters shows that no systematic changes in the chemical composition of the parent magma took place during the eruption of these rocks. The primary differences between the members of the younger volcanic group cannot, therefore, be

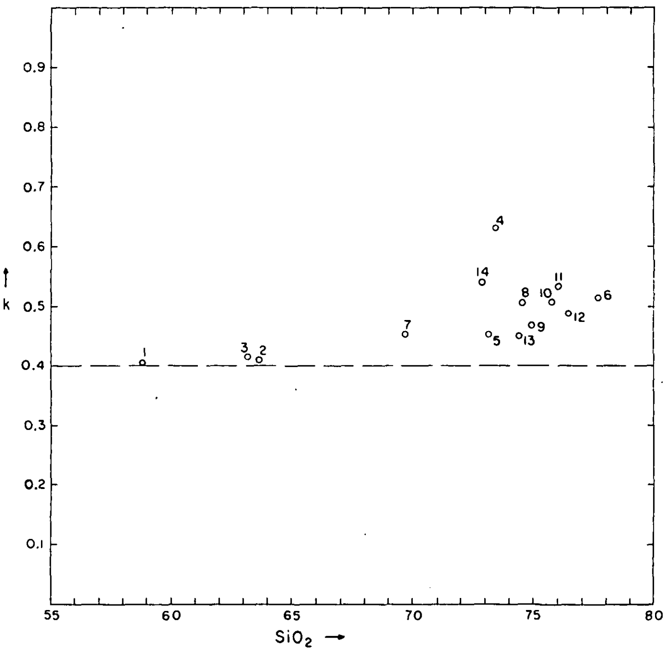


FIGURE 46.—Diagram showing "k" ratio plotted against SiO_2 content in the volcanic rocks of the Thomas Range.

1. Dark labradorite-rhyodacite, Harrisite mine
2. Rhyodacite, south end of Eagle Rock Ridge
3. Rhyodacite, south end of Thomas Range
4. Quartz-sanidine crystal tuff, Colored Pass
5. Porphyritic rhyolite, north end Eagle Rock Ridge
6. Porphyritic rhyolite, Autunite No. 8
7. Vitric tuff, near Bell Hill mine
8. Obsidian, north of Wildhorse Spring
9. Red rhyolite, south-southeast of Dugway Pass
10. Gray rhyolite, southeast of Dugway Pass
11. Gray rhyolite, east-northeast of Wildhorse Spring
12. Gray rhyolite Topaz Valley
13. Rhyolite, Thomas Range (Cross, 1886, p. 438)
14. Green glass, Colored Pass

fully explained by fractional crystallization, which operates as a function of time; they are probably due in the main to processes operating locally, such as assimilation or gaseous transfer.

A fifth variation diagram (fig. 46) was prepared in which the SiO_2 content of all the volcanic rocks in the Thomas Range is plotted against the "k" ratio—the molecular ratio of K_2O to K_2O+Na_2O. When the weight percent of K_2O and Na_2O are equal, the "k" ratio is 0.4, and when it is higher, the weight percent of K_2O exceeds that of Na_2O. The "k" ratio is higher than 0.4 in all these rocks.

The "k"-SiO_2 variation diagram was used by Merriam and Anderson (1942, p. 1723–1725) to compare the volcanic rocks of California, western Nevada, central Nevada, and Utah; many of the available analyses of these rocks list only the SiO_2, Na_2O, and K_2O content. Merriam and Anderson showed that the "k" ratio equals or exceeds 0.4 in most of the Utah volcanic rocks and is rather high in some of them; it is between 0.4 and 0.5 in most of the volcanic rocks of central Nevada, between 0.3 and 0.5 in most of the volcanic rocks of western Nevada, and less than 0.4 and usually less than 0.3 in most of the volcanic rocks of California. The average "k" ratio thus rises in general from west to east. The "k" ratios of rocks in the Thomas Range are generally high, like those compiled by Merriam and Anderson for rocks in other parts of Utah. Apparently, moreover, the K_2O enrichment extends at least from central Nevada through western Utah and into parts of New Mexico (Merriam and Anderson, 1942, p. 1725; Nolan, 1935, p. 50; Butler, Loughlin, Heikes, and others, 1920, p. 89; and Lindgren, Graton, and Gordon, 1910, p. 43–44). The reason for this regional abundance of K_2O is not known. It cannot be explained simply as a result of local hydrothermal alteration, but must be due to some larger scale phenomenon, such as differences in the original composition of the magma between one region and the next. Such regional differences in the average composition of the volcanic rocks as the gradual rise in the "k" value from California to Utah may be commoner than previously suspected. The layers at depth, though probably much more uniform than those nearer the surface, may show gradational changes from one region to the next. Material erupted from these deeper layers would show similar differences which, when modified by such factors as fractional crystallization and assimilation, would show up in the volcanic rocks on the surface.

URANIUM CONTENT OF THE VOLCANIC ROCKS

The uranium content of fresh unaltered volcanic rocks from the younger volcanic group is at least three times that of the average rhyolitic rock.

Equivalent uranium and uranium contents of 25 volcanic rocks are compiled in table 16. The equivalent uranium content represents a radiometric measurement based on the assumption that all the radiation comes from the daughter products of uranium, and that these daughter products are in equilibrium with the uranium. If other radioactive substances such as thorium or K^{+40} are present or if the uranium is not in equilibrium with its daughter products, then the assumption is erroneous. The uranium content is determined by chemical methods and represents the true amount of uranium in the sample, irrespective of the amount of radiation.

The equivalent uranium content in most of the rocks of the Thomas Range (table 16) is higher than the uranium content. The difference can be explained by the presence of the radioactive potassium isotope K^{+40} and of thorium.

TABLE 16.—*Uranium analyses of volcanic rocks from the Thomas Range, Utah*

Field sample	Laboratory number	Volcanic group	Rock type	Equivalent uranium (percent)	Uranium (percent)
SC-9-55	B390	Older	Dark labradorite-rhyodacite.	[1] 0.0020	[2] 0.0016
SC-10-55	B391	do	Rhyodacite	[1] .0020	[2] .0015
SC-16-55	B394	do	do	[1] .0015	[2] .0007
BH-19-52	58828	do	do	[3] .003	[4] .001
WJC-24-54	237547	do	Quartz-sanidine crystal tuff.	[5] .003	[6] .002
CS-26-55	237376	do	do	[1] .004	[7] .001
SO-11-52	73657	do	Porphyritic rhyolite	[3] .004	[8] .001
SC-15-55	B393	do	do	[1] .0022	[2] .0006
CS-30-55	237378	do	do	[1] .004	[7] .001
CS-38-55	237386	do	do	[1] .005	[7] .002
BH-20-52	58829	do	do	[3] .004	[4] .001
SC-13-55	B392	Younger	Vitric tuff	[1] .0066	[2] .0056
SC-6-54	222722	do	do	[9] .004	[10] .004
SC-7-54	222723	do	do	[9] .002	[10] .003
SC-14-54	237545	do	Obsidian	[5] .007	[6] .003
CS-27-55	237375	do	do	[1] .005	[7] .003
SO-10-52	73656	do	Rhyolite	[3] .003	[8] .001
CS-23-55	237701	do	do	[1] .005	[6] .003
CS-24-55	237702	do	do	[1] .009	[6] .006
WJC-124-55	237703	do	do	[1] .007	[6] .003
SC-15-54	222734	do	do	[11] .006	[12] .006
CS-25-55	237375	do	do	[1] .006	[7] .002
CS-31-55	237379	do	do	[1] .006	[7] .001
WJC-23-54	237546	do	Green glass	[5] .004	[6] .003
WJC-123-55	237387	do	do	[1] .005	[7] .002

[1] Radiologist, C. G. Angelo
[2] Analyst, H. H. Lipp
[3] Radiologist, S. P. Furman
[4] Analysts, Jesse Meadows and Wayne Mountjoy
[5] Radiologist, D. L. Schafer
[6] Analyst, R. P. Cox
[7] Analysts, R. P. Cox and M. T. Finch
[8] Analyst, Wayne Mountjoy
[9] Radiologist, B. A. McCall
[10] Analysts, L. B. Jenkins and Grafton Daniels
[11] Radiologist, Percy Moore
[12] Analyst, Roosevelt Moore

The average uranium analyses of all the volcanic rocks was 0.004 percent equivalent uranium and 0.002 percent uranium. These analyses were also grouped according to rock type and averaged (table 17). Many of the rock types are represented by too few specimens to give a good overall average, but nevertheless a significant difference is seen between rocks of the older and the younger volcanic groups.

Individually, rocks of the older volcanic group have a uranium content of 0.002 or lower; rocks of the younger volcanic group have a uranium content that ranges from 0.001 to 0.006. Hence, rocks with a uranium content of 0.003 percent or higher probably belong to the younger volcanic group.

TABLE 17.—*Average equivalent uranium and uranium contents of the volcanic rocks from the Thomas Range, Utah*

Rock group and type	Specimens analyzed	Equivalent uranium (percent)	Uranium (percent)
Older volcanic group	11	0.003	0.001
Rhyodacite	4	.002	.001
Quartz-sanidine crystal tuff	2	.004	.001
Porphyritic rhyolite	5	.004	.001
Younger volcanic group	14	.005	.003
Vitric tuff	3	.004	.004
Obsidian	2	.006	.003
Rhyolite	7	.006	.003
Green glass	2	.005	.003

A comparison of the uranium content of the volcanic rocks in the Thomas Range with that of similar rocks in other parts of the United States is difficult owing to the lack of sufficient reliable data. To obtain a general average, the authors compiled analyses of 64 samples of rhyolite and rhyolitic glass collected by R. R. Coats, of the U.S. Geological Survey, in Nevada, Oregon, Idaho, Wyoming, Montana, Washington, California, Arizona, Colorado, and Utah. The average of these rocks is not representative of the entire United States, and, because the samples do not represent proportionately the amount of volcanic rocks in each State, they are not truly representative of western United States. The 64 samples, however, were collected from 40 different counties, and the selection may be large enough and widely enough scattered to give a fair approximation of the average uranium content of the rhyolitic rocks in this region. The uranium content of these 64 samples ranges from 0.0002 to 0.0090 percent, and averages 0.0007 percent. This figure is nearly the same as the average we obtained for the rocks of the older volcanic group. The rocks of the younger volcanic group, with an average of 0.003 percent uranium, contain roughly three times as much uranium as the average rhyolitic rock in western United States. Concentrations of this magnitude are probably significant, and areas surrounding bodies of igneous rock with such a uranium content would seem favorable for seeking new ore deposits.

AGE OF THE VOLCANIC ROCKS

The age of the volcanic rocks determined from the overlying and underlying rocks ranges from Pleistocene to post-Middle Mississippian. The only fossils found in the volcanic rocks were petrified logs, which were not well enough preserved to date closer than post-Devonian.

The Larsen radioactive-decay method of determining age (Larsen, Keevil, and Harrison, 1952), however, indicated about 19 million years or middle Tertiary and probably Miocene according to Holmes, time scale B for a rock in the older volcanic group. The analysis was made by H. W. Jaffe, of the U.S. Geological Survey, on zircon recovered from two specimens of quartz-sanidine welded crystal tuff collected about 1,900 feet northwest of Colored Pass. Both specimens had an alpha activity of 552 α per mg per hr; one contained 4.3 ppm lead and the other 4.5. Average figure of 4.4 ppm lead was used in the age calculation.

The age of volcanic rocks elsewhere in west-central Utah has not been conclusively determined, except in the Long Ridge area west of Nephi where Muessig (1951, p. 234) found middle or late early Eocene plant fossils in limestone interbedded with volcanic rocks. At Gold Hill the volcanic rocks were tentatively assigned to the late Pliocene (Nolan, 1935, p. 53) on the basis of geomorphic evidence. Thus in a distance of about 100 miles, ages of volcanic rocks may range from Eocene through Pliocene; this range indicates that volcanism in western Utah probably occurred during most of the Tertiary.

The younger group of volcanic rocks in the Thomas Range has not yet been dated. Through indirect reasoning, however, it is possible to show that these rocks are probably Pliocene in age. Inasmuch as they overlie the older volcanic group of rocks, the younger volcanic group of rocks can not be older than Miocene, and because they are overlain by Lake Bonneville sediments, they can not be younger than Pleistocene. Three lines of evidence suggest there was a significant time interval between the emplacement of the older and younger groups. First, it is fairly certain that the younger group was emplaced after the major part of Basin and Range faulting tilted and uplifted the Paleozoic and older volcanic rocks; second, the younger group lies upon an irregular erosion surface cut on the older rocks; and third, an oxidized red conglomerate is present locally between the Paleozoic rocks and the base of the younger group. Thus, the younger lavas as a whole are flat-lying and are little disturbed by faulting, although structural features within the flows, such as flow banding, show steep and diverse dips; nowhere do the flows dip as steeply as the Paleozoic and older volcanic rocks. In some places the lavas extend across faults without evident displacement, as in the central part of the Dugway Range where the extensions of numerous southward-trending faults are not evident in the younger volcanic flows. In the southwestern part of the Dugway Range a reddish-brown conglomerate consisting chiefly of waterlaid sand, pebbles, and cobbles of the Paleozoic rocks, and a few pieces of rhyodacite apparently rests on Paleozoic rocks and is overlain by rhyolite. Its red color indicates a high state of oxidation, that suggests a period of weathering. This red conglomerate is believed to be a fanglomerate deposited during erosion after the major part of Basin and Range faulting and prior to extrusion of the younger rhyolites. The red color is present everywhere the conglomerate is exposed and did not result from Recent weathering. Van Houten (1956), who summarized the stratigraphy of Cenozoic sedimentary and volcanic rocks of Nevada and northwestern Utah, pointed out that in east-central Nevada and northwestern Utah a widespread fairly well dated (upper Miocene to lower and middle Pliocene) unit, which he called the "vitric tuff unit," is unconformably underlain by undated "reddish-brown and tan conglomerate and breccia containing pebbles and cobbles derived from Paleozoic rocks" (Van Houten, 1956, p. 2806). Although in most areas where they have been described these rocks are much thicker than the conglomerates in the Dugway Range, their lithology and stratigraphic position are similar.

If the foregoing conclusions are correct, we must allow time for some faulting and tilting and for a period of considerable erosion and weathering after eruption of the older volcanic group and before extrusion of the younger lavas. It seems reasonable to assume that the earliest date for deposition of the younger group of lavas is early Pliocene.

By similar reasoning, we may put an upper date on the younger rhyolite. As can be seen from plate 1, the top of the Thomas Range is a fairly flat, partly dissected upland, which appears in general to represent the top of the youngest flows. The upper surface of the rhyolite has a vesicular and locally glassy appearance over wide areas, and is the almost uneroded top of a flow. There has been some dissection of this surface, however, as shown by the isolated remnants of what may be the same uppermost flow; a small remnant is preserved near the center of the range north of Colored Pass, and a larger one in the north-central part of the range. Locally some deep valleys have been cut in the flanks of the rhyolite masses, but structural evidence indicates that these valleys are in the same general position as those formed before the latest flow and that they were probably only partly filled by earlier flows. Because the amount of erosion is slight to locally moderate, the length of time in which erosion took place was probably also moderate, and the youngest age for the younger lavas could reasonably be late Pliocene.

To suspend so many assumptions on one zircon age date is perhaps highly presumptive, but, lacking better evidence, the foregoing tentative conclusions are offered as the best currently available.

SUMMARY OF VOLCANIC HISTORY

Many areas of uncertainty in the volcanic history of the Thomas and Dugway Ranges have been pointed out in the detailed descriptions above. Despite these shortcomings, the following summary of the volcanic history may be deciphered from the known facts.

The first volcanic activity probably took place in early Miocene time, when rhyodacite and probably rhyodacite breccia and associated tuffs were intruded and deposited upon Paleozoic sedimentary rocks. At about the same time, or soon after, pyroclastic material was erupted from several vents along the east side of the Thomas Range. The Black Rock Hills were at least partly under water during this time, inasmuch as a rhyodacitic sandstone was deposited along the lower parts of the hills. This sandstone was deposited before all the rhyodacite was emplaced, because it is cut by a small rhyodacite dike.

After eruption of the rhyodacite, a series of rhyolitic volcanics were emplaced, probably in middle Miocene time. A number of different types of crystal tuffs, each related to one or more vents, were probably formed first, and they are scattered throughout this region. Most of these rocks were deposited subaerially, but sandstone was deposited locally in a small lake on the west site of the Thomas Range. Porphyritic rhyolite was then intruded into the Paleozoic sedimentary and older volcanic rocks. The upper parts of some of these rhyolite bodies reached the surface. Intrusive breccia probably was the last rock in the older volcanic group to be formed. The rocks of the older volcanic group were then uplifted, tilted, and eroded to a mature surface.

A second period of volcanism followed, probably in Pliocene time, during which successive sequences of eruption produced vitric tuff, breccia, and rhyolite in that order. This same succession was repeated five times; slight erosion occurred locally between deposition of some of these subgroups. The first two subgroups were erupted in the southern part of the Dugway Range; the later ones were more widespread and occurred mainly in the Thomas Range. In general the volcanism started in the north and shifted southward with time. The rhyolite flowed out from five major centers and a number of small ones. The northernmost major center was Pyramid Peak in the southern part of the Dugway Range, and the southernmost one was Topaz Mountain. The five main centers of eruption form a rough north-south line near the center of the Thomas and Dugway Ranges. During and following the rhyolite eruptions, green glass filled fissures or vents and remelted and assimilated wall rock. Hence, areas of green glass mark some of the numerous fissures which served as passageways for the molten lava.

The volcanic centers were repeatedly active during the eruption of the various subgroups, and some centers were the source of material for at least three separate subgroups. In most places the material which formed the pyroclastic rocks was thrown out of vents which probably lay on a line about 1 mile west of the volcanic centers from which the rhyolite issued. At Pyramid Peak, however, both rhyolite and pyroclastic sediments appear to have come from the same or closely adjoining vents.

ROCKS OF QUATERNARY AGE

LAKE BONNEVILLE BEDS

Distribution.—At the time of greatest extent of Pleistocene Lake Bonneville, about one-half of the area mapped was beneath water. Virtually all the intermontane area adjoining the Thomas and Dugway Ranges is underlain by poorly consolidated sediments deposited in this lake. The maximum elevation of these rocks is about 5,200 feet, the height of the highest or Bonneville shoreline as described by Gilbert (1890, p. 93–126). The Lake Bonneville beds (Gilbert, 1875, p. 94) are most conveniently described by placing them in three categories: (1) clay and marl, (2) sand and gravel, and (3) tufa and associated conglomerate.

Clay and marl beds occupy topographically low parts of basins and are best exposed (pl. 1) in the valleys between the eastern part of the Thomas Range and the Black Rock Hills, and in the valley of Pismire Wash between the Thomas and Dugway Ranges on the west and Keg Mountains on the east.

Sand and gravel deposited by Lake Bonneville are widely distributed; commonly, these deposits form shoreline features such as beaches, spits and bars. Gravel bars occur across the mouths of many valleys and canyons, and are well-exposed where they have been breached by erosion. A long bar lies across the valley between Antelope Ridge and the hill to the east; behind it is a small playa. The largest bar in this area is on the northwestern end of Spor Mountain, is semicircular in shape, about 50 feet high, and half a mile long. Gravel, sand, and conglomerate overlie the marls in many areas, but the coarse material is difficult to distinguish from later alluvium.

Tufa and tufa-cemented conglomerate are restricted to the shorelines of Lake Bonneville, chiefly at the outer edges of the 5,200-foot Bonneville and 4,800-foot Provo terraces. The tufa-cemented conglomerate is conspicuous on outcrops of Paleozoic rocks on the south side of Spor Mountain and on the east side of the Black Rock Hills.

Lithology.—Marl and clay deposits consist of white to yellow fine-grained soft clay of variable carbonate content with lenses of calcareous loosely cemented sand. These beds weather easily and typically crop out as low rounded hummocks. Analyses of three types of sand and marl are given in table 18.

TABLE 18.—*Insoluble-residue and mechanical-analysis data on samples of marl and calcareous sand deposited in Lake Bonneville*

	Sample		
	1	2	3
Sand median diameter .... millimeter..	0.18	0.08	....
Sand sorting coefficient	1.30	1.41	....
Soluble matter .... percent..	15.5	45.0	70.3
Sand .... do....	84.2	6.4	1.9
Clay and silt .... do....	.3	48.6	27.8

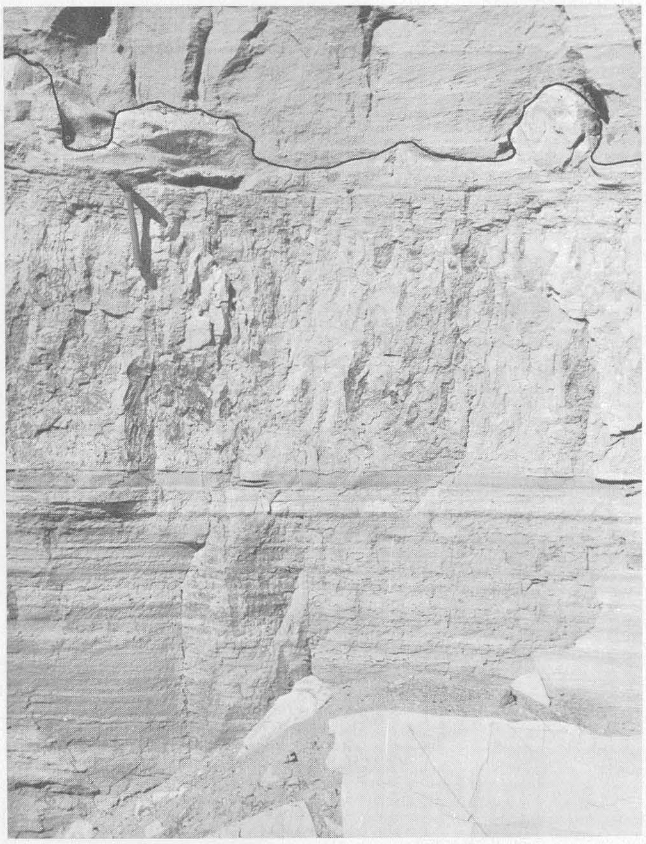


FIGURE 47.—Exposure of Lake Bonneville beds in cut bank of Pismire Wash, showing laminated and massive marls overlain unconformably (just above black line) by calcareous crossbedded sand.

The section from which the samples of table 18 were taken is shown in figure 47 and is described below.

Section of calcareous Lake Bonneville beds exposed in a cut bank of Pismire Wash, NW¼NE¼ sec. 31, T. 11 S., R. 10 W., Juab County, Utah

Sample	Lithology	Approximate thickness (feet)
	Surface of ground.	
	Recent(?) alluvium:	
	Sand, tan, loose, windblown	1.0
	Conglomerate, gray to brown, crossbedded..	3.0
	Unconformity.	
	Pleistocene, Lake Bonneville beds:	
	Sand, gray, limy, fine- to medium-grained, loosely cemented, crossbedded, well-sorted; contains a few thin lenses of pebbles and sandy marl	2.5
	Unconformity.	
	Marl, white, massive; contains calcareous shell fragments. Top of bed is eroded and channeled	0.5
	Marl, light-yellow, thin-bedded, laminated..	0.5
3....	Marl, limy, light-yellow, massive; contains a trace of fine sand	2.5

Section of calcareous Lake Bonneville beds exposed in a cut bank of Pismire Wash, NW¼NE¼ sec. 31, T. 11 S., R. 10 W., Juab County, Utah—Continued

Sample	Lithology	Approximate thickness (feet)
2	Marl, light yellow-brown, very fine grained, laminated; contains a few lenses of light-green clay and a little very fine to coarse-grained sand of quartz and rock fragments	4. 5
	Gravel, brown, iron-stained, loosely cemented; composed of pebbles in a sandy clay matrix	0. 1
1	Sand, gray, calcareous, fine-grained, incoherent, permeable; composed of subangular clear quartz grains in the finer sizes and of rounded limestone and quartzite and subordinate volcanic rock fragments in the coarser sizes; contains a few granules and pebbles	1. 5
	Base of exposure.	
	Total	16. 1

The marl beds locally contain abundant white fragile shells of a fresh-water gastropod, which was identified by D. W. Taylor as *Lymnaea bonnevillensis* Call. Several diatoms, identified by K. E. Lohman, were found in the fine fractions of sample 2 (table 18). The most abundant of these was *Suirella testudo* Ehrenberg. Other diatoms in this sample included *Epithemia turgida* Kützing, *Cymbella mexicana* (Ehrenberg) Cleve, and *Navicula oblonga* Kützing. According to Lohman, "* * * deposition in a shallow, cool to cold saline lake is indicated by these diatoms" (1956, written communication).

Sand and gravel beds deposited by Lake Bonneville are mostly incoherent and well sorted, and contain subangular to well-rounded sand- to boulder-size pieces of locally derived rocks. These beds make up the greater part of the exposures in the area mapped.

Well-indurated tufa-cemented conglomerate, a few inches to 4 feet thick, contains angular to rounded rock fragments. Tan massive tufa with only a few rock particles occurs locally; this rock is highly porous and has an extremely rough, irregular surface.

Terraces.—The three major shorelines of Lake Bonneville present in this area are the Bonneville, Provo, and Stansbury. Wave-cut terraces of the Bonneville or highest shoreline are well exposed on an isolated hill directly south of Spor Mountain and on the northwest extremity of the Dugway Range. The Provo shoreline terrace is conspicuous along the northwest sides of the Thomas and Dugway Ranges (fig. 48*B*) and in the Black Rock Hills.

The Stansbury shoreline terrace is exposed only at the northwest tip of the Dugway Range. It may be traced southwestward from this point as a strand line crossing the alluvium to the northern end of the Black Rock Hills.

Aerial photographs show a remarkable series of evenly spaced minor shorelines on the alluvial fans on the southwest flank of the Dugway Range. These features were probably caused by short stillstands of the lake during its recession from the Provo to the Stansbury.

ALLUVIUM

The valleys and flats in and around the Thomas and Dugway Ranges are covered with alluvium of Quaternary age. Below 5,200 feet the alluvium overlies the Lake Bonneville sediments, and it is difficult to distinguish between them. Alluvial fans composed of sand, gravel, and boulders washed down from the mountains are present but are not as well developed as in some other desert ranges. Alluvial cover extends up some of the valleys for long distances, as in Pismire Wash in the Thomas Range and in Fandangle Canyon in the Dugway Range. Talus and slope wash are common at the base of some of the rhyolite cliffs in the Thomas Range. Windblown sand and silt a few inches to several feet thick are present in some areas on the larger flats.

STRUCTURE

The Thomas and Dugway Ranges are part of a long uplift that includes Granite Mountain to the north and the Drum and Little Drum Mountains to the south. The individual ranges that make up this uplift trend northwest, whereas most of the other ranges in this part of the Great Basin trend north or north-northeast. The uplift is composed of segments containing Paleozoic and possibly Precambrian sedimentary rocks tilted to the west and northwest, granitic rocks of unknown age and structure (Granite Mountain), and flat-lying volcanic rocks of Tertiary age. The Paleozoic rocks are highly faulted; the volcanic rocks, particularly the younger group, are for the most part unfaulted. Folding, though present, is of minor importance.

Four general episodes in the structural history are recognized: (1) an early period or periods of compression that formed thrust faults, possibly a few transverse faults, and gentle minor folds, (2) a period in which hundreds of diversely oriented transverse and strike faults were formed, (3) a period in which the mountains were elevated and tilted by Basin and Range faults, and (4) a later period during which eruption of the major part of the volcanic rocks, followed by minor faulting, took place. These periods overlapped to some extent, and renewed movement probably occurred on some faults. The following description of structural features is based on the above episodes.

COMPRESSIONAL FEATURES

At least one and possibly several periods of compression are recorded in the Thomas and Dugway Ranges by thrust faults and minor folds. These structures are displaced by younger faults.

The average strike of the sedimentary rocks in the area mapped is almost north, but varies between about N. 35° E. on Spor Mountain and about N. 20° W. in the northern part of the Dugway Range. The average dip is about 35° but ranges from about 10° to 65°. It is westerly, except in a few areas. Rock attitudes that do not conform to the regional pattern are commonly due to rotation of fault blocks or to drag along faults.

The only large-scale fold in the Thomas or Dugway Ranges is a gentle syncline whose axis trends from east to northeast along Buckhorn Canyon in the northeastern part of the Dugway Range (pl. 1). This fold plunges about 15° W., and the dips range from about 15° near the axis to about 40° on the south limb. It is terminated on the west by the Buckhorn thrust fault. South of the mouth of Gilson Canyon, beds of the Sevy dolomite and Engelmann formation strike more eastward and dip northward as they approach the Buckhorn thrust (pl. 1). This fold is due to large-scale lateral drag on the thrust fault.

Gentle folds, characterized by low dips and variable strikes, are present in the southern Black Rock Hills and on the west side of the Dugway Range, but no distinct pattern could be distinguished in these areas.

Minor folds less than 200 feet across are fairly common in the thin-bedded parts of the Trailer limestone, Woodman formation, and Garden City formation. A few folds of this type are present southwest of the head of Bullion Canyon.

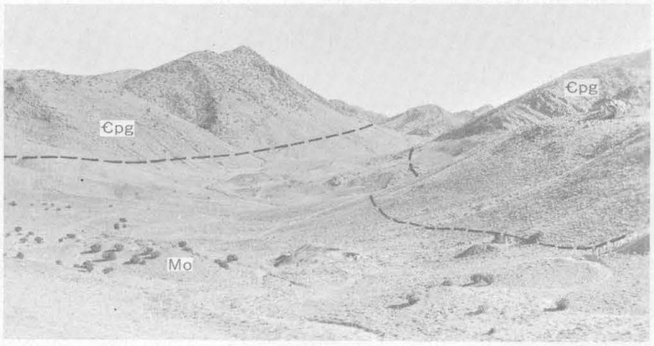
One large and four very small thrust faults have been mapped in the Dugway and Thomas Ranges; a few other faults whose traces are sinuous may also be thrusts. In general these faults dip steeply, as much as 58° in places.

The largest thrust fault is named the Buckhorn from exposures near the head of Buckhorn Canyon (pl. 1, 6). It extends about 6.5 miles northwestward from Fandangle Canyon to a point about 1.5 miles northwest of the Four Metals mine, where it disappears beneath the alluvium near the north end of the Dugway Range. In addition, the Buckhorn thrust fault probably extends southward for at least 3 miles along the west side of Fandangle Canyon.

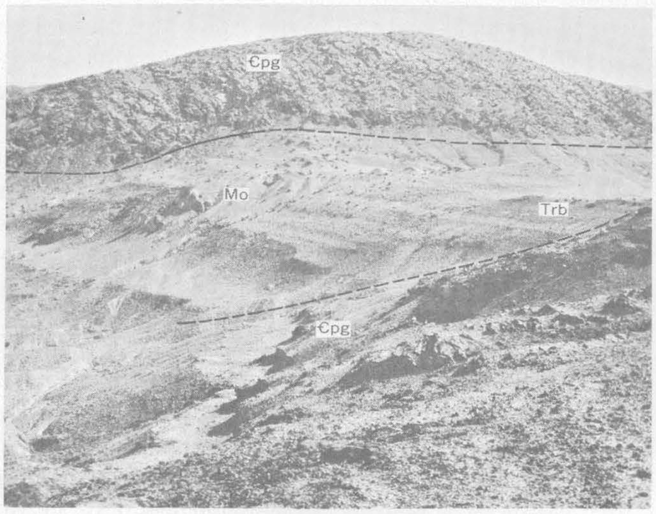
Northwest of Fandangle Canyon the Buckhorn thrust dips northeast and brings Devonian and Mississippian rocks over Cambrian rocks. Along the west side of Fandangle Canyon the fault dips east and brings Ordovician and Silurian rocks over Cambrian rocks. Only three good exposures of the thrust plane are known. One is at Engelmann Canyon where the Engelmann formation is thrust over the Fandangle limestone and the fault dips 47° NE. Another is on the west side of Fandangle Canyon where silicified Paleozoic rocks rest on the Fandangle limestone and the thrust dips 58° E. The best exposure is about 5,500 feet N. 64° W. of the Four Metals mine in a small ravine north of the mapped area, where limestone, probably the Madison equivalent, is thrust over the Prospect Mountain quartzite; here the fault dips 20° N.E., and slickensides on the underlying quartzite plunge about 20° N. 50° E. A dip of 34° E. was measured on the map at the point where the fault crosses the divide between Fandangle Canyon and Green Grass Valley.

Parts of the thrust plane are poorly exposed and are masked by silicified rock in down-faulted segments in the Bertha trough (section *A–A′*, pl. 2). In Kellys Hole the thrust plane is also down-faulted on normal faults along the sides of this graben (fig. 48), and lies below the surface. A small remnant of dolomite of probable Mississippian age occurs north of the mapped area high on the side of the ridge of Prospect Mountain quartzite 2,000 feet northwest of the Black Maria shaft. This dolomite is apparently an erosional remnant of the upper plate of the thrust that has been preserved by down faulting.

In the Kellys Hole area the Buckhorn thrust fault brings the Ochre Mountain limestone (Upper Mississippian) over the Prospect Mountain quartzite (Lower Cambrian); this overthrusting results in the omission of at least 15,000 feet of beds. The total thickness of the beds omitted, however, may be several thousand feet greater, inasmuch as an unknown thickness of the Prospect Mountain quartzite is cut out. In the Kellys Hole area, the fault is probably near the base of the Ochre Mountain limestone, but eastward it cuts downward through the Woodman formation, Madison limestone equivalent, and probably the formations of Late Devonian age (section *A–A′*, pl. 2). The dip of these beds in the upper plate flattens as the thrust plane is approached, and in some places the beds are nearly parallel with the plane. This feature is well exposed in the area between Fandangle and Engelmann Canyons (pl. 1). Near the head of Fandangle Canyon the stratigraphic displacement is about 5,000 feet; in



A



B

FIGURE 48.—Kellys Hole graben. *A*, Kellys Hole viewed from the northwest rim. Ridges on either side are Prospect Mountain quartzite (Ꞓpq) of Early Cambrian age; outcrops on the valley floor are Ochre Mountain limestone (Mo) of Late Mississippian age. The Buckhorn thrust fault, which in this area brings Upper Mississippian rocks over Lower Cambrian rocks, is down-faulted along the faults shown and lies beneath the floor of the valley. The three sets of workings on the Metal States property are visible at lower right. *B*, View of north side of northwest rim of Kellys Hole showing the fault (extension of Castle Mountain fault) along the east side of Kellys Hole. Ridge on skyline and rocks in foreground are Prospect Mountain quartzite (Ꞓpq); block in center is Ochre Mountain limestone (Mo). Note well developed Provo terrace of Lake Bonneville in left center of view and outcrops of rhyodacite breccia (Trb) overlying Ochre Mountain limestone at right center of view.

that area the Ordovician Garden City formation is thrust over the Cambrian Fandangle limestone.

Although the true nature of the Buckhorn fault is by no means clear, the available evidence appears to favor a thrust. At least two possibilities may be considered, however: (1) that it is a thrust of moderate dip as shown on plate 2, sections *A–A′*, *B–B′*, and *C–C′*, or (2) that it is a low-angle normal fault.

Features that suggest that the Buckhorn fault is a thrust are (1) a moderately low dip which in one place is 20°, (2) the large stratigraphic displacement, particularly in the northern part of the fault, where the minimum displacement is estimated at 15,000 feet, (3) the presence at the surface in the Bertha and Kellys Hole grabens of rocks of the same age, and (4) the necessity of having a heave of at least 30,000 feet (assuming an average dip of the fault of 30°) if the fault is normal. On the other hand, the obviously lower elevation east of the fault of the younger rocks relative to the older suggests that it could be a low-angle normal fault.

The folds in the hanging wall of the Buckhorn fault may have been produced by a period of strike-slip movement in which the east side of the fault moved relatively southeastward as a result of compression from the northwest. Such compression could also account for the Buckhorn syncline.

All the other faults mapped as thrusts are in the Spor Mountain area (pl. 1 and 6). One is near the northwest end of Spor Mountain, two others are exposed on the west side of Eagle Rock Ridge, and one is at the south end of Spor Mountain. These faults dip westward and have a dip-slip movement of less than 1,000 feet; at the surface they are confined to rocks of Silurian age.

The hanging-wall side of the Buckhorn thrust, which includes the eastern and northeastern parts of the Dugway Range, is much less faulted than the footwall side. Similarly, the Black Rock Hills contain few faults compared to Spor Mountain. This sudden change in pattern in fault density has raised the possibility of a thrust separating these two areas and trending northward along the west side of the Dugway Range. No evidence for this fault other than the change in fault densities is known, but, because this area is thickly mantled with Lake Bonneville sediments, additional evidence would undoubtedly be hidden. If such a thrust fault exists, it might possibly be a down-faulted segment of the Buckhorn thrust.

South and east of Kellys Hole are northeast-trending transverse faults that separate the Prospect Mountain quartzite from the Cambrian and Ordovician carbonate rocks. The irregular traces of these faults and one recorded dip of 43° SE. suggest that they may be steep thrust planes. It is also possible that they are strike-slip faults produced by the same period of compression that caused the Buckhorn thrust fault. Some of the other transverse northeast-trending faults in the central Dugway Range may also be related to early compression.

Compressional features of the Thomas and Dugway Ranges have no consistent orientation, and therefore do not suggest a simple stress pattern. The trends of the two largest structures, the Buckhorn syncline and thrust fault, are nearly at right angles.

Thrust faults on Spor Mountain dip in the opposite direction from the Buckhorn thrust. The possible transverse thrust or strike-slip faults south of Kellys Hole are parallel to the Buckhorn syncline, but they are nearly at right angles to the Buckhorn thrust. The inconsistent orientation of these structures suggests compression in several directions at different times.

TRANSVERSE AND STRIKE FAULTS

Hundreds of steep transverse and strike faults cut the Paleozoic rocks in the Thomas and Dugway Ranges. Even though these faults are all discussed together, the possibility that some of them are related to the previous compressional episode should be kept in mind. For convenience in discussion, the area has been divided into blocks (pl. 6), which, though arbitrary to some extent, encompass areas having somewhat different fault patterns. The blocks are bounded in most places by major faults, principally of the Basin and Range type, which are discussed on page 126. In addition, the large area of volcanic rocks is considered as a separate block inasmuch as it is comparatively little disturbed by faulting; however, it is probably underlain by highly faulted Paleozoic rocks. The structure of the volcanic rocks is discussed on page 128.

Considering the area as a whole, several aspects of the transverse and strike faults are evident (pl. 1): First, coincidentally or not, these faults are most numerous in rocks of Silurian and Middle and Late Ordovician age in the Spor Mountain and Castle Mountain blocks; and although there are hundreds of faults in these two areas, most of them have displacements of less than 500 feet (pl. 2). Second, it is equally apparent that nearby areas such as the northern parts of the Dugway Ridge and Black Rock Hills blocks and the eastern part of the Buckhorn block are comparatively unfaulted. Third, strike faults occur mainly in the Spor Mountain block. Fourth, the transverse faults show no consistent regional trend or offset pattern between one block and the next. Fifth, transverse and strike faults offset the large faults that bound the blocks in only a few places.

The first of the foregoing general statements should be qualified to some extent. In part, the concentration of faults in Upper Ordovician and Silurian rocks is only apparent, because formations of this age are comparatively thin and small faults are more readily discerned. In addition, large areas of Cambrian and Lower Ordovician rocks in the north-central Dugway Range are dolomitized; hence, recognition of faults and formations is more difficult. Rocks of Devonian and Early Mississippian age, however, have not been extensively dolomitized, and faults are scarce in rocks of this age.

The foregoing observations suggest that each structural block of the Thomas and Dugway Ranges has acted more or less independently during the formation of the transverse and strike faults and that lines of weakness that later guided many of the faults that bound the blocks existed for some time before the main movement occurred along them.

SPOR MOUNTAIN BLOCK

Details of the structure of the Spor Mountain area have been described elsewhere (Staatz and Osterwald, 1959, p. 42–45), and only a summary of the important features is included here.

The Spor Mountain block, which includes the area of Spor Mountain, Eagle Rock Ridge, and the low hills to the south and west (pl. 6) is the most highly faulted of the eight blocks; nearly 1,000 faults were mapped (Staatz and Osterwald, 1959, pl. 1), but only the more important of these are shown on plate 1. Displacement along these faults is generally moderate, and only a few have a displacement of as much as 1,000 feet. Northeast-trending strike faults form the dominant structural feature of the Spor Mountain block, and, together with faults of several other trends, result in a mosaic outcrop pattern (pl. 1) resembling shattered glass.

The sequence of sedimentary rocks on Spor Mountain is repeated (pl. 2, *E–E′*, fig. 49) many times by the strike faults. The Harrisite dolomite, for example, is repeated 11 times in less than 4 miles.

The transverse and strike faults in the Spor Mountain block have been grouped in three sets (Staatz and Osterwald, 1959, p. 43–44) from older to younger: (1) northeast-trending normal and reverse strike faults, with moderate dip, (2) northwest-trending transverse faults, mostly high angle, and (3) east-trending transverse faults. The first two fault sets are prevolcanic, but some faults of the last set cut and displace rocks belonging to the older volcanic group. Bodies of intrusive breccia are common along the northeast-trending strike faults in this area (fig. 49).

BLACK ROCK HILLS BLOCK

The Black Rock Hills and the low hills to the southeast make up a structural block composed of Upper Devonian rocks.

The Black Rock Hills show the same scarcity of transverse faults as the western part of the Spor Mountain block. The rocks north of Goshoot Canyon strike north and dip about 20° W. and are un-

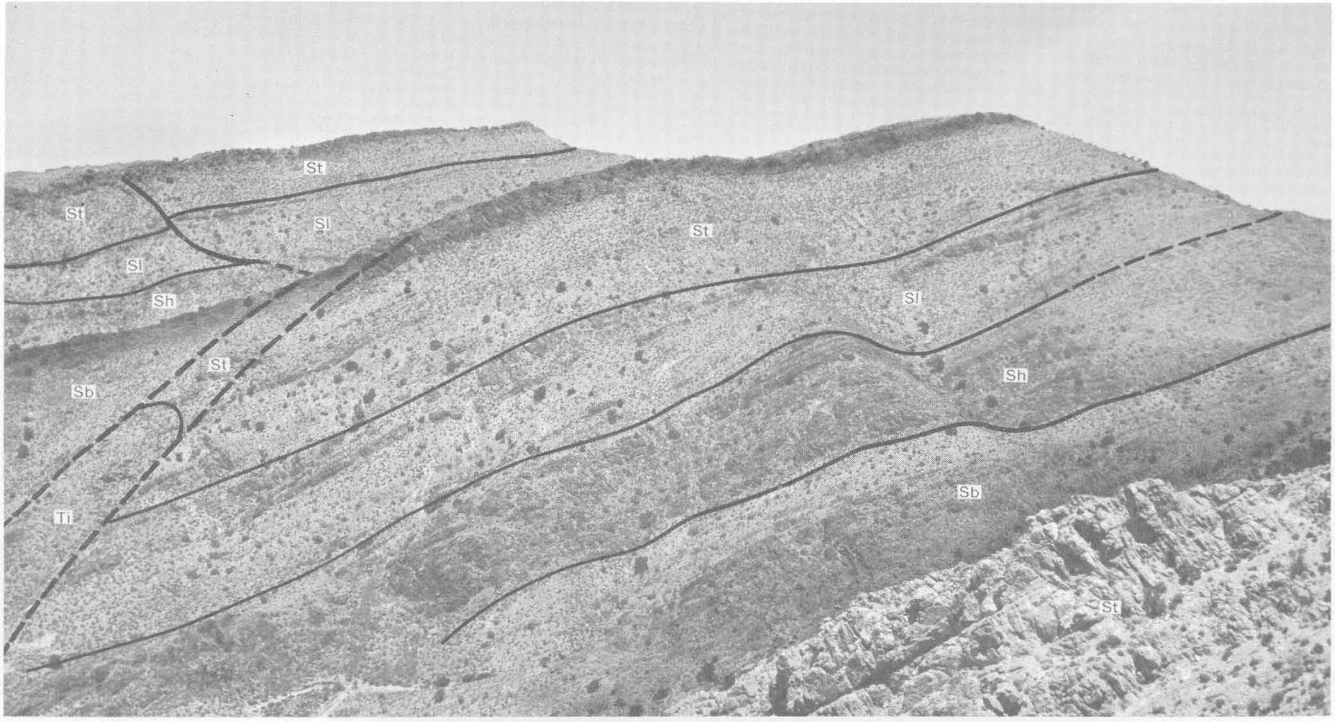


FIGURE 49.—Repetition of section along northeast-trending faults in the northern part of Spor Mountain. Note intrusive breccia (Ti) along faults at lower left. Sb, Bell Hill dolomite, Sh, Harrisite dolomite, Sl, Lost Sheep dolomite, St, Thursday dolomite.

broken except for one east-trending fault of moderate displacement. Strikes and dips south of Goshoot Canyon average N. 81° W. and 15° S., respectively, but the strikes vary from west through north to northeast and the dips from 6° to 20° south and west. Rocks in the southern Black Rock Hills are cut by several west- or northwest-trending faults of small displacement and steep to moderate southerly dip. Repetition of beds in the southeastern Black Rock Hills suggests the presence of a northeast-trending fault with moderate throw under the alluvium between the hills.

CASTLE MOUNTAIN BLOCK

The large Castle Mountain block occupies the west-central part of the Dugway Range; it is bounded by the volcanic rocks on the south, upper Fandangle Canyon on the east, the Buckhorn thrust fault on the northeast, transverse faults south of Kellys Hole on the northwest, and the range front on the southwest. Rocks of Cambrian through Silurian age occupy most of this block, but Devonian rocks crop out on low hills in the northwest corner. The prevailing strike of beds is north, but northwest and northeast strikes are found in some areas. The average dip is about 35° W.

The Castle Mountain block is complexly faulted, and parts of it show a pattern like that of the Spor Mountain block, though strike faults are less common. Faults are difficult to trace in many parts of the block because there are large areas of nondistinctive dolomitized rock, or rather uniform carbonate rock, as in the Garden City formation and Fandangle limestone. As shown by sections *B–B′* and *C–C′* (pl. 2), the block consists of several smaller blocks bounded by large normal faults. Within these smaller blocks are many normal faults, and a few reverse faults whose combined effect is to repeat the Ordovician and Silurian rocks. This pattern is most evident just northwest of the north edge of the volcanic rocks and 1.5 miles west of Castle Mountain.

Most of the faults in the block strike northeast, north, or northwest, though some do not fit into any of the above sets. No consistent pattern of offset is apparent, but in general the northwest-trending set is the youngest, and the large faults of this group are part of the younger Basin and Range fault system discussed on page 126. Most of the faults within the block are normal and dip between 55° and 80°.

Faults of the sparsely developed northeast-trending set are in general the oldest and show the smallest displacement, although there are many exceptions; commonly they die out in short distances or are terminated or offset by the other faults. Such relations are well shown in the area about 1.5 miles west-southwest of Castle Mountain where a small northeast-trending fault separates the Harrisite and Bell Hill dolomites. It is offset twice by small northwest-trending faults and is terminated by a north-trending fault. Northeast-trending faults that die out within several hundred yards can be seen on a ridge about 0.7 mile southwest of peak 6775 (pl. 1) near the south end of the block, where they displace the contact between the Thursday and Lost Sheep dolomites.

Most of the north-trending faults have displacements of several hundred feet or more. In general they are persistent steep normal west-dipping faults that commonly end only against the major northwest-trending faults (pl. 1 and 2). This group of faults most nearly approaches the strike of the sedimentary rocks and is mainly responsible for the repetition of formations in areas such as those at the south end of the Castle Mountain block on both sides of the narrow capping of rhyolite that marks the northern end of the rhyolite flows. Other groups of faults belonging to the north-trending set are seen on Castle Mountain, to the west of Castle Mountain, and in the area south of the head of Bullion Canyon.

Northwest-trending faults are the most conspicuous in the block and in many places are the youngest, because they commonly offset faults of the other two groups. The most important ones are of the Basin and Range type (p. 126). Many smaller faults of northwest trend are present throughout the block, but are most numerous in the Silurian and Ordovician rocks in the areas 1.5 miles west and 1 mile southwest of Castle Mountain. A few small faults of northwest trend split from, or terminate against, north-trending faults.

Several important faults in the block are difficult to assign to any of the three sets because they curve, or because their strike is intermediate between the three principal directions. One such fault cuts diagonally across the block from the west edge of the range south of Castle Mountain northwestward and north to the Buckhorn thrust fault at a point about 1.5 miles northwest of the head of Engelmann Canyon. South and west of Castle Mountain this fault separates Silurian from Lower Ordovician rocks in most places; northwest of Castle Mountain Cambrian rocks occur on both sides of it; it is probably a high-angle reverse fault (section *B–B′*, pl. 2), but exposures of the fault plane are poor. Another important fault of this type separates Ordovician and Silurian rocks from Cambrian rocks in the southern part of the block. It begins near the west edge of the range about 0.8 mile southwest of peak 6,775 and is traceable in a northeasterly direction nearly to Fandangle Canyon with numerous offsets on northwest- and north-trending faults.

Two isolated slivers of Garden City formation, 2,000 to 2,500 feet long and a few feet to 250 feet wide, are enclosed by branching faults in the southern part of the block. One sliver lies 600 feet west of peak 6,401 and 1.2 miles southeast of Castle Mountain, the other lies 3,000 feet west of peak 6,775. The faults bounding these slices dip eastward, appear to be normal and almost parallel, and show opposite relative movement (section *C–C′*, pl. 2), but one fault is of larger displacement than the other.

DUGWAY RIDGE BLOCK

The Dugway Ridge block, which extends along the east side of the Dugway Range from the Fandangle fault southward to the knolls southeast of Dugway Pass (pl. 6), is one of the least faulted of the structural blocks. For this reason and because of the steepness of its eastern escarpment, it contains some of the best exposures in the Thomas and Dugway Ranges. The beds strike north throughout the block, and dip from about 45° W. in the northern part to about 35° W. in the southern part. Most of the faults, which increase slightly in number to the south, are steep normal faults transverse to the strike of the beds and to Dugway Ridge. A few low-angle normal faults, some of which are strike faults, occur in the southern part of the block. Many of the small faults die out within a few hundred feet.

One of the largest faults in the block is 1,500 feet south of Dugway Pass; it trends nearly west and dips 65° S. It offsets the Cambrian rocks and also cuts and displaces the volcanic rocks of the younger group. This fault is paralleled in Dugway Pass by a smaller fault that offsets Cambrian formations about 1,000 feet. Other similar faults of smaller displacement are present in the vicinity of Shadscale Canyon, Trailer Wash, and Fera Canyon. Most of these dip moderately to steeply northward. The northwest-trending oblique fault in Straight Canyon is believed to be part of the Basin and Range fault system; it is discussed on page 126. A northwest-trending fault about a mile north of Fera Canyon slices through the Fandangle formation and ends against the large Fandangle fault. The concentration of small faults in the Fish Haven dolomite and Swan Peak formation near the northwest corner of the block may be a result of adjustments to the change in strike of the Buckhorn thrust.

FANDANGLE BLOCK

The Fandangle block, which consists entirely of Prospect Mountain quartzite, appears to have a structural pattern similar to that of the Dugway Ridge block, but faults are somewhat more numerous. It is bounded on the southwest by the large Fandangle fault (pl. 6) and on all other sides by alluvium. The combination of poor exposures of shale units, the lenslike character of both shale and quartzite units, and a thick uniform upper quartzite unit made tracing of faults difficult. The strike of beds is north and the dip is about 45° W.

All the faults mapped are transverse or oblique to the beds. The largest is the one that is inferred to separate units of the Prospect Mountain quartzite on the mountain to the north from dissimilar units of the Prospect Mountain on the large hill to the south. Another fault with a horizontal displacement of about 2,000 feet is near the south edge of the main mountain. A down-faulted wedge of quartzite lies between two east-trending faults that apparently meet just east of the center of the block. These two faults and others in this area decrease in throw abruptly along strike, as do some of the faults in the previously described Dugway Ridge block.

Numerous fractures or joints are present in the quartzite in this area. On the large hill to the south of the main mountain, the joints strike northwest and dip steeply northeast.

BUCKHORN BLOCK

The Buckhorn block includes the area northeast of the main trace of the Buckhorn thrust fault and west of the northern part of Fandangle Canyon (pl. 6). Paleozoic rocks exposed in this block are Devonian and Mississippian in age, except for a small outcrop of Silurian rocks west of the mouth of Fandangle Canyon.

The beds dip 25° to 35° W. in much of the block, but near the Buckhorn thrust and along the Buckhorn syncline the strike and dip are variable.

Compared to the Fandangle block, dips of the rocks in the Buckhorn are lower, and faults, though less numerous, are more diversely oriented. In number and pattern of faults the Buckhorn is most like the Black Rock Hills block.

The southeastern part of the block has only a few small normal faults that strike northwest, dip 55° to 75° E., and have displacements of about 150 feet or less. The Engelmann fault, which is discussed on page 126, dies out near the middle of the block; to the north of Engelmann Canyon it splits into several small breaks that produce many fault slivers of the Goshoot and Gilson formations.

A northeast-trending fault that dips steeply southeast and offsets the formations about 500 feet extends from Bullion Canyon across Hanauer Ridge (section *A–A′*, pl. 2). It probably continues southwestward under alluvium in Bullion Canyon, where it appears to offset the Buckhorn thrust fault at least 1,000 feet.

A zone of poorly exposed northwest-trending faults in the Bullion Canyon area results in numerous wedges of Upper Devonian and Mississippian rocks. Some of these faults are probably reverse faults (section *A–A′*, pl. 2).

KELLYS HOLE BLOCK

The Kellys Hole block is in the northwest corner of the Dugway Range, west of the main trace of the Buckhorn thrust and north of transverse faults south of Kellys Hole (pl. 6). Except for small patches of the Cabin shale, Busby quartzite, and Shadscale formation in the southwest corner, the Paleozoic rocks exposed consist of the Prospect Mountain quartzite, Ochre Mountain limestone, and Woodman formation. The strike of the rocks averages N. 20° W., and the dip 35° SW, but attitudes vary. Faulting in this block has little or no similarity to the adjoining Buckhorn or Castle Mountain blocks.

Most of the transverse and strike faults mapped in this block are in the Mississippian rocks exposed in the Kellys Hole and Bertha trough areas. The majority of them strike northwest. In the Bertha trough they cut the Woodman formation and Ochre Mountain limestone into many small slivers (pl. 1). These faults, together with several that trend northeast, offset the Buckhorn thrust fault and expose it in several isolated segments (section *A–A′*, pl. 2).

Another group of transverse faults cuts the Prospect Mountain quartzite in the southwest corner of the Kellys Hole block. These have small displacements generally of less than 100 feet and diverse trends; they result in a mosaic outcrop pattern of shale and quartzite units. About 0.5 mile southwest of this area the same type of fault pattern occurs in Busby quartzite and Shadscale formation.

Only a few other faults were mapped in the Prospect Mountain quartzite in this block, but doubtless more are present. A system of faults of unknown displacement occurs north of Cannon Canyon. These all trend north to northeast, and in places have moderate to low dips to the east. South of Cannon Canyon a steep northeast-trending fault cuts across the quartzite from Kellys Hole to the west edge of the range. Like the other faults in quartzite, its displacement could not be determined.

BASIN AND RANGE FAULTS

Faults of the Basin and Range type were formed during the third structural episode in the Thomas and Dugway Ranges and include most of the large faults in the area. Elevation of the mountains resulted from uplift on many of these faults, which in most places form the boundaries between the structural blocks, as previously described.

Faults discussed here generally have the following features in common: (1) they are major persistent structural breaks with displacements amounting to more than 300 feet; (2) they are normal faults; (3) they trend either north or N. 45°–65° W.; (4) they terminate virtually all other structures; (5) they have good topographic expression; and (6) they divide parts of the ranges into large tilted blocks.

All the major Basin and Range faults, both exposed and inferred, are shown on plate 6. Some of the larger ones have been named. The main faults are readily divided into those that trend within a few degrees of north, and those that trend N. 45°–65° W.

The north-trending group is exposed principally in two areas—the eastern part of the Dugway Range and the eastern side of Spor Mountain. Actual exposures of the north-trending faults are rare, and some are partly inferred from topography.

The east face of the Dugway Range is an escarpment that extends in a fairly straight line for about 6 miles. The Paleozoic rocks are tilted about 40° W. No large faults are exposed at the base of the escarpment, but several small faults with a north trend have been mapped near Straight Canyon and Trailer Wash. Repetition of outcrops of Prospect Mountain quartzite, Cabin Shale, and Busby quartzite near Trailer Wash indicate the presence of additional north-striking faults. The major fault in this group is probably located to the east beneath the alluvium, and may be close to Dugway-Topaz Well, which produces hot water. (See p. 5). It is also possible that the Fandangle fault may curve to a more southerly strike and pass close to this well. Other north-trending faults in the eastern Dugway Range are probably present beneath the alluvium in Fandangle Canyon.

Faults with a north trend have been mapped on either side of Eagle Rock Ridge on the east side of Spor Mountain. At least one of the two faults continues southward to Searle Canyon, where it is either offset or bends southeastward. The best exposure of the easternmost fault is along the east side of Eagle Rock Ridge where volcanic rocks of Tertiary age are faulted against Silurian rocks. A dip of 48° E. was observed at one place on this fault; plunge of striations indicates that the last movement was nearly dip slip. West of the south end of Eagle Rock Ridge near the foot of Spor Mountain a dip of 66° E. was recorded on another north-trending fault.

Unlike the north-trending faults in the Dugway Range, which closely parallel the strike of the sedimentary rocks, the fault between Eagle Rock Ridge and Spor Mountain truncates the sedimentary rocks at angles of as much as 45°. It should also be noted that this fault is offset by an east-trending fault near the south end of Eagle Rock Ridge.

The other main group of Basin and Range faults, the northwest-trending set, includes some of the largest faults in the Thomas and Dugway Ranges. Most of the northwest-trending faults are in the northern and western parts of the Dugway Range. They will be discussed in the order in which they appear from northeast to southwest.

One of the largest of the faults is the Fandangle. It is not exposed, but must have a stratigraphic throw of at least 9,000 feet (section *B–B′*, pl. 2) and probably has much more, because the Prospect Mountain quartzite is brought opposite rocks of Silurian age on the east side of Fandangle Canyon. Johnson and Cook (1957, p. 59) found a large gravity anomaly near the southeastward projection of this fault, and they also reported a large anomaly along the northeast side of the Dugway Range north of the mapped area. It thus appears that the Fandangle fault may extend from the north tip of the range south-eastward at least 11 miles.

The next important fault of northwest trend follows Straight Canyon and crosses Dugway Ridge to Fandangle Canyon, and may not properly belong to the Basin and Range system. It is included here because it parallels the Fandangle fault and others in this area. It apparently ends against the Buckhorn thrust fault in upper Fandangle Canyon, but its actual termination is obscure. In places it is a high-angle reverse fault (section *C–C′*, pl. 2); a dip of 83° NE., was measured at the head of Straight Canyon. In the bottom of Straight Canyon the Cambrian formations are offset about 300 feet.

Southwest of Fandangle Canyon is the Engelmann fault, which can be traced for nearly 6 miles from the head of Green Grass Valley northward for about 1.5 miles, and thence northwestward across Engelmann Canyon nearly to Buckhorn Canyon, where it dies out. It dips westward 60 to 80°. Near the south end the throw is a little more than 1,000 feet (section *C–C′*, pl. 2); in that area it results in the omission of the upper part of the Lamb dolomite and most of the Straight Canyon formation. Farther north the displacement decreases to about 500 feet (section *B–B′*, pl. 2). In Engelmann Canyon, the Engelmann fault offsets the Buckhorn thrust fault about 500 feet. North of this point the Engelmann fault splits for a short distance into a zone consisting of several small faults, some of which dip moderately to the northeast. After curving to a more westerly trend, it dies out in the Madison limestone equivalent about a mile northwest of the branching fault zone. The Engelmann fault shows particularly well the tendency of some of these northwest-striking faults to swing to a more southerly trend as they are followed southward, in harmony with the outline of the Dugway Range. The area in which the change of strike occurs, upper Fandangle Canyon, is broken by many faults, some of which may represent adjustment of the rocks to this change in strike.

The next northwest-trending Basin and Range faults are those that bound the Bertha trough between Kellys Hole and the Four Metals mine. These faults are poorly exposed on either side of this trough for a distance of about a mile. They converge southward and join just southeast of the Bertha mine. A dip of 68° NE. was noted at one place on the more westerly of the two faults. The two faults probably dip toward each other and form a graben of down-faulted Mississippian rocks between ridges of Prospect Mountain quartzite. The displacement on these faults cannot be accurately measured. Toward the south it is at least 600 feet, inasmuch as the Buckhorn thrust fault, which is downfaulted into the graben, must have been dropped at least the height of the adjacent ridges of Prospect Mountain quartzite.

The longest structural feature mapped in the northern Dugways is the Castle Mountain fault. It begins near the northern limit of the volcanic rocks in the west-central part of the Dugway Range and extends northwestward nearly 8 miles, past Castle Mountain, through Kellys Hole, and northward under the alluvium. It dips westward from about 40° to 80° (sections *A–A* and *B–B′*, pl. 2). Southeast of Castle Mountain it closely parallels the Engelmann fault, and it, or a branch of it, probably continues southward beneath the capping of rhyolite and talus south of peak 6,775. The Castle Mountain fault offsets Cambrian formations only about 500 feet near its south end, but its throw increases northward. On Castle Mountain it is offset about 1,000 feet on several northeast-trending faults, and in this area also it splits into several subparallel branches with moderate throw. Northwest of Castle Mountain, it brings the Lamb dolomite against the Garden City formation, and just southeast of Kellys Hole the Garden City formation is opposite the Fandangle limestone; this offset indicates a stratigraphic throw of at least 3,500 feet. The Castle Mountain fault is well exposed at the extreme south end of Kellys Hole in a small prospect pit a few feet east of the jeep trail, where it dips 41° SW. Northwest of this prospect the Castle Mountain fault apparently splits to form the Kellys Hole graben; one northeast-dipping branch follows the west side of Kellys Hole, and the main Castle Mountain fault continues along the east side of the valley. This graben is about 9,000 feet long and 1,800 feet wide at its widest point. As in the Bertha graben to the east, exposures are poor and the fault planes are nearly everywhere buried beneath quartzite talus. One dip of 76° to the southwest was measured on the Castle Mountain fault near the north end of Kellys Hole. The minimum displacement on the faults bounding the graben is estimated to be about 1,000 feet; the faults converge and probably meet at a point in the Prospect Mountain quartzite about 1,000 feet below the center of the bottom of Kellys Hole (section *A–A′*, pl. 2).

The next important northwest-trending fault displaces the Dugway Ridge dolomite and the Garden City and Swan Peak formations about a mile south of Castle Mountain. This fault begins at the west edge of the Dugway Range where it dips 60°–70° SW. One mile south of Castle Mountain it splits into a fault zone much like the northern part of the Engelmann fault in which some of the smaller faults dip to the northeast. In this area these faults cut at nearly right angles to the strike of the rocks.

The westernmost major Basin and Range fault of northwest trend lies along the western margin of the Dugway Range. It is well exposed for only about 0.8 mile along the foot of the mountains about 2 miles west-southwest of Castle Mountain. Here it coincides closely in many places with the contact between alluvium and the rocks of the mountain front (section *B–B′*, pl. 2). The fault can be projected both northwest and southeast from this area, although except at two points it is concealed beneath alluvium. Near the most northerly point of observation it brings the Goshoot formation down against the Thursday dolomite, a displacement of about 4,000 feet. This fault is offset several hundred feet at least twice on northeast-trending faults.

In the Black Rock Hills another fault of the northwest set, the Goshoot Canyon fault (pl. 6), follows the north side of Goshoot Canyon and separates Upper Devonian formations from a block of undivided Upper Devonian rocks of different lithology. It is paralleled a few hundred feet to the north by a much smaller fault that offsets the contact between the Engelmann and Goshoot formations about 500 feet. The minimum stratigraphic throw on the Goshoot Canyon fault is estimated to be 3,100 feet.

West of Spor Mountain the distribution of isolated exposures of the Sevy dolomite and Engelmann formation suggests the presence of at least one, and probably several, concealed northwest-trending faults. This fault system, though doubtless complicated by faults of other trends, offsets the Sevy-Engelmann contact nearly a mile.

STRUCTURE OF THE VOLCANIC ROCK

Volcanic rocks, which cover a large area from the south-central Dugway Range to the south end of the Thomas Range, are relatively unfaulted compared with the underlying older rocks. The younger group of flows of the Thomas Range is generally flat-lying (section *D–D′*, *E–E′* pl. 2), although the internal flow structure is highly contorted in many areas. A structure contour map (pl. 5) on the base of one of the flows of the younger group shows that, whereas the general interflow surface is relatively horizontal, gentle undulations in this surface appear to coincide rather well with present topographic features; the structurally high points on the map probably represent the vent areas. Local sharp irregularities in obsidian layers at the base of flows are generally initial dips of the glass deposited on an eroded surface.

The attitude of the rocks of the older volcanic group, due to their poor exposure, is more difficult to determine, but in some places they have approximately the same strike and dip as the Paleozoic rocks.

Twenty-two faults were noted within the volcanic block; of these, 18 trend from north to northwest, one trends east, and three northeast. In addition, volcanic rocks outside the block in the vicinity of Spor Mountain are cut by faults in some places. All the faults dip rather steeply and displacement on most of them is very small, and may reflect renewed movement on older faults in the basement rock.

The Colored Pass fault (pl. 6), the largest within the volcanic block, can be traced northward for nearly 2 miles from the vicinity of Colored Pass. It is a steep normal fault dipping east (pl. 4), and, although the displacement is difficult to measure, the throw is several hundred feet. A small fault of parallel trend is present about 0.7 mile northeast of Colored Pass, and another trending north-northeast cuts porphyritic rhyolite and tuff southwest of Colored Pass (pl. 1).

A fault of northeast trend lies on the southeast side of Topaz Mountain where it extends for about a mile from Topaz Valley eastward. It has a vertical displacement of approximately 60 feet at a point just west of the Autunite No. 8 claim. There are several small faults of northwest trend in the Topaz Mountain area.

Two minor north-trending faults occur in the north-central part of the Thomas Range. The largest has a throw of about 50 feet. A series of minor northwest- and north-trending faults cuts the volcanic rocks in the south-central part of the Dugway Range. The maximum vertical displacement of these is about 100 feet. Their trend is parallel to some of the faults in the underlying Paleozoic rocks.

Three border faults are exposed or inferred on the edges of the volcanic block. Two are Basin and Range faults that form the boundary between the volcanic and the Spor Mountain blocks. The other is an east-trending fault that forms part of the boundary between the volcanic and the Dugway Ridge blocks. The vertical displacement on this east-trending normal fault is at least several hundred feet near the east edge of the Thomas Range where the volcanic rocks are brought down against the Cambrian sedimentary rocks, but to the west where rhyolite bounds both sides of the fault the amount of displacement cannot be estimated.

Numerous fractures were noted in the volcanic rocks. At the Autunite No. 8 and Buena No. 1 claims north-trending fractures in rhyolite contain uraniferous opal. At several places near the southeast corner of Antelope Ridge and on the north side of the hills about 0.5 mile east of Antelope Ridge, a number of northwest-trending fractures were noted. Rhyolite, normally light gray in color, is locally bleached white or stained orange in the vicinity of these fractures. The scattered outcrops of rhyolite about 4 miles northwest of Dugway Pass are highly fractured and in some places contain tuffaceous pebble dikes and manganiferous calcite veins.

AGE OF FAULTING

The precise age of the faulting in the Thomas and Dugway Ranges is not known. Gilluly (1932, p. 85–86) found that an early Tertiary age for some of the faulting in the Stockton-Fairfield quadrangles was the most reasonable, but that a later stage, Basin and Range faulting, probably had its principal movement in Miocene or early Pliocene time. Nolan (1935, p. 63–64) recognized several cycles of faulting in the Gold Hill area; the earliest he believed began in Cretaceous or early Eocene time, the latest he thought began in late Pliocene time. Lovering (1949, p. 13) believed that the faulting in the East Tintic district was probably contemporaneous with that of the Wasatch (Upper Cretaceous and Eocene). He recognized no Basin and Range faulting in in the East Tintic district.

Generally Basin and Range faulting has been ascribed to the Pliocene (Eardley, *in* Hansen and Bell, 1949, p. 22–23), but, as Gilluly (1928, p. 1118–1120) pointed out, Basin and Range faulting appears to have begun at different times in different regions. Nolan (1943, p. 183–184) concluded that Basin and Range faulting probably began in Oligocene time and has continued intermittently since then, but that Basin and Range faults that show good topographic expression are not older than Pliocene.

In the Thomas and Dugway Ranges all the faulting is younger than the Mississippian sedimentary rocks, and most of it is older than the older group of volcanic rocks.

The oldest structural features in the area, the thrusts and minor folds, cannot be clearly dated with the evidence at hand; they may be as old as Pennsylvanian or as young as Miocene. Evidence from other areas, however, (Spieker, 1946, p. 150–155; Christiansen, 1951, p. 11–17; Eardley, 1944, p. 863–865) points to a Late Jurassic to Eocene age for these features.

Most of the numerous transverse and strike faults predate the rocks of the older volcanic group, which are probably Miocene in age (p. 116), and therefore, the age of principal movement on these faults is probably early Miocene or older.

The Basin and Range faults that presumably elevated the ranges and tilted some of the Paleozoic sedimentary rocks also tilted at least some of the rocks of the older volcanic groups, but have only locally disturbed those of the younger group. Inasmuch as the younger volcanic rocks are probably Pliocene in age (p. 116), the principal Basin and Range faulting probably occurred in late Miocene or early Pliocene time.

Small faults that cut the younger group of volcanic rocks may have formed at any time from the Pliocene to the Recent.

SUMMARY OF STRUCTURAL HISTORY

The structural evolution of the Thomas and Dugway Ranges may be divided into four episodes, some of which undoubtedly overlapped in time. (1) The first structural event that is clearly recorded by the rocks of this area was compression of regional extent, probably in Cretaceous or early Tertiary time. The direction of this compression is unknown; it is indicated mainly by small northeast-trending thrust faults on Spor Mountain, the northwest-trending Buckhorn thrust fault, and the east-northeast-trending Buckhorn syncline in the northern Dugway Range. All these features are cut by faults of later age, but normal faults may have been formed during, or very soon after, thrusting. (2) After thrusting and minor folding, a period occurred, probably between Eocene and middle Miocene time, when hundreds of diversely oriented transverse and strike faults were formed. Such faulting was particularly intense in the Spor Mountain and Castle Mountain blocks. Some elevation and tilting of the ranges probably was accomplished at this time, some of the older group of volcanic rocks may have been emplaced late in this episode, and lines of weakness that later controlled development of the large Basin and Range faults probably caused different parts of the area to react more or less independently to the stresses. Some tilting of the Paleozoic rocks probably occurred before the large Basin and Range faults, inasmuch as the strike of these rocks in some areas is nearly at right angles to the Basin and Range faults. (3) Next came additional elevation and major tilting of parts of the mountains by the Basin and Range faults of north and northwest trend. These faults terminate almost all other structural features. (4) Finally, after a period of erosion, the younger group of flat-lying volcanic rocks was emplaced, probably in Pliocene time. These rocks were then displaced to a small extent on several north-trending faults, and to a moderate extent on one east-trending fault. A few small offsets of Basin and Range faults and some additional movement on Basin and Range faults probably occurred between Pliocene and Recent time.

The relative recency of movement on some of the large Basin and Range faults is attested by geomorphic evidence, particularly in the Dugway Range. The surface of the large fault that lies at the base of the northwestern flank of the Dugway Range is well exposed in several places; its trace lies almost exactly at the boundary of the alluvium and the steep-faceted mountain spurs, which represent in many places the actual fault surface. In the Kellys Hole block (pl. 1), the drainage pattern is sharply transverse to the structure in a number of places and crosses at right angles the very resistant Prospect Mountain quartzite instead of taking a northward path of least resistance through Mississippian limestone. Northwest-trending Kellys Hole and the Bertha trough to the east are floored with limestone, yet the principal drainage of both valleys is westward through deep canyons cut in the resistant quartzite. This anomalous drainage is probably the result of rather recent faulting, principally on the Castle Mountain fault, which dropped the block of limestone across an antecedent valley cut in the quartzite. The recency of this faulting, however, does not alter the supposition that the major movement on these and other faults probably occurred in early or pre-Pliocene time.

MINERAL DEPOSITS

The mineral deposits in the Thomas and Dugway Ranges may be subdivided into three principal groups: uraniferous fluorspar deposits, uranium deposits, and lead-zinc-copper-silver deposits. Each of these types is found in a separate area characterized by a particular type of country rock, ore control, and mineralogy. The uraniferous fluorspar deposits are in pipes and veins in dolomite throughout Spor Mountain and consist chiefly of fluorspar with minor silica minerals and clay. The uranium deposits are in replacement bodies and veins in rhyolite and tuffaceous sandstone at the south end of the main part of the Thomas Range; they consist of uranium minerals with opal and minor fluorite. The lead-zinc-copper-silver deposits are chiefly veins in limestone, dolomite, and quartzite in the northern part of the Dugway Range and contain galena, sphalerite, fluorite, barite, quartz, pyrite, chalcopyrite and their alteration products.

The only organized mining district is the Dugway mining district in the northern part of the Dugway Range. The Spor Mountain area is locally called the Thomas Range fluorspar district, and has been referred to as such in several publications (Fitch, Quigley, and Barker, 1949, p. 63; Staatz and Osterwald, 1959). No district name has been proposed for the area in which the uranium deposits are found.

URANIFEROUS FLUORSPAR DEPOSITS

CLASSIFICATION OF DEPOSITS

Fluorspar has been found in approximately 50 deposits large enough to warrant some development work. These deposits fall into three types: (1) pipe- or chimneylike bodies, (2) veins, and (3) disseminated deposits. Figure 50 shows the location of properties mentioned in this section.

Pipes.—Pipelike bodies are by far the most important deposits in the district, and 27 out of 31 producing deposits, from which has come more than 99 percent of the total production, are of this type. Pipelike ore bodies are responsible for most of the production at the Lost Sheep, Bell Hill, Blowout, Fluorine Queen, Floride, Lucky Louie, Hilltop, Oversight, Dell No. 1, Dell No. 5, and Green Crystal properties (fig. 50).

The pipelike bodies range from less than a foot in diameter to 155 feet long by 106 feet wide. Ore bodies with their longest horizontal axes more than 100 feet long include the main Lost Sheep pipe, the large pipe on the Bell Hill property, the Blowout pipe, the two large pipes on the Fluorine Queen property, the western pipe on the Dell No. 5 property, and the Floride pipe. In plan some pipes are oval, such as the Lucky Louie mine, and others are highly irregular, as at the Bell Hill and Blowout properties. In section a few pipes are vertical, but most show an eastward plunge at angles of 52° to 90°. Table 19 gives the angle and direction of plunge of some of the better defined ore bodies. Most pipes show little variation in plunge, but the Bell Hill pipe shows an abrupt sudden change just below the 87-foot level. Above this level the pipe plunges 52 ° NE. and below this level it plunges 70° ESE.

TABLE 19.—*Plunge of some of the uraniferous fluorspar ore bodies on Spor Mountain*

Property	Ore body	Plunge
Bell Hill	Largest ore body above 87-foot level	52° N. 62° E. 70° S. 81° E.
	Small pipe adjacent to largest ore body	75° N. 74° E.
	Second largest pipe	65° S. 58° E.
Blowout	Main ore body	71° N. 49° E.
Floride		77° S. 32° E.
Floride No. 5		61° S. 46° E.
Fluorine Queen	West ore body	90°.
	East ore body	82° E.
Harrisite	Largest ore body	65° S. 62° E.
Lucky Louie		60° N. 89° E.

Most of the fluorspar pipes show a consistent tendency to narrow with depth. Some pinch rapidly, as does the Lucky Louie, which has an oval cross section with a length of 35 feet and a maximum width of 14 feet at the surface, and a length of 10 feet and a maximum width of 7.5 feet at a depth of 120 feet below the surface. The oval pipe on the Harrisite property is 6 feet long by 4 feet maximum width at the surface and is 4 feet long by 2 feet wide at a depth of 22 feet below the surface. Other pipes that diminish in size at depth are the Floride, the east pipe of the Fluorine Queen, the Blowout, the two large pipes on the Bell Hill property, the Lost Sheep, and the Oversight. Although much of this decrease in size is gradational, some ore bodies seem to show an abrupt widening or flaring toward the present ground surface. Some of these ore bodies include the Lost Sheep, the large ore body of the Bell Hill, the Floride, and the east ore body of the Fluorine Queen. The flaring of the Lost Sheep ore body started approximately 50 feet below the present surface.

Some ore bodies also change radically in shape with depth. Some ore bodies split with depth, as does the large ore body on the Oversight property, which divides into two smaller pipes about 60 feet below the surface (H. L. Bauer, Jr.; see footnote, p. 7). The large body on the Bell Hill property is H-shaped on the surface, is lenticular on the 60-foot level, and below the 150-foot level splits into two lenticular ore bodies. The east ore body of the Fluorine Queen on the adit level has a large irregular horse of dolomite not found on the surface.

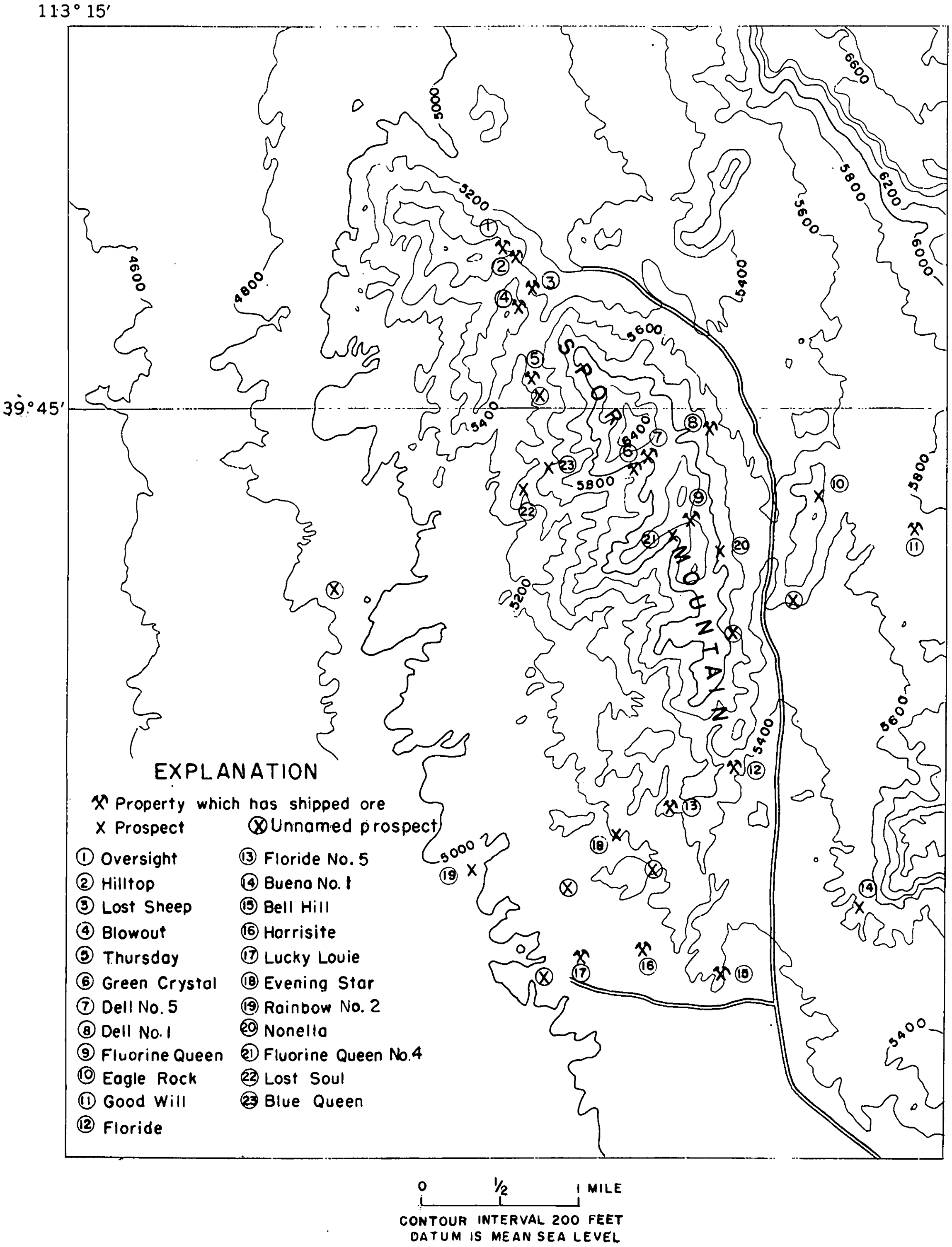


FIGURE 50.—Index map showing the location of uranium and fluorspar properties in the Spor Mountain area of the Thomas Range, Utah.

Veins.—Veins are common throughout Spor Mountain but most of them are small. Production has come from only three veins, two of which have produced at most only a few tons; the third, the Thursday property, produced about 55 tons (H. L. Bauer, Jr., see footnote, p. 7). The Eagle Rock, Lost Soul, and Blue Queen claims (fig. 50) were also located on vein deposits. Fluorspar is commonly found in small veins adjacent to pipe deposits.

Fluorspar veins range in width from a fraction of an inch to 14 feet and in length from a few inches to at least 240 feet. Only one vein, the Thursday, however, has been traced for more than 40 feet. One of the chief characteristics of the veins is their variation in thickness. In the west end of the trench on the Eagle Rock property, for example, a vein at a depth of 2 feet is less than an eighth of an inch thick but at a depth of 6 feet it is 4 feet thick.

The veins strike in all directions and most of them dip steeply. In some places they occur in irregular networks. Examples of these networks may be seen at several places on the Bell Hill property and on the adit level of the Oversight mine.

Disseminated deposits.—Fluorite is disseminated in volcanic rocks along the south and west side of Spor Mountain. The fluorite content of these deposits does not exceed 15 percent, and no attempt has been made to market this low-grade material for fluorite.

The size and shape of the disseminated deposits are not known. The areas in which these deposits occur are at a low elevation and are generally heavily mantled with Lake Bonneville gravels. Most exposures are limited to pits and trenches.

The distribution of fluorite in the volcanic rocks is irregular; it may constitute 15 percent of the rock in one place and only a fraction of a percent a few feet away. The richest and most extensive deposits occur in the more porous tuff, where fine-grained purple fluorite replaces clay-rich layers around large lithic fragments in the tuff and around some of the smaller vitric fragments. Fluorite in rhyolite and rhyodacite occurs as thin veinlets and as tiny crystals lining cavities and fractures.

At the Harrisite mine (fig. 50) and at a prospect 1,650 feet northwest of the Lucky Louie mine, disseminated deposits in the volcanic rocks are adjacent to veins and pipelike fluorspar bodies in the dolomite.

RELATION OF ORE DEPOSITS TO COUNTRY ROCK

Fluorspar pipes and veins are found at the surface in the Lost Sheep dolomite, Harrisite dolomite, Bell Hill dolomite, Floride dolomite, Fish Haven dolomite, intrusive breccia, and rhyolite. Veins also occur in quartzite of the Swan Peak formation, Thursday dolomite, Sevy dolomite, and vitric tuff of the younger volcanic group. Most of these latter occurrences are quite small; however, the largest vein found in the area was in the Thursday dolomite.

The pipes when followed to depth commonly cross several rock units and cut the sedimentary rocks at an angle of between 40° and 80°. Two pipes on the Dell property, reported to have been followed to the massive quartzite member of the Swan Peak formation, end at the quartzite, although small anastamosing fluorspar veins, as much as 6 inches wide, extend for at least several feet into the quartzite. The fluorspar veins, however, appear to become smaller the farther they penetrate into the quartzite.

No fluorspar has been noted below the top 10 feet of the massive quartzite of the Swan Peak formation of Middle Ordovician age or above the lower 100 feet of the Sevy dolomite of Devonian age. All deposits that have produced more than 100 tons of fluorspar occurred in either the Upper Ordovician dolomite (Fish Haven), the Ordovician or Silurian dolomite (Floride), or the lower three Silurian dolomites (Bell Hill, Harrisite, and Lost Sheep). Only small veins and pipes have been found in rhyolite and intrusive breccia, and in most places the fluorspar deposit is partly in these volcanic rocks and partly in dolomite country rock.

Disseminated deposits occur principally in tuff, although a few occur in the altered zone between rhyodacite or rhyolite with dolomite. The altered zone between the two rock types is several feet thick and grades from fresh volcanic rock to rock that is soft and clayey to dolomite. The carbonate content of this zone increases in the same direction. Original texture of the volcanic rock can be traced in the contact zone to within approximately 1 foot of the dolomite. Larger disseminated deposits occur in altered zones in vitric tuff, as at the Rainbow No. 2 prospect (fig. 50).

RELATION OF ORE DEPOSITS TO STRUCTURAL FEATURES

The fluorspar deposits are formed by replacement along shattered or porous zones in dolomite and volcanic rocks. Most of the deposits are in dolomite along shattered zones formed by faulting, and intrusive breccia bodies.

Fluorspar pipes and veins are commonly found along or adjacent to faults in the highly faulted Spor Mountain area. Most of the faults associated with fluorspar bodies have a northeasterly or easterly trend; the big vein on the Thursday property and two prospects, the Nonella and the Blue Queen, are, however,

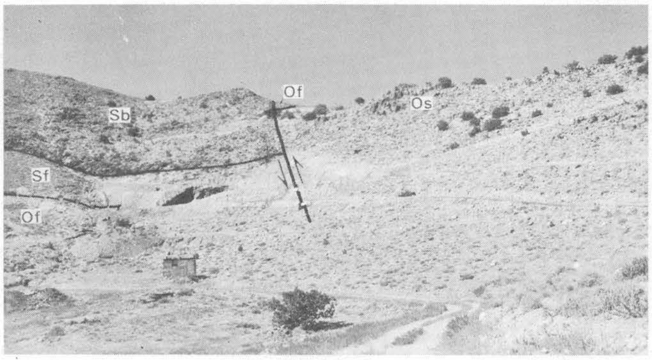


FIGURE 51.—View of the Floride mine from the east showing the pit on the ore body (left center) and normal fault which drops the Bell Hill (Sb), Floride (Sf), and Fish Haven (Of) dolomites against quartzite of the Swan Peak formation (Os).

associated with northwesterly trending faults. Fluorspar ore bodies associated with faults include (1) the largest pipe on the Bell Hill property, which is in a fracture zone between two faults, (2) the second largest pipe on the Bell Hill property, which is in the footwall of a fault, (3) another smaller pipe in the same fault zone, (4) the Floride ore body on the hanging-wall side of a fault (fig. 51), (5) both the Harrisite pipes, and (6) the Thursday vein. The disseminated ore body in tuff on the Rainbow No. 2 prospect is also within 20 feet of a fault.

Fluorspar pipes and veins are also commonly found in fractured and brecciated dolomite adjacent to intrusive breccia bodies. Fluorspar ore bodies of this type include three pipes on the Dell property, the southern small pipe on the Dell No. 5 property, the two Hilltop pipes, the Blowout pipe, the main Lost Sheep pipe, and the Eagle Rock vein. Some fluorspar is found in intrusive breccia bodies but consists chiefly of veins of no great economic interest. Veins in intrusive breccia occur in the cut to the main Lost Sheep pipe, near the mouth of the adit to the Blowout pipe, and near the mouth of the adit to the northernmost Dell pipe.

Fluorspar deposits also occur in porous zones. For the most part these include the disseminated deposits which are found in vitric tuffs and in the soft altered contact zone between various volcanic rocks and dolomite.

Some fluorspar pipes show no apparent relation to shattering caused by faulting, to intrusive breccia bodies, or to porous zones. The main ore body at the Oversight mine is 65 feet from the closest fault and 150 feet from an intrusive breccia body. The Lucky Louis pipe is also in a faulted area but is approximately 90 feet from the nearest fault. Similarly, both large pipes on the Fluorine Queen property and the Green Crystal pipe are in a faulted area but not adjacent to any faults. These ore bodies may overlie an intrusive body, during whose intrusion the overlying sedimentary rocks were shattered forming channelways for later fluorine-rich fluids. In some places intrusive breccia bodies may be hidden inasmuch as they show little resistance to weathering. For example, at the Hilltop property a small intrusive breccia body adjacent to the two ore bodies was exposed only after 3 feet of overburden were removed.

MINERALOGY OF THE ORE

Fluorite.—The fluorspar ore of Spor Mountain contains 65 to 95 percent fluorite. But unlike the coarsely crystalline material of most other fluorspar deposits, this is generally a soft powdery clay-like mass, a hard boxwork, or a dense aphanitic mass, in which not a crystal can be seen.

The color may be blue, white, yellow, purple, brown, or any admixture. Fluorite in the largest ore body on the Bell Hill property is generally white or yellow, although some blue and deep-purple ore is present; in the second largest ore body on the Bell Hill property, it is mainly deep blue or purple. Fluorite from the Hilltop and Oversight properties is generally brown, and in the other pipes may be a mixture of these colors.

In appearance the fluorite resembles that of either a soft pulverulent clay or dense fine-grained silica. Where it is blue or purple, the fluorite is fairly easy to recognize, but where it is white, yellow, or brown, it shows little resemblance to the fluorite from most other parts of the country. Hard crystalline fluorite in which distinct crystals are recognizable in the hand specimen is rare and was noted only on the Hilltop property, the Dell No. 5 property, and the claim on the northern part of Spor Mountain (fig. 50). This fluorite occurs in colorless or pale-purple cubes, 1 to 2 mm across, scattered through veinlets.

Bloecher (1952, p. 13), while investigating recoverability of uranium from fluorspar ore, noted that when he roasted dark-purple fluorite from the Bell Hill property to more than 400°C it turned pale yellow or white. One explanation of this color change is that the deep-purple color in the original fluorite is formed by lattice distortion brought on by the radioactive decay of uranium minerals, and when the mineral is heated, the structure expands, the distortion vanishes, and the color changes from purple to white. In order to prove the correctness of this explanation, Bloecher (1952, p. 18) sorted out the purple from the white ore and analyzed the two ores. His results showed, however, that the white fluorite contained a much higher uranium concentration than the purple fluorite. The color of the fluorite from this pipe is of particular interest because this fluorite had the highest uranium content of any fluorspar deposit. Although Bloecher did not explain why the white fluorite had the highest uranium content, Przibram (1956, p. 193) in a later article noted that prolonged and intense radiation can lead to bleaching of colored fluorite. He cited the examples of bleaching in fluorite in some radiactive halos and the bleaching of deep-purple fluorite by radium when it was stored in the Blue John mine, Derbyshire, during World War II. A possible explanation of the color change noted may be that dark-blue or purple fluorite is an intermediate stage between pale-blue and white fluorite. The conditions needed to form white fluorite probably depend not only on the uranium content, but on the proximity of the uranium-bearing mineral to the particular fluorite grain, the grain size of the fluorite, and the length of time since the deposit was formed.

Uranium minerals.—Although all the fluorspar deposits show abnormal radioactivity, visible uranium minerals are quite rare. Fine-grained powdery yellow uranium minerals were found sparsely in six deposits: the Eagle Rock vein, a small ore body 100 feet west of the Eagle Rock vein, the large pipe on the Bell Hill property, a small vein on the contact between rhyodacite and dolomite on the Harrisite property, the Floride pipe, and the west pipe on the Fluorine Queen property. Uranium minerals are rare except on the Eagle Rock property. At only two of these deposits—the vein at the Eagle Rock property and the west pipe of the Fluorine Queen—did the megascopic uranium mineral occur in the fluorspar; in the others it was found on the dolomite or rhyodacite adjacent to the fluorspar ore body. In hand specimen the yellow uranium minerals from the various deposits appear quite similar. X-ray examination of the yellow uranium minerals from the Eagle Rock and Bell Hill properties showed them to be carnotite, but the powder pattern of the yellow uranium mineral from the Harrisite property did not match that of any known mineral. A spectrographic analysis showed that uranium and silicon were the two major constituents.

Uranium occurs in some areas, such as the Jamestown district, Colorado (Goddard, 1946, p. 19), as pitchblende scattered through the fluorspar ore. Several samples from the large pipe on the Bell Hill property, which has the highest uranium content, were put in heavy liquids, but no heavy minerals were obtained. Pitchblende may occur, however, in small amounts in some deposits, but it does not appear to be an important uranium mineral in this district.

Autoradiographs were made of several specimens of ore containing more than 0.10 percent uranium in an attempt to determine distribution of the uranium-bearing mineral. The autoradiographs showed no concentration of uranium but a more or less uniform haze over the entire autoradiograph. F. W. Bloecher (1952, p. 5) sieved the ore and noted that the uranium from the Bell Hill property was more or less equally divided between the various size fractions. The preceding data indicates that the uranium may be present as either U^{+4} in the fluorite lattice or as a distinct uranium mineral with clay-size dimensions.

Sulfides and oxides.—No metallic sulfides or oxides are visible in any of the fluorspar deposits nor were any recovered in heavy mineral separations of the ore from a number of pipes. Trace amounts of pyrite, hematite, magnetite, and chalcopyrite have been reported elsewhere—(Bloecher, 1952, p. 5) in a heavy-mineral separate made on ore from the lower part of the opencut on the largest pipe of the Bell Hill property.

Gangue minerals.—Gangue minerals found in the various fluorspar ore bodies are montmorillonite, quartz, dolomite, calcite, and chalcedony. Montmorillonite is the most common gangue mineral and occurs as a white waxy clay mineral resembling mutton tallow. On drying by exposure to air, it becomes a white powdery substance that is not readily distinguishable megascopically from white fluorite. Six samples of this clay were collected from the lowest adit on the Blowout pipe, from a stope on the 87-foot level of the Bell Hill mine, and from surface workings of the largest pipe on the Harrisite property. X-ray and petrological study of these samples by E. W. Tooker showed that all samples are calcium-magnesium montmorillonite. Montmorillonite is most prevalent in the deeper parts of a deposit and commonly occurs in rounded balls or masses. In the lower underground workings of the Blowout pipe, these masses of clay are as large as 1 foot across.

Chalcedony ranks next in abundance to montmorillonite as a gangue mineral and is found in the Lucky Louie pipe, the main Lost Sheep ore body, the east ore body of the Fluorine Queen, the largest ore body on the Bell Hill property, and a number of small prospects. The chalcedony is a dark-gray dense aphanitic mineral that resembles some of the chert found in the dolomite.

Quartz occurs in small clear crystals which coat a boxwork type of ore in the Oversight and Blowout mines and is also found in the lower part of the Bell Hill and Lost Sheep mines, where it commonly coats chalcedony.

White wedge-shaped dolomite crystals accompany the quartz in a number of places, and in one place in the Oversight mine they fill fractures in the dolomite country rock.

Calcite is much less common than dolomite and was observed only from the Eagle Rock vein, and the underground workings of the Blowout mine.

Changes with depth.—Not only does the size of the deposits change with depth, but in some the character of the ore changes also. Some of the deposits have been worked only near the surface and no information is available at depth. In the opencut of the Blowout mine, fluorspar contains few impurities, but on the adit level 240 feet below, the fluorspar contains masses of montmorillonite with minor quartz, dolomite, and calcite. Similarly, at the surface the Lucky Louie pipe was made up almost entirely of fluorite, at 90 feet below the surface black angular pieces of chalcedony are found in the ore, and at 120 feet below the surface all except the outermost part of the pipe consists of chalcedony. Another example is the large pipe on the Oversight property, which from the surface to a depth of approximately 80 feet consists of a brown boxwork of fluorite; however, on the adit level, 150 feet below the surface, the ore body consists of fractured dolomite surrounded by a boxwork of brown fluorite veinlets. Also changing with depth is the large ore body on the Bell Hill property, which from the surface to the 129-foot level consists of pulverulent fluorite, on the 150-foot level contains an 8-foot band of vuggy quartz and light-colored dolomite in the east end of the ore body, and on the lower levels contains even more abundant impurities.

Most ore bodies have shown a change of mineralogy with depth, and those that have been mined to depths greater than 80 feet show that the upper part of the ore body contains chiefly fluorite and that the lower part contains various other minerals in addition to fluorite. Although the overall tenor of the ore body may decrease considerably with depth, many of these impurities occur on one side or part of the ore body. The fluorspar mined in areas between masses of chalcedony, montmorillonite, or quartz commonly contains as much as CaF_2 as the ore in the upper parts of the deposit.

CHEMICAL COMPOSITION OF THE ORE

The fine-grain size of the ore and the lack of distinctive character of most of the minerals make it extremely difficult to estimate by visual inspection the tenor of the ore. Thus, the variation in both the fluorite and uranium contents of the ore is best determined from chemical analyses.

Fluorite content.—The fluorite content of many of the deposits is high, especially in the upper part of the deposit. The first carload [3] of fluorspar shipped from the Floride mine in 1944 contained 95 percent CaF_2 and 1 percent SiO_2 (Fitch, Quigley, and Barker, 1949, p. 65). A carload of ore shipped from the main pipe of the Lost Sheep mine in 1948 contained 94.9 percent CaF_2, 0.044 percent SiO_2, and 0.12 percent sulfur (Fitch, Quigley, and Barker, 1949, p. 66). The average grade of ore mined from this deposit between May 1948 and December 1951, according to Bauer (see footnote, p. 7) is 85.4 percent CaF_2. Ray Spor (1953, written communication) reported that the Floride mine between 1944 and 1948 averaged 77.5 percent CaF_2 and 0.9 percent SiO_2. The southern pipe on the Dell No. 5 property, which was also operated by the Spor family, averaged 71.9 percent CaF_2 and 5.2 percent SiO_2. Fred Staats (1953, written communication) reported that carload lots from the Oversight mine in 1952 contained from 73 to 89.8 percent CaF_2 and 2.2 to 4.2 percent SiO_2. W. W. Watson (1953, written communication) of Chief Consolidated Mining Co. stated that, although assay values for every shipment were not returned, a composite assay of those provided showed that ore from the Lucky Louie in 1952 averaged 81.6 percent CaF_2 and 5.2 percent SiO_2. Seventy samples from the deposits on Spor Mountain were analyzed by the U.S. Geological Survey for fluorine. From these results, the fluorine content is calculated and presented in table 20. The results range from 2.9 percent CaF_2 in a small disseminated ore body to 94.3 percent for high grade ore in the winze of the Bell Hill mine. Excepting samples from the drill hole in the Bell Hill mine, where the ore commonly was mixed with country rock, the lowest grade sample from a producing deposit contained 49.5 percent CaF_2 in the Floride deposit. The analyses show considerable variation in grade in the same deposit from opposite sides of the ore body. This variation is due mainly to increase or decrease of the SiO_2 content, which is the main impurity. The SiO_2 content of some mines, such as the Blowout, Lost Sheep, and Fluorine Queen, comes mainly from montmorillonite, because quartz and chalcedony are but minor constituents of the ore.

Uranium content.—The uranium content of 181 samples taken from the veins, pipes, and disseminated deposits ranged from 0.003 to 0.33 percent uranium (table 20). A sample containing 0.59 percent uranium was obtained from the Eagle Rock property, but represents selected pieces of the highest grade material and is not representative of any large part

[3] A carload of ore generally weighs between 50 and 55 tons.

TABLE 20.—*Analyses of fluorspar samples from the uraniferous fluorspar deposits on Spor Mountain, Utah*

[Analyses by U.S. Geological Survey except where noted]

Property	Field sample	Ore body	Location	Equivalent uranium (percent)	Uranium (percent)	Fluorite [1] (percent)
Bell Hill [2]	SB-43-50	Trench No. 1, south body	Surface	[3] 0.028	[4] 0.029	
	SB-44-50	do	do	[3].044	[4].059	
	SB-45-50	Trench No. 2	do	[3].012	[4].012	
	SB-46-50	Trench No. 3, west body	do	[3].030	[4].036	
	SB-47-50	Trench No. 3, east body	do	[3].012	[4].010	
	CS-5-51	do	do	[3].038	[5].038	
	CS-7-51	Trench No. 4	do	[6].006	[5].006	
	SB-52-50	Pit No. 1	Opencut	[3].27	[4].32	[7] 78.5
	SB-51-50	do	do	[3].22	[4].26	[7] 88.2
	SB-53-50	do	do	[3].085	[4].093	[7] 90.1
	SB-1-50	do	do	[3].25	[8].25	
	SB-2-50	do	do	[3].33	[8].33	
	SB-3-50	do	do	[3].16	[8].17	
	SB-4-50	do	do	[3].19	[8].18	
	SO-22-52	do	69-ft level	[6].19	[9].17	
	SO-23-52	do	do	[6].11	[9].094	
	SO-24-52	do	do	[6].17	[9].15	[7] 80.8
	SO-25-52	do	do	[6].067	[9].049	
	SO-26-52	do	do	[6].19	[9].15	
	SO-27-52	do	do	[6].095	[9].069	
	CS-1-51	do	87-ft level	[6].13	[5].11	[7] 87.8
	CS-2-51	do	do	[6].15	[5].15	[7] 88.2
	SO-12-52	do	do	[6].15	[10].14	
	SO-15-52	do	do	[6].18	[9].14	
	SO-64-52	do	do	[6].069	[9].049	
	SO-65-52	do	do	[6].058	[9].051	[7] 63.0
	SO-66-52	do	do	[6].088	[9].059	
	SO-16-52	do	108-ft level	[6].10	[9].076	
	SO-17-52	do	do	[6].18	[9].12	
	SO-18-52	do	do	[6].043	[9].029	[7] 67.6
	SO-19-52	do	do	[6].074	[9].056	
	SO-20-52	do	do	[6].10	[9].090	
	SO-21-52	do	do	[6].10	[9].072	
	SO-43-52	do	129-ft level	[6].094	[9].070	
	SO-44-52	do	do	[6].19	[9].16	
	SO-46-52	do	do	[6].072	[9].060	[7] 89.5
	SO-47-52	do	do	[6].12	[9].096	
	SO-48-52	do	do	[6].066	[9].050	
	SO-37-52	do	150-ft level	[6].14	[9].12	
	SO-38-52	do	do	[6].17	[9].15	
	SO-39-52	do	do	[6].12	[9].092	[7] 84.8
	SO-40-52	do	do	[6].17	[9].14	
	SO-41-52	do	do	[6].14	[9].12	
	SO-42-52	do	do	[6].14	[9].13	
	SO-32-52	do	168-ft level	[6].18	[9].15	
	SO-33-52	do	do	[6].093	[9].074	[7] 84.8
	SO-35-52	do	do	[6].14	[9].11	
	SO-36-52	do	do	[6].11	[9].080	
	SC-10-54	do	213-ft level	[11].16	[12].15	
	SC-11-54	do	237-ft level	[11].13	[12].11	
	SO-34-52	do	Southwest-trending winze	[6].11	[13].090	[7] 94.3
	BH-15-52	do	103 ft down Northeast-trending winze	[6].21	[13].15	[7] 88.0
	BH-14-52	Small vein	Drill hole 2, 256.3-256.8 ft	[6].087	[13].060	[7] 25.6
	BH-8-52	Pit No. 1	Drill hole 2, 291.6-296.7 ft	[6].070	[13].051	[7] 65.6
	BH-9-52	do	Drill hole 2, 296.7-299.7 ft	[6].076	[13].054	[7] 55.1
	BH-4-52	do	Drill hole 2, 299.7-304.7 ft	[6].14	[13].11	[7] 63.3
	BH-5-52	do	Drill hole 2, 305.8-307.8 ft	[6].15	[13].12	[7] 76.4
	BH-6-52	do	Drill hole 2, 307.8-311.2 ft	[6].13	[13].10	[7] 63.5
	BH-7-52	do	Drill hole 2, 311.2-312.3 ft	[6].13	[13].10	[7] 75.2
	BH-10-52	do	Drill hole 2, 312.3-315.8 ft	[6].11	[13].080	[7] 46.7
	BH-11-52	do	Drill hole 2, 315.8-320.7 ft	[6].11	[13].008	[7] 5.17
	BH-1-52	do	Drill hole 2, 320.7-323.7 ft	[6].11	[13].090	[7] 61.5
	BH-2-52	do	Drill hole 2, 323.7-328.1 ft	[6].19	[13].15	[7] 77.0
	BH-3-52	do	Drill hole 2, 328.1-330.4 ft	[6].10	[13].076	[7] 75.2
	BH-12-52	do	Drill hole 2, 330.4-334.2 ft	[6].12	[13].088	[7] 58.9
	BH-13-52	do	Drill hole 2, 334.2-334.0 ft	[6].014	[13].009	[7] 7.78
	CS-8-51	do	Ore bin	[6].19	[5].21	[7] 88.8
	CS-10-51	do	do	[6].19	[14].20	[7] 88.0
	CS-11-51	do	do	[6].19	[14].15	[7] 84.5
	CS-12-51	do	do	[6].15	[14].18	[7] 72.5
	CS-13-51	do	do	[6].14	[14].16	[7] 81.5
	CS-14-51	do	do	[6].13	[14].086	
	CS-16-51	do	do	[6].042	[14].047	
	SB-5-50	Pit No. 2	Opencut	[3].070	[8].073	
	SB-48-50	do	do	[3].048	[4].052	
	SB-49-50	do	do	[3].061	[4].061	
	SB-50-50	do	do	[3].067	[4].064	
	SC-14-55	do	do	[15].047	[16].046	[17] 92.5

See footnotes at end of table.

TABLE 20.—*Analyses of fluorspar samples from the uraniferous fluorspar deposits on Spor Mountain, Utah*—Continued

[Analyses by U.S. Geological Survey except where noted]

Property	Field sample	Ore body	Location	Equivalent uranium (percent)	Uranium (percent)	Fluorite [1] (percent)
Blowout	SB-76-50		Opencut	[8].010	[5].005	[7] 92.0
	SB-77-50		do	[3].028	[5].033	[7] 79.6
	SO-58-52		do	[6].007	[9].008	
	SO-59-52		do	[6].014	[9].011	[7] 86.8
	SO-60-52		do	[6].011	[9].011	
	SB-66-50		Lower adit	[8].013	[14].013	[7] 72.1
	MHS-3-53		do	[6].008	[18].004	
	MHS-4-53		do	[6].012	[18].004	
	MHS-5-53		do	[6].012	[18].005	
Blue Queen	FWO-35-52		Adit	[6].006	[10].004	
Dell	SC-13-54	Main ore body	Bottom of ore body	[11].028	[12].028	
	SB-41-50	North ore body	Adit	[8].076	[4].083	
	SB-42-50	Vein adjacent to north ore body	do	[3].015	[4].016	
Dell No. 5	SB-59-50	North ore body	Surface	[8].024	[14].020	
	SB-57-50	South ore body	Adit	[8].012	[4].012	
	SB-58-50	do	do	[8].033	[14].030	
	SC-4-54	Large west ore body	Surface	[11].018	[12].013	[17] 62.5
	SC-5-54	do	do	[11].016	[12].012	
	CS-1-56	do	do	[15].009	[19].019	[17] 80.2
	DW-17-56	do	do	[15].014	[24].010	[25] 92.8
Eagle Rock	SB-69-50	Vein	Trench	[8].16	[14].17	
	F-2812 [23]	do	do	[20].083	[20].090	
	SC-1-54	do	do	[11].092	[12].088	[17] 34.6
	SB-70-50	do	Dump	[8].18	[14].18	
	F-2811 [23]	do	Dump, selected	[20].29	[20].31	
	CS-3-56	Altered dolomite boxwork	Pit	[15].023	[19].031	
	CS-4-56	do	Select high grade from dump	[15].42	[19].59	
Evening Star	SC-9-54	Vein	Dump	[11].024	[12].023	
Floride	MHS-1-53		Surface	[6].017	[18].008	
	MHS-2-53		do	[6].029	[18].021	
	SO-28-52		do	[6].035	[9].025	[7] 49.5
	SO-29-52		Upper-adit level	[6].022	[9].015	[7] 66.8
	SO-30-52		Lower-adit level	[6].014	[9].010	[7] 63.5
	SO-31-52		do	[6].007	[9].006	
	SB-9-50		do	[8].016	[8].015	
	SB-79-50		do	[8].006	[5].005	[7] 55.1
Floride No. 5	SC-8-54		Pit	[11].026	[12].029	[17] 68.5
	CS-37-55		do	[15].025	[21].027	
	DW-11-56		Top of raise	[15].038	[24].032	[25] 72.5
Fluorine Queen	SB-60-50	West ore body	Opencut	[8].040	[14].039	
	SB-61-50	do	do	[8].033	[14].018	
	SB-62-50	East ore body	do	[8].017	[14].020	[7] 61.0
	SB-63-50	do	do	[8].021	[14].019	[7] 71.3
	CS-23-51	do	do	[6].016	[14].023	
	SO-4-52	do	Adit	[6].012	[10].010	[7] 68.0
	SO-5-52	do	do	[6].015	[10].006	[7] 82.5
	SO-6-52	do	do	[6].013	[10].008	[7] 72.6
	SO-7-52	Western small ore body	Surface	[6].013	[10].010	
	FWO-9-52	Prospect	do	[6].002		
Fluorine Queen No. 4	SB-80-50		do	[8].019	[5].022	
	FWO-51-52		do	[6].014	[10].015	
	FWO-56-52		do	[6].017	[10].012	
	FWO-59-52		do	[6].019	[9].015	[7] 57.3
	CS-2-56		Opencut, road level	[15].016	[19].022	[17] 79.8
Green Crystal	SC-3-54		Opencut	[11].022	[12].020	[17] 92.5
	SC-16-54		do	[11].034	[12].038	
Harrisite	SB-8-50	Wash zone	do	[8].12	[8].13	
	SB-54-50	do	do	[8].13	[4].16	
	SB-55-50	do	do	[8].088	[4].095	
	SB-56-50	do	do	[8].15	[4].17	
	CS-4-51	do	do	[6].11	[5].073	
	SB-6-50	Vein	Trench	[8].084	[8].089	
	CS-3-51	Rhyodacite ore body	Opencut	[6].039	[5].039	
	CS-9-51	do	do	[6].094	[5].094	
	CS-6-51	Prospect	Opencut 800 ft NW of main workings	[6].037	[5].039	
Hilltop No. 1	CS-20-51	North ore body	Opencut	[6].007	[14].010	
	SO-63-52	do	do	[6].005	[9].006	[7] 59.5
	CS-19-51	South ore body	do	[6].009	[14].011	
Lost Sheep	SB-64-50	Main ore body	do	[8].020	[14].020	[7] 82.7
	SB-65-50	do	do	[8].014	[14].009	[7] 88.0
	CS-22-50	do	do	[6].018	[14].011	
	SO-50-52	do	do	[6].024	[9].016	[7] 88.5
	SO-55-52	do	do	[6].019	[9].014	
	SO-56-52	do	do	[6].021	[9].029	[7] 78.6
	SO-57-52	do	do	[6].021	[9].016	
	SC-12-54	do	do	[11].022	[12].021	[17] 84.7
	SO-49-52	Vein 25 feet east of main ore body	do	[6].048	[9].033	
	F-2813 [23]	do	do	[20].027	[20].031	
	SB-67-50	South ore body	Surface	[8].016	[14].014	[7] 66.7
	SO-54-52	do	Adit	[6].012	[9].009	[7] 82.5

See footnotes at end of table.

TABLE 20.—*Analyses of fluorspar samples from the uraniferous fluorspar deposits on Spor Mountain, Utah*—Continued

[Analyses by U.S. Geological Survey except where noted]

Property	Field sample	Ore body	Location	Equivalent uranium (percent)	Uranium (percent)	Fluorite [1] (percent)
Lost Soul No. 1	FWO-25-52	North vein	Adit	[6] .005	[10] .003	
	FWO-26-52	South vein	do	[6] .005	[10] .004	
Lucky Louie	SB-68-50		Surface	[3] .059	[14] .051	[7] 60.4
	CS-24-51		6 ft below surface	[6] .069	[14] .078	[7] 74.0
	SO-9-52		59 ft below surface	[6] .059	[10] .049	[7] 78.6
	SO-53-52		86 ft below surface	[6] .014	[9] .011	
	SO-52-52		109 ft below surface	[6] .032	[9] .029	
	SO-51-52		122 ft below surface	[6] .030	[9] .023	
Nonella	SB-81-50		Surface	[3] .014	[5] .008	
Oversight	SO-62-52	Main ore body	do	[6] .007	[9] .006	[7] 62.1
	CS-18-51	do	Ore pile	[6] .005	[14] .007	
	SO-61-52	do	Adit	[22] [6] .004	[22] [9] .003	[7] 83.5
	CS-21-51	Southeast ore body	21 ft below surface	[6] .005	[14] .005	
Thursday	SB-78-50	Large vein	Large opencut	[3] .012	[5] .012	
	FWO-19-52	Prospect	Small pit	[6] .002		
Unnamed adit	FWO-118-52		Adit	[6] .002		
Prospect	SO-1-52	Vein	3,550 ft south of the Eagle Rock	[6] .001		
	SO-2-52	do	4,300 ft southeast of the Fluorine Queen	[6] .019	[10] .011	
	CS-17-51	do	3,200 ft northeast of the Lucky Louie	[6] .12	[14] .15	
	CS-15-51	Disseminated ore body	do	[6] .012	[14] .019	
	CS-25-51	Vein	1,650 ft northwest of the Lucky Louie	[6] .059	[14] .064	
	CS-26-51	Disseminated ore body	do	[6] .016	[14] .021	
	FWO-102-52	do	6,000 ft west of the Bell Hill	[6] .009	[10] .007	[7] 2.9
	FWO-124-32	do	9,300 ft southwest of the Thursday	[6] .005	[10] .004	[7] 3.8

[1] Fluorite content calculated from fluorine analyses.
[2] Pit and trench numbers of the Bell Hill are those used in plate 9 (Staatz and Osterwald, 1959).
[3] Radiologist, J. N. Rosholt, Jr.
[4] Analyst, Jesse Meadows.
[5] Analyst, James Wahlberg.
[6] Radiologist, S. P. Furman.
[7] Analyst, Blanche Ingram.
[8] Analysts, G. W. Boyes, Jr., A. C. Horr, and E. C. Mallory, Jr.
[9] Analyst, R. F. Dufour.
[10] Analyst, Wayne Mountjoy.
[11] Radiologist, Percy Moore.
[12] Analyst, Roosevelt Moore.
[13] Analysts, G. T. Burrows and Wayne Mountjoy.
[14] Analyst, G. W. Boyes, Jr.
[15] Radiologist, C. G. Angelo.
[16] Analysts, J. R. McClure, R. L. Daywitt, and James Wahlberg.
[17] Analyst, Richard Cox.
[18] Analysts, Jesse Meadows and J. P. Schuch.
[19] Analysts, H. H. Lipp and James Wahlberg.
[20] Analyses by U.S. Bureau of Mines, Salt Lake City, Utah.
[21] Analysts, R. P. Cox and Mary Finch.
[22] Rock consists of a network of brown friable fluorspar surrounding blocks of dolomite. Sample consists of only the fluorspar part.
[23] Samples taken by R. F. Winkle of the U.S. Atomic Energy Commission.
[24] Analyst, J. P. Schuch.
[25] Analyst, L. F. Rader, Jr.

of the ore body. Only four properties had deposits from which samples containing more than 0.10 percent uranium were obtained. The largest of these deposits is the large ore body on the Bell Hill property from which four near-surface samples contained over 0.20 percent uranium. The ore bodies on the other three properties are small. These include (1) a vein of dark-purple fluorspar several inches thick and about 6 feet long in a prospect 3,200 feet northeast of the Lucky Louie mine, (2) a similar-appearing vein with a maximum width of 4 feet, a length of at least 40 feet, in a pit exposing altered dolomite coated with carnotite on the Eagle Rock claim, and (3) two small pipes and several veins containing white fluorspar on the Harrisite claim.

The uranium content was determined for most samples both by chemical analysis and by measuring its radioactivity (equivalent uranium). The uranium content is equal to the equivalent uranium content if all the radiation has come from the daughter products formed by decay of uranium, and if these daughter products are in equilibrium with uranium. The results of the analyses (table 20) show some variation in some samples, but the small difference in most samples suggests that the equivalent uranium content is a fair measurement of the total uranium content.

The uranium content of an individual deposit varies from place to place even on the same level (table 20). For example, in the Bell Hill mine, 7 samples from the 87-foot level ranged from 0.049 to 0.15 percent uranium and 6 samples from the 108-foot level ranged from 0.029 to 0.12 percent uranium.

A distinct decrease in uranium content also occurs in a number of deposits between the surface and underground workings. An excellent example of this is also furnished by the large ore body on the Bell Hill property. Samples from the opencut contained 0.32, 0.26, 0.093, 0.25, 0.33, 0.17, and 0.18 percent uranium and samples from the 69-foot level contained 0.17, 0.094, 0.15, 0.049, 0.15, and 0.069 percent uranium. Another example is the east pipe of the Fluorine Queen, where samples from the opencut contained 0.020, 0.019, and 0.023 percent uranium and those from the adit contained 0.010, 0.006, and 0.008 percent uranium. A similar trend but on fewer samples is seen at the Oversight, where a surface sample contained 0.006 percent uranium and one from the adit 150 feet below contained 0.003 percent uranium, and at the south ore body on the Lost Sheep property which had 0.014 percent uranium at the surface and 0.009 percent uranium in the adit 45 feet below. The main ore body on the Lost Sheep property showed no apparent decrease in uranium content from the opencut to a depth of 150 feet.

At first it was believed that the change in uranium content was due to zoning with a gradual decrease in uranium content with depth. Inasmuch as some of the ore deposits are exposed only at the surface and others are accessible only at two levels (the surface and one underground working), this theory appeared feasible. Table 20 and graphs of individual samples plotted against depth also seem to substantiate this view. When the Bell Hill mine was deepened, it was possible to obtain numerous samples from a number of elevations. A series of samples were taken on eight underground levels and from a drill hole that cut the ore body (table 20). The analyses from all levels below and including the 69-foot level showed no greater deviation than was found between individual samples from the same level. A sharp increase in grade occurred, however, between this group of analyses and those taken above in the opencut. A similar abrupt increase in grade came at approximately the same depth from the surface in the east ore body on the Fluorine Queen property. The higher grade samples came from between 5 and 20 feet below the surface, and the lower grade ones from the adit 53 feet below the surface. The change in grade can also be shown to occur close to the surface in the south ore body on the Lost Sheep property, where the lower grade sample came from 42 feet below the surface. The CaF_2 content of the deposits shows no apparent relation to the uranium content and may either increase or decrease with an increase of uranium. Thus, the increase of the uranium grade at the top appears related to the present topographic surface rather than to gradual zoning.

Inasmuch as the deposits all occur well above the present ground-water table, the increase in uranium content near the surface probably was caused by slow leaching of the uppermost part of the ore body, in part from material being actively eroded. The uranium is carried downward and redeposited as the water is adsorbed by the dry powdery ore below, at some level between a few inches and approximately 30 feet below the surface. The leaching of the fluorspar deposits is slow because of the small annual precipitation. Although no record of the amount of precipitation has been kept in this area, the annual precipitation is probably between 5 and 8 inches (table 1). Most of the precipitation in the Thomas Range falls as snow during the winter months. The slow-melting snow saturates the upper few inches to few feet of the ore body and leaches the uranium out of the fluorite. The downward-migrating ground water is quickly adsorbed by the dry underlying ore, and the uranium is precipitated as carnotite or some other secondary mineral. After the snow disappears, the rest of the ore quickly dries out. This type of enrichment will only take place in a dry arid climate where the water table is deep. The depth of the water table is unknown on Spor Mountain, but in tunnels on the Dell and Blowout properties, which pass 220 and 240 feet below the surface exposure of the ore bodies, the water table has not been reached.

ORIGIN OF THE URANIFEROUS FLUORSPAR DEPOSITS

Magmatic source.—The eastern part of the Thomas Range consists entirely of volcanic rocks and a light-gray rhyolite that makes up more than 95 percent of the total. The rhyolite is noted for the presence of the fluorine-bearing mineral topaz, which occurs as small euhedral crystals in lithophysae and as larger crystals in vugs. Smaller light-gray rhyolite bodies are found in and adjacent to Spor Mountain as dikes, plugs, and flows. Although little topaz is visible in the hand specimen in this rhyolite, small euhedral grains can be seen in thin section to make up part of the groundmass. The topaz in the groundmass appears to have formed early during the crystallization of the rhyolite, but the well-formed topaz crystals in the vugs appear to have formed after most of the rhyolite solidified. This sequence of formation suggests that the rhyolite magma contained an excess of fluorine, some of which combined during the crystallization of the rhyolite to form small topaz crystals in the groundmass and some of which formed the larger topaz in the lithophysae and vugs.

The fact that topaz is also found in some of the rhyolitic tuffs but is not found in rhyodacite suggests that the fluorine was concentrated in the more silicic later part of the volcanic sequence. Thus, it is probable that the fluorine was progressively concentrated during the differentiation of the volcanic magma and that an excess of fluorine was left in a hydrothermal fluid after the consolidation of at least most of the rhyolite. These fluids are believed to be the source of the fluorine that formed the fluorspar deposits on Spor Mountain.

The uranium in the uraniferous fluorspar deposits may also have come from the rhyolitic magma, inasmuch as rocks of the younger volcanic group, which make up the greater part of the volcanic rocks, contain roughly three times the uranium content of the average rhyolitic rock in Western United States. (See

712-190 O—64——10

section on "Uranium Content of the Volcanic Rocks," pages 115–116.) Thus, the magma from which the rhyolite was derived contained abnormally large quantities of both fluorine and uranium.

Character of ore-forming fluids.—Hydrothermal fluids that formed the fluorspar were probably derived from a magmatic source well below the deposits, so that these fluids had to pass through hundreds of feet of country rock. Changes may have occurred in the ore-forming fluids as they moved through the dolomite, quartzite, shale, or limestone that underlie Spor Mountain and the various fluorspar deposits.

The major elements found in the fluorspar deposits in amounts exceeding 0.5 percent are calcium, magnesium, silicon, aluminum, fluorine, hydrogen, and oxygen. Fluorine is the only element in this group that could not have been derived in significant quantities from the country rocks adjacent to the deposits. Calcium may have come largely from the country rock at the site of deposition of the fluorite; this source is suggested by the fact that all the medium to large deposits are in dolomite. The minor elements, which make up between 0.01 and 0.5 percent of the fluorspar, include uranium, vanadium, and strontium. Strontium may have been derived from the surrounding country rock; uranium and vanadium probably were not. Thus, the original ore-forming fluid may have been quite simple, consisting only of fluorine with minor amounts of uranium and vanadium. Other compounds or elements, such as H_2O, CO_2, and chlorine, may have escaped from the ore bodies in a gaseous state and left little trace of their existence.

Fluorite may be deposited under a wide range of temperatures (Cox, 1945, p. 268). In some places it is found as a primary constituent of igneous rocks, and in others as a constituent of hot-spring deposits. The fluorspar deposits on Spor Mountain probably formed under low temperatures, and may be in part hot-spring-type deposits. The fine-grained character of the fluorite and the associated minerals is similar to that in other low-temperature fluorspar deposits described by Cox (1945, p. 270–279). Some of these deposits, such as those at Wagon Wheel Gap, Colo., and Ojo Caliente, N. Mex., are associated with hot springs. Lack of alteration around the ore bodies on Spor Mountain also suggests deposition at low temperatures. The contact between the fluorspar and the dolomite country rock is sharp and has no intermediate zone of partly altered dolomite.

The probable low temperature of formation of these fluorspar deposits suggests that they were deposited at sites well removed from the first contact of the ore-forming fluids with the carbonate rocks. The fluids evidently rose along fractures with little reaction with the carbonate country rock in the early stages. Garrels and Dreyer (1952, p. 329–341) pointed out that the solubility of calcium carbonate increases with an increase in pressure or the addition of salts, and with a decrease in temperature, pH, and CO_2 content. Fluorine-rich fluids rising along channelways would gradually decrease in temperature and pressure and increase in content of CO_2 and salts. The decrease in carbonate solubility caused by the increase in CO_2 content, however, would be more than offset by the decrease in pH caused by this increase in CO_2 content. Changes in temperature are probably the most important factor in increasing the solubility of calcium carbonate, because a change from 65° to 25° C causes approximately a tenfold increase in the solubility (Garrels and Dreyer, 1952, p. 340). Fluorine-rich fluids would, therefore, show little reaction with the carbonate country rock until the temperature had fallen to a point where the carbonate rock was soluble in relatively large amounts. White (1957, p. 1652) suggested that in a hot spring where sodium chloride water reacts with limestone the temperature where significant solution begins is close to 100° C.

Formation of the ore bodies.—The fluorspar ore bodies on Spor Mountain were formed by replacement of the country rock by hydrothermal fluids. The most obvious examples of replacement are in the disseminated deposits where fluorite may make up less than a quarter of the rock. Here fluorite can readily be seen in clay-rich layers around fragments in a tuff or in certain areas in altered rhyodacite. Relict structures are also present in the more completely replaced fluorspar pipes in the dolomite, although they are generally scarce. Bauer (see footnote, p. 7) stated that the chert from the black bed in the lower part of the Lost Sheep dolomite can be traced through both the Blowout and main Lost Sheep pipes. In the lowest underground workings of the Blowout deposit, relict bedding which conforms to that of the adjacent wall rocks can be seen in the fluorspar ore body. Silurian corals completely replaced by fluorite have been found in three mines. Bauer (see footnote, p. 7) found a *Favosites* sp. in the main Lost Sheep ore body. We discovered another *Favosites* sp. in the east pipe on the Fluorine Queen property and a horn coral in the large pipe on the Bell Hill property (fig. 52).

Age of the mineralization.—The fluorspar deposits were in general formed after most of the volcanics were erupted, as can be illustrated in a number of places: (1) in the lower tunnel to the Blowout mine,

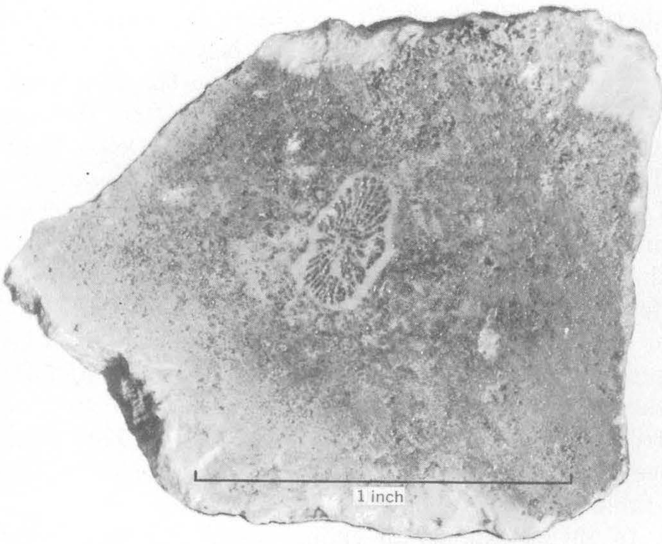


FIGURE 52.—Horn coral completely replaced by fluorite, from center of large ore body, Bell Hill property. The whole specimen is fluorite.

where a small purple fluorspar vein cuts the intrusive breccia composed of rhyolite fragments, (2) at the north end of a small tunnel in the Dell property, where a fluorspar pipe partially replaces a rhyolite plug, (3) on the Harrisite property, where a small fluorspar vein occurs on a dolomite-rhyodacite contact and partially replaces both, (4) at the Rainbow prospect where fluorite is disseminated in tuff, (5) at a prospect 6,000 feet west of the Bell Hill mine which contains fluorite in a tuff, and (6) at a prospect 7,500 feet northwest of the Bell Hill mine, which also contains fluorite disseminated in a tuff. Bauer (see footnote, p. 7) also described fluorite veinlets in a volcanic breccia. Although most of the fluorspar formed later than both the older and younger groups of volcanic rocks, at one place the volcanics appear to be younger. This place is in the underground workings of the Bell Hill mine, where an intrusive rhyolite tuff or rhyolitic pebble dike cuts the main fluorspar ore body. Thus, the fluorspar deposits formed after the bulk of the volcanic activity, but before the last eruptions.

Because the age of all the vulcanism is not known, the age of the fluorspar deposition can only be approximated. The only volcanic rock dated was a crystal tuff from the older volcanic group, which is middle Miocene in age. The older group was tilted and eroded before the younger volcanic group was deposited, and near the very end of this period of volcanic activity the fluorspar deposits were formed. Hence, a considerable period of time could have elapsed between the deposition of the tuff in probable Miocene time and the fluorspar deposits. The deposition of the fluorspar deposits occurred, however, before Lake Bonneville time, for boulders of fluorspar were found in the Lake Bonneville gravels on the Lucky Louie property. The above data indicates the fluorspar deposition most likely took place some time during the Pliocene.

SUGGESTIONS FOR PROSPECTING

Uraniferous fluorspar deposits have been found from the north to the south end of Spor Mountain and on the adjacent Eagle Rock Ridge (fig. 50). Most of the deposits occur, however, in the central and eastern parts of Spor Mountain; little fluorspar has been found in the western part. The lack of known deposits on the west side of Spor Mountain may be due to a lack of sufficient prospecting, but it may also be due to this area's being less favorable.

The area within Spor Mountain can be somewhat limited because no fluorspar deposits have been found in the quartzite of the Swan Peak formation or the sedimentary rocks below and no ore has been produced from sedimentary rocks above the Thursday dolomite. Thus, the favorable sedimentary rocks are the four Silurian dolomites (Thursday, Lost Sheep, Harrisite, and Bell Hill), the Ordovician or Silurian Floride dolomite, and the Ordovician Fish Haven dolomite.

Within these sedimentary rocks, most of the ore bodies are adjacent to either faults or intrusive breccia bodies. Inasmuch as Spor Mountain is cut by approximately 1,000 faults the job of prospecting along all of them is enormous. Prospecting is most likely to be fruitful, however, in the vicinity of known fluorite veins or pipes, because commonly the ore deposits occur in groups. Prospecting around intrusive breccia pipes is somewhat easier for they are considerably less in number.

The fluorspar deposits are soft and easily eroded and form topographic lows generally covered by dolomite slope wash. In areas where the dolomite occurs as prominent outcrops, oval or circular covered areas surrounded by dolomite are favorable sites for finding either concealed fluorspar pipes or concealed volcanic plugs. Float has been an invaluable aid in the early prospecting. Unfortunately the weathered, detrital fluorspar is very soft and is rarely found far from the deposits. Commonly it is included in the debris surrounding ant hills and badger and other animal burrows above the deposits. In areas where the dolomite is chiefly a slope-maker or where the bed rock is covered in part by Lake Bonneville sediments, the ore deposits are difficult to find. One such deposit, the large ore body of the Dell No. 5, was found 6 feet below the surface, during construction of a road to another deposit.

The ore bodies are all abnormally radioactive, so a scintillation counter or a Geiger counter is helpful in exploring for fluorspar bodies if the overburden is not too thick. This method was used by the Chief Consolidated Mining Co., which found the Lucky Louie, during its prospecting (Fitch, Quigley, and Barker, 1949, p. 66).

If the prospector is interested chiefly in the uranium rather than the fluorite content of the deposits, then the area to prospect is somewhat more limited. Although all the fluorspar deposits showed some abnormal radioactivity, only at the Eagle Rock prospect on the Eagle Rock Ridge and on three properties in the southernmost part of Spor Mountain did any of the ore contain more than 0.10 percent uranium. Detailed maps of these two areas at 1:6,000 have been published (Staatz and Osterwald, 1959, pls. 3, 4). The area on the south end of Spor Mountain appears to be the most favorable area, but much of it is mantled or partly mantled with Lake Bonneville sediments. Here, the ore deposits are generally related to faulting. Prospecting should be carried on in the less covered parts with the aid of a scintillation counter. Covered areas, along faults, especially in the area where other fluorite mineralization is present, should be trenched.

HISTORY AND PRODUCTION

Commercial use of fluorite has grown rapidly in the last thirty years. The prospector of the early twentieth century was not interested in Utah fluorspar because of its low value and remoteness from markets in the East, and hence little early prospecting was done for this ore. Although a little fluorspar was produced in Utah prior to 1944, the increasing demand and prices stimulated by World War II caused production to increase sharply in that year (Thurston, Staatz, Cox, and others, 1954, p. 3). Since 1948 most of Utah's fluorspar production has come from the Spor Mountain area.

The first fluorspar deposit located in the district was the Floride, which was found in 1936 by Chad and Ray Spor in prospecting northward from the Drum mining district (Fitch, Quigley, and Barker, 1949, p. 65). No production occurred until 1944, however, when the Spor brothers shipped their first carload of ore to Geneva Steel Co. at Geneva, Utah. In the 5 years, 1944 through 1948, 8,748 tons of fluorspar was produced (table 21). In 1949 the mine was idle; in 1950, 463 tons of ore was produced and from that time through 1956 the mine was idle. All the ore above the lower level (70 feet below the surface) was removed; ore occurs in this mine below that level.

The second major discovery was on the Dell property, which was located in May 1947 by Earl Willden, T. A. Claridge, and Lafe Morley, all of Delta, Utah. They sold this property to Ward Leasing Co. of Salt Lake City, which mined three ore bodies. The main ore body was intersected just above its contact with the quartzite of the Swan Peak formation about 200 feet below the surface. By 1950 the main ore body as well as one of the others had been mined from the surface to the quartzite, with the production of 5,100 short tons of ore. The only mining on this property from 1950 through 1956 was in 1953 or 1954 when lessees removed some of the pillars in the main pipe (table 21).

In 1948 a number of claims containing large pipes were located. The first of these was the Fluorine Queen, located by W. E. Black and F. B. Chesley of Delta, Utah, in March 1948. Two large pipes were discovered on this claim which lies astride a 6,200-foot saddle in the central part of Spor Mountain. Production started in 1948 (table 21) from the western pipe. Mining was shifted to the eastern pipe in 1950, where it continued until the fall of 1953 when the mine was shut down. Mining was resumed in the fall of 1955 and was shifted back to the western pit in 1956. This property has been one of the larger producers in the district and had produced through 1956 a total of 24,087 short tons (table 21).

The next large discovery was made by Albert and Earl Willden on May 10, 1948, in the northern part of Spor Mountain. The claim located on this pipe was called the Lost Sheep because the Willdens were chasing stray sheep when they noted fluorspar ore in a mound from a badger hole (H. L. Bauer, Jr.; see footnote, p. 7). The overburden was cleared off, and production was started by open-pit methods. The opencut in the fall of 1956 had vertical walls approximately 125 feet high. The Lost Sheep has produced more fluorspar than any other property in the district and has operated almost continuously since its discovery to 1956.

The Blowout claim was located on a pipe adjacent to the Lost Sheep claim by Tass and Rex Claridge on May 19, 1948. The pipe is on the divide at the crest of Spor Mountain. The first ore was shipped from an opencut on the pipe. Mining ceased in the opencut in the fall of 1950 when large blocks of dolomite as much as 20 feet across caved into the pit. An adit begun in 1950 on the east side of the mountain cuts the ore body 240 feet below the surface. Mining has been carried out by a series of stopes above the adit level, but the ore contains considerable clay and is lower grade than that exposed in the opencut.

During 1948 smaller pipes and veins were also found on the Oversight, Lucky Louie, Thursday, Eagle Rock, Nonella, Fluorine Queen No. 4, Hilltop, and Dell No. 5 claims.

In 1949 interest shifted to the southern end of Spor Mountain where many claims were located, including the Bell Hill and Harrisite. The Bell Hill is the only property on the south end of Spor Mountain that has produced more than 2,000 tons of ore. It was located by C. D., D. W., and H. E. Searle and H. J. Ruthiford on July 7, 1949. Several ore bodies occur on this property, but most of the ore has come from the largest pipe, which was mined from an opencut to a maximum depth of 35 feet in 1950. A 233-foot adit driven from the base of the hill on which the ore body occurs cuts the pipe 87 feet below the surface. An inclined winze from the end of this adit was sunk in the ore, and the fluorspar was mined from stopes on four levels below the adit. Later, another more permanent winze was sunk from the adit level in the dolomite. In the spring of 1956 there were a total of six levels below the adit, the deepest being 237 feet below the surface. In the summer of 1956 part of the side of the opencut caved in and the rock broke through the pillars between the levels and made the mine inaccessible. Five smaller ore bodies have been found on this property. Total production of this property through 1956 was 23,644 short tons (table 21), of which more than 90 percent came from the main ore body.

Many additional ore bodies have been found on claims where other ore bodies occur. Several smaller ones have been found since the original discovery on the Lost Sheep and Fluorine Queen properties. Some of the more recent discoveries such as the Floride No. 5 pipe and the large pipe on the Dell No. 5 occur on claims that have been located on much smaller fluorspar occurrences. Although hundreds of claims had been located on Spor Mountain through 1956, only two claims, the Lucky Louie and the adjoining Enid, had been patented. These claims were owned in 1956 by Chief Consolidated Mining Co. of Eureka, Utah.

Prior to 1949 all the fluorspar was shipped to Geneva Steel Co., but since 1949 most of the fluorspar has been bought by Continental Ore Buying Co., although some has gone to Colorado Fuel and Iron Corp. and to the Sheffield Steel Co.

Since 1953 production of fluorspar from Spor Mountain has declined chiefly because of competition from ore imported from Mexico and because of the discovery of large high-grade fluorspar deposits on Crystal Mountain near Darby in Ravalli County, Mont.

Total production of the Thomas Range fluorspar district is 111,700 short tons of fluorspar, most of which contained more than 70 percent CaF_2. Although ore has been shipped from 14 different properties, 78 percent of the production has come from three properties: the Lost Sheep, Fluorine Queen, and Bell Hill. The next four properties, the Floride, Blowout, Dell, and Lucky Louie, shipped another 21 percent of the total, and the other seven 2 percent. All available production data are given in table 21 on a yearly basis.

INDIVIDUAL DEPOSITS

A brief description of the various fluorspar properties on Spor Mountain in 1950 was made by Staatz, Wilmarth, and Bauer (Thurston, Staatz, Cox, and

TABLE 21.—*Fluorspar production of the Thomas Range fluorspar district from 1944 through 1956*

[Data, unless otherwise stated, provided by owners and published with their permission]

Property	Deposits producing the fluorspar	Production (short tons)													
		1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	Total
Bell Hill	3	0	0	0	0	0	0	←7,480→		4,466	5.443	2,379	3,407	[1] 469	23,644
Blowout	1	0	0	0	0	0	1,100	2,355	1,313	1,128	1,000	0	0	0	6,896
Dell	3	0	0	0	0	800	3,000	1,300	0	0	←157→		0	0	5,257
Dell No. 5	2	0	0	0	0	0	205	0	0	0	0	0	0	(2)	(2)
Floride	1			←8,748→			0	463	0	0	0	0	0	0	9,211
Floride No. 5	1	0	0	0	0	0	0	0	0	0	0	125	120	500	745
Fluorine Queen	3	0	0	0	0		←9,071→		4,321	3,727	2,968	0	200	[3] 3,800	24,087
Harrisite	2	0	0	0	0	0	0	0	55	0	0	0	0	0	55
Hilltop No. 1	2	0	0	0	0	0	0	0	0	[4] 100	0	0	0	0	100
Lost Sheep	2	0	0	0	0		←11,625→		5,729	6,241	(2)	(2)	[1] 3,771	[5] 4,768	(2)
Lucky Louie	1	0	0	0	0	0	0	0	0	1,432	0	0	0	0	1,432
Oversight	2	0	0	0	0	0	0	0	0	598	0	0	0	0	598
Thursday	1	0	0	0	0	0	[6] 55	0	0	0	0	0	0	0	55
Total															111,651

[1] Production data obtained from Frank Kelly of the U.S. Bureau of Mines.
[2] Production during these years included only in total for district.
[3] Production includes some ore from the adjoining Fluorine Queen No. 4.
[4] Tonnage estimated from size of workings.
[5] Includes some production from the Dell No. 5 and Green Crystal properties.
[6] From Bauer, H. L., Jr., 1952, Fluorspar deposits, north end of Spors Mountains, Thomas Range, Juab County, Utah: Utah Univ., Master's thesis.

others, 1954, p. 24–45). During the next two years, the district was studied in detail and many of the properties were described more fully by Staatz and Osterwald (1959, p. 62–91). Mining continued from 1952 through 1956, but few new data are available on the geology of most of the ore deposits. During this period fluorspar bodies were found on the Dell No. 5, Green Crystal, Floride No. 5, and Evening Star claims, and the mines working were enlarged on the Eagle Rock claim. These properties are discussed below. The geology of the Dell, Floride, Nonella, and Thursday properties is described in the report by Thurston, Staatz, Cox, and others (1954), the geology of the Bell Hill, Blowout, Blue Queen No. 1, Fluorine Queen, Fluorine Queen No. 4, Harrisite, Hilltop No. 1, Lost Sheep, Lost Soul No. 1, Lucky Louie, and Oversight properties, in the report by Staatz and Osterwald (1959).

DELL NO. FIVE

The Dell No. 5 property, in the central part of Spor Mountain (fig. 50) astride a pass at an elevation of 6,100 feet, was located on April 6, 1948, by Albert and Earl Willden, T. A. Claridge, and Lafe Morley of Delta, Utah. The workings are reached from the main haulage road along the east side of Spor Mountain by a steep private road a little over 1 mile in length.

Two small fluorspar pipes are exposed on the claim, one near the low point of the saddle and the other about 250 feet to the north and 140 feet higher up the ridge. The Spor brothers leased this property in 1948 and drove an adit 48 feet west-northwest to the lower ore body; later they extended the adit for 272 feet toward the upper ore body, which it did not meet. The lower ore body was intersected at about 25 feet below the surface and was stoped for 15 feet above and 27 feet below the adit level. The Spor brothers produced 205 tons of fluorspar from this stope. The upper ore body is partly exposed by bulldozer workings and is prospected by a 15-foot adit. No production has come from this ore body. The property was inactive except for assessment work until 1954 when Al and Earl Willden, in bulldozing a road to the Green Crystal claim, uncovered a large pipe on the west end of this property under 6 to 15 feet of overburden. The ore body was mined from an opencut that by the end of 1956 was 140 feet in length, 120 feet in maximum width, and 35 feet deep on the uphill side (fig. 53). The production of this pipe is not known, but it is estimated to be more than 1,000 tons of fluorspar.

Geology and ore deposits.—The two small fluorspar ore bodies occur on the crest of the range in the Fish Haven dolomite adjacent to a porphyritic rhyolite plug. The southernmost of these two pipes was about 15 feet in diameter and contained friable white to purple fluorspar. The north pipe had a minimum diameter of 15 to 20 feet, and although the fluorspar was in part powdery, it contained many hard ribs of siliceous material. These two pipes were described by Staatz (Thurston, Staatz, Cox, and others, 1954, p. 33).

The large ore body on the west end of the property also is in Fish Haven dolomite, but the surface exposure is only a short distance above the Swan Peak formation-Fish Haven dolomite contact, and is 90 feet west of a fault offsetting this contact (fig. 53). The ore body is roughly oval in plan, and although it is not completely exposed, the maximum dimensions in the pit are 150 feet long by 140 feet wide. The ore body has near vertical walls and probably extends to the quartzite of the Swan Peak formation. Whether the ore extends down along the contact in the dolomite is not known, but it is likely to end at the quartzite, inasmuch as only small veins of fluorspar have been found extending into the quartzite below pipes in other parts of Spor Mountain. The ore body thus probably ends between 25 and 130 feet below the surface (fig. 53).

Most of the ore from the large western pipe is a light reddish-brown, very fine grained friable boxwork. Some of the ore is dark purple that grades into white, and some is hard and compact. The hard compact ore generally occurs as lumps in the more friable ore, but along the western side of the pipe it makes up large areas. White calcium-magnesium montmorillonite is found in scattered pockets throughout the fluorspar. Three samples of ore contained from 62.5 to 92.8 percent CaF_2 (table 20). The highest grade ore came from the more compact material along the west side of the pipe.

The uranium content of five samples from the west pipe ranged from 0.010 to 0.030 percent uranium; that of one sample from the small north pipe was 0.020 percent uranium; and that of one sample from the south pipe was 0.012 percent uranium (table 20).

EAGLE ROCK

The Eagle Rock property is in a small hollow on the east side near the north end of Eagle Rock Ridge (fig. 50). The center of this hollow is at an altitude of approximately 5,820 feet, 120 feet above the base of Eagle Rock Ridge. In the flats just east of Eagle Rock Ridge a dirt road parallels the ridge. From this road a short mine road that ends 200 feet laterally and 100 feet lower has been constructed to the main workings. A second, very steep mine road in poor

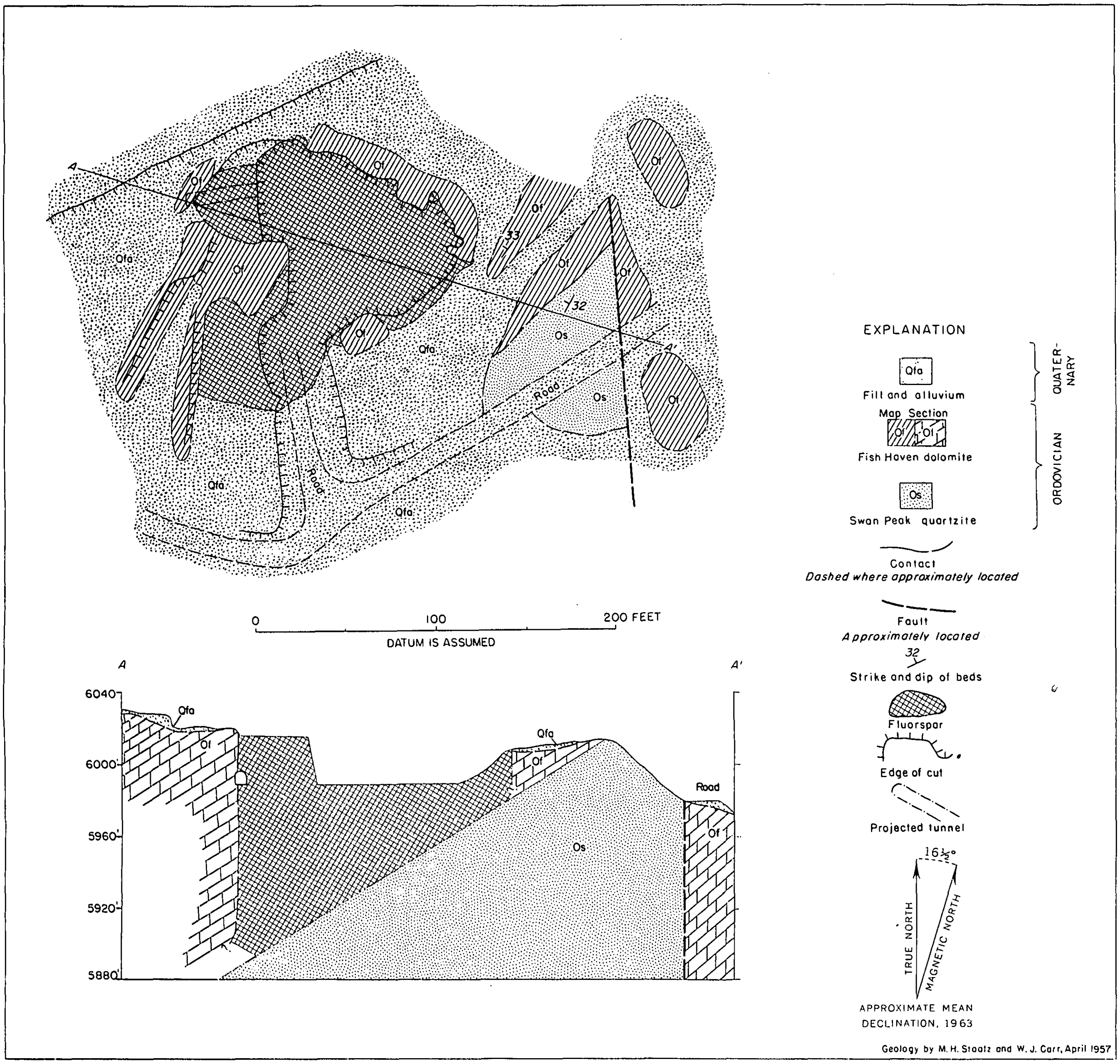


FIGURE 53.—Geologic map and section of the west pipe on the Dell No. 5 property, Spor Mountain.

condition reaches the workings from the north end of the ridge.

The property was located by T. A. and Rex Claridge and Al and Earl Willden, all of Delta, Utah, on August 15, 1948. The discovery trench was dug on a small fluorspar vein (pl. 7). A second trench was dug entirely in dolomite 13 feet northeast of this trench, and to the west two bulldozer trenches and an opencut were made to explore a covered area, which is underlain by highly altered dolomite. The newest workings consist of an adit started at an elevation of approximately 5,710 feet on the side of the ridge and driven S. 83° W. toward the discovery trench. In April 1957 it was 169 feet long and had just reached the altered dolomite. No ore has been shipped from this property.

Geology.—The Bell Hill, Harrisite, and Lost Sheep dolomites crop out on the Eagle Rock property (pl. 7). These dolomites strike approximately N. 45° E. and dip 30° NW. In the central part of the property a gentle sloping depression is covered by slope wash; similar smaller depressions are found elsewhere on the property. The dolomite near the edges of these depressions is commonly brecciated and the fractures filled with silica. Rocks exposed in the bulldozer trenches in the large depression and in the pit in the opencut are a pale-buff to red calcareous claylike material that locally is highly siliceous and has a boxwork structure. During the spring of 1956 a churn hole was drilled by the owners near the south end of the depression. Cuttings from a depth of approximately 50 feet contained quartz and sanidine and indicate an underlying volcanic body. The depressions occur in the soft claylike material and were probably formed by the heat and by volatiles from the underlying volcanic intrusive body on the overlying dolomite.

Ore deposits.—Most of the fluorspar exposed on this property is in a small vein on the southeast corner of the large depression. The vein is vertical, and can be traced for 40 feet. This vein is best exposed in the discovery trench and is extremely irregular in size and shape. The fluorspar vein thins from 4 to ½ foot thick in 10 feet along its strike; near the middle of the trench it also thickens from less than an inch to 4 feet thick in 4 feet of depth.

Small masses of fluorspar with a maximum diameter of 1 foot are exposed in a siliceous boxwork at the end of the adit at the contact of the dolomite with red calcareous clay.

The fluorspar vein is a dark-purple siliceous boxwork and is unusually hard and resistant in contrast to the powdery fluorspar common in the district. Quartz can be seen in most specimens and makes up at least 50 percent of the vein. The fluorspar content of the vein is low. The one sample analyzed for fluorine was a 1.7-foot channel sample cut across the vein approximately 7 feet below the surface. The fluorite content of this sample is 35 percent. Small white botryoidal masses of calcite, 1 to 2 mm across, are found plastered on the siliceous fluorspar boxwork in a few places.

Bright-yellow powdery carnotite coats the fluorspar in some places. More carnotite is visible in this vein than in any other fluorspar deposit in the district. Three channel samples cut across this vein contained from 0.088 to 0.17 percent uranium. Two samples from the ore pile mined from this vein contained 0.18 and 0.31 percent uranium. The last sample, however, was of selected high-grade rock. Uranium minerals are also exposed in the pit 100 feet west of the fluorspar vein at the west end of one of the bulldozer trenches. This pit is on the south edge of the depression, and its south wall is silicified dolomite. The rest of the pit shows a mixture of calcareous clay and silicified material, which is in part a boxwork. Some of the clay is montmorillonite. A little purple fluorite and bright-yellow carnotite coat some of the silicified material. A few pieces of rocks show green copper staining. A horizontal channel sample across the north side of the pit, 7 feet below the surface, contained 0.031 percent uranium (table 20). A second sample consisting of the highest grade rock available was selected from the dump; this sample contained 0.59 percent uranium.

EVENING STAR

The Evening Star property covers a low hill in the southwestern part of Spor Mountain (fig. 50). The workings lie on the northwest side of the hill which is 2,300 feet S. 63° W. of the Floride No. 5 pipe, in the NW¼ sec. 10, T. 13 S., R. 12 W. The property is connected to the road around the south end of Spor Mountain by a dirt road about a mile long.

The Evening Star claim was located November 6, 1953, by Glen Bunker and Sydney Searle. The workings consist of a bulldozer trench approximately 80 feet long and about 6 feet deep near its center. In the center of the trench an inclined shaft about 8 feet deep has been sunk. Production, if any, from this property appears to have been small.

Geology and ore deposits.—A porphyritic rhyolite intrusion makes up the central part of the low hill and is surrounded by dolomite. The rhyolite contains about 20 percent phenocrysts (0.5 to 1 mm across) of clear sanidine and smoky quartz in a purplish-gray aphanitic groundmass. Commonly the rhyolite weathers dark brown. Rubble from the rhyolite and Lake Bonneville gravels obscures the contact between the rhyolite and the dolomite. The only exposure is in the bulldozer trench, where the rhyolite is in contact with the lower part of the Lost Sheep dolomite. Along this contact is a zone about 15 feet wide of light-gray clayey material, formed by reaction between the rhyolite and the dolomite. Slickensides indicate some shearing or faulting with a trend of N. 26° E. and a dip of 60° SW.

Fluorspar is spottily distributed in the contact zone in irregular masses surrounded by clayey material. Several small veins also occur in this zone; the largest noted was 8 inches wide. The fluorspar is exposed along this zone for a distance of 72 feet; it is fine grained, massive, and dark purple. A grab sample of the dark-purple fluorspar off the dump contained 0.023 percent uranium (table 20).

FLORIDE NO. FIVE

The Floride No. 5 property is on the steep south side of a ridge in the southern part of Spor Mountain (fig. 50), in the SE¼ sec. 3, T. 13 S., R. 12 W.

The ore body is near the crest of a ridge at an altitude of approximately 5,470 feet. The ore bin is connected by a road, 1.7 miles long, to the road that passes around the south end of Spor Mountain.

The Floride No. 5 was located by George, Ray, and Chad Spor on April 27, 1944. The first ore, however, was not shipped until the fall of 1954; this came from an opencut. Owing to the difficulty of building a road to the ore body, an adit 205 feet long was driven toward the ore body from an altitude of about 5,340 feet (fig. 54). From its end a raise was extended to the surface at an altitude of 5,440 feet. A 50-foot trench (fig. 54) was cut from the top of the raise to the opencut, and the ore above this level was trammed to the raise and dropped down it. After the ore was mined to the level of the top of the raise, a second inclined raise was constructed off the first raise to the ore body, which was reached approximately 50 feet below the bottom of the opencut. The adit was extended late in 1956 toward the ore body, but by the end of the year had not reached it.

Through 1956 total production of this ore body was 745 tons (table 21). The ore was being shipped to Kaiser Steel Co. in Fontana, Calif.

Geology and ore deposits.—The Floride No. 5 ore body occurs in the lower half of the Bell Hill dolomite in one of the larger fault blocks on Spor Mountain. The ore body at the surface is an oval pipe having a length of 27 feet and a maximum width of 20 feet (fig. 54). The pipe has steep walls and plunges 61° S. 46° E.

The ore is purple to deep blue; some of it is soft and friable and some occurs as hard boxwork. The chief impurity is white clay; the boxwork of fluorite in places is coated with small white crystals of calcite. Two chip samples, taken in the pipe from 6 and 60 feet below the surface, contained 68.5 and 72.5 percent CaF_2. Chad Spor (oral communication,

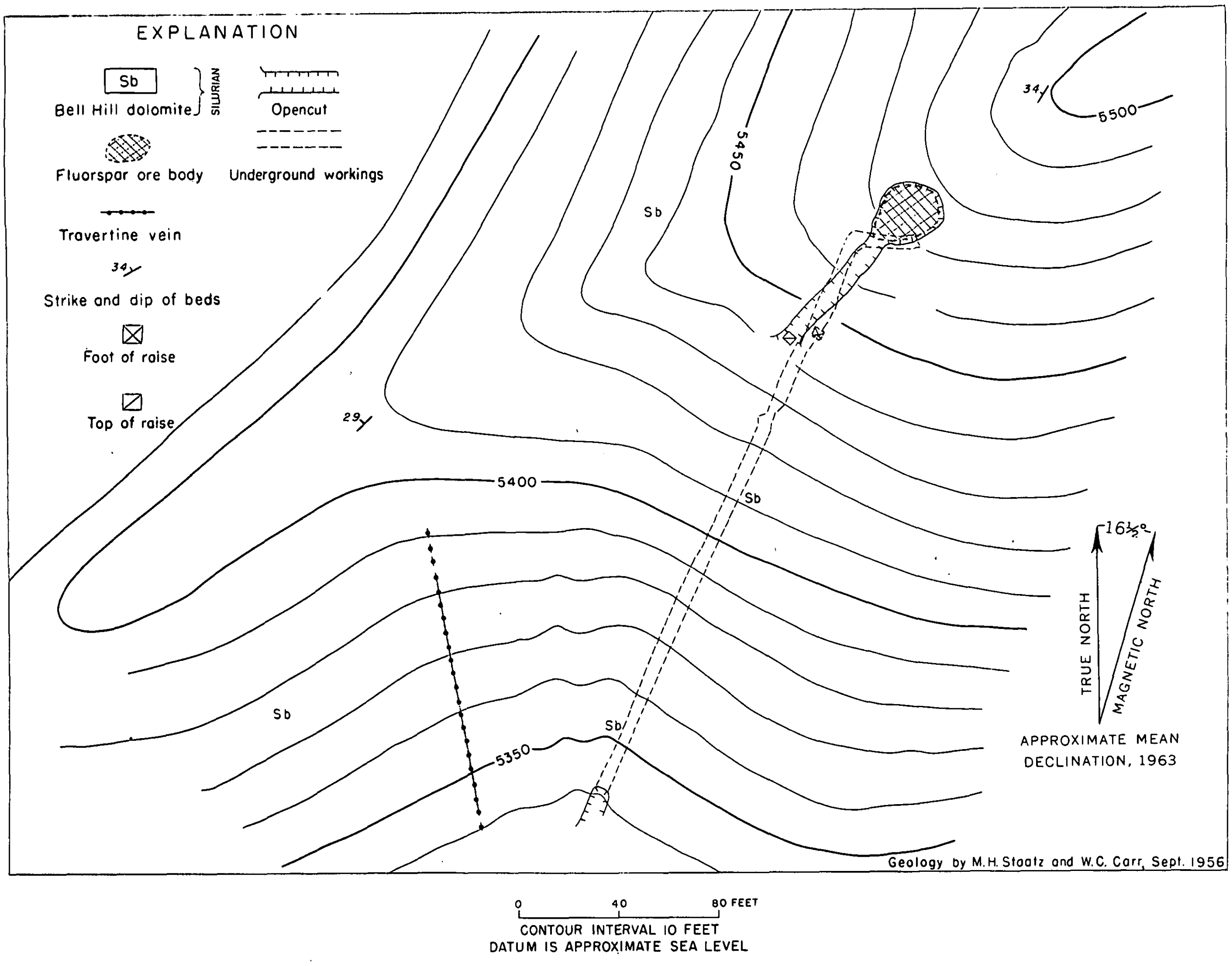


FIGURE 54.—Geologic map of the Floride No. 5 fluorspar mine, Spor Mountain.

1956), however, reported carload lots containing as much as 80 percent CaF_2. No uranium minerals are visible in this ore body. The uranium content of three samples taken from this ore body (table 20) ranged from 0.027 to 0.032 percent uranium.

GREEN CRYSTAL

The Green Crystal property is in the central part of Spor Mountain on the west side of the main divide (fig. 50), and adjoins the Dell No. 5 property to the northeast. The Green Crystal workings lie on the northwest side of a prominent southwest-trending canyon at an altitude of approximately 5,900 feet. The workings are reached from the main haulage road along the east side of Spor Mountain by a steep private road about 1¼ miles long.

The Green Crystal claim was located on October 1, 1952, by Al and Earl Willden and T. A. Claridge of Delta, Utah. In 1954 the road to the Dell No. 5 was extended to the Green Crystal. The first ore was produced in late 1955 or early 1956 when, according to Al Willden, 8 carloads, or about 500 tons of fluorspar, were shipped. Workings as of the fall of 1956 consist of an opencut approximately 20 feet wide, 40 feet long, and of a maximum depth of 35 feet.

Geology and ore deposits.—The Green Crystal pipe crops out mainly in the lower part of the Floride dolomite, although a few feet of the pipe on the south side is in the underlying Fish Haven dolomite. This ore body does not appear to be within 150 feet of any fault.

The pipe is oval in plan and is 43 feet long by about 18 feet wide. It appears to plunge steeply in an east-southeast direction.

The ore is generally pale to dark purple, although in places it is light reddish brown. The fluorspar is very fine grained and occurs mainly as a boxwork, although in some places it is found in solid masses. Brown clay is the chief impurity; some chalcedony and white clay were also noted. A 9.5-foot channel sample taken in the upper part of the ore body along its northwest side contained 92.5 percent CaF_2 (table 20). This sample also contained 0.020 percent uranium and a sample taken 15 feet lower in the pipe contained 0.038 percent uranium.

URANIUM DEPOSITS

Deposits important chiefly for uranium are found in a poorly defined area in the southern third of the main part of the Thomas Range. These deposits are of two types: veins and disseminated deposits.

VEINS

Vein deposits are found in several places in the southern part of the Thomas Range. These deposits are of little economic interest and no ore had been shipped from any of them through 1956. A small amount of development work has been done on several deposits including the Buena No. 1 (fig. 50) and the Autunite No. 8 (pl. 1). The deposits consist of a number of small veins from one-thirty-second to one-half an inch thick that fill steeply dipping irregular fractures. These veins may be from less than half an inch to more than 1 foot apart. The areas in which the veins occur are generally not large; the largest known is on the Autunite No. 8 property; it is about 100 feet long and has a maximum width of 25 feet. Some areas are only 10 feet long and a few feet wide; in a few places only a single veinlet is present.

Veins are most common in the porphyritic rhyolite of the older volcanic group, but they are also found in rhyolite and vitric tuff of the younger volcanic group.

The relation of the uranium-bearing veins to structural features is not as clear as is that of the uraniferous fluorspar deposits. Four groups of fractures contain veins with abnormally high radioactivity on the Autunite No. 8 property. These lie from 100 to 800 feet south of one of the few faults cutting the volcanic rocks. The fault has a northeast trend and most of the fractures have a northerly trend; these trends suggest the possibility that the fractures were formed by tension set up by shearing movement along the fault.

DISSEMINATED DEPOSITS

Disseminated uranium deposits are known only on the Good Will property in the central part of The Dell (fig. 50). The only uranium production through 1956 came from these deposits.

Uranium in the disseminated deposits occurs in limestone pebbles or cobbles in a limestone conglomerate and in a tuffaceous sandstone that underlies the conglomerate. Inasmuch as the limestone cobbles make up only a small part of the conglomerate and only a few of the cobbles contain any uranium minerals, the conglomerate is of little economic interest. Uranium deposits in the tuffaceous sandstones, however, are of considerable potential economic interest.

The exact size and shape of the uranium deposits in the tuffaceous sandstone are difficult to determine except in the various workings because the entire area is covered with slope wash and alluvium. Areas of abnormally high radioactivity, however, range from patches a few inches square to the main ore body, which is at least 120 feet long by 65 feet wide. In plan view the deposits are generally rectangular or oval in shape. The uranium minerals occur chiefly as fillings of pore spaces in the sandstone.

Few structural features are visible in the vicinity of the Good Will property because the area is largely covered. One fault was noted on the east side of the Good Will property; all known abnormally radioactive areas lie west of this fault, and the main ore body is about 180 feet from it.

This section is briefer than the importance of disseminated deposits warrants. It was kept brief because disseminated deposits occur only on the Good Will property, and a mine description of this property would require much repetition. This type of deposit is discussed further on pages 154 to 157.

MINERALOGY

The mineralogy of the veins and of the disseminated deposits is similar in that both contain minerals known to form at low temperatures and both contain some of the same gangue and uranium minerals. The mineralogy differs in the amount of gangue, the kinds of some of the uranium and gangue minerals, and the occurrence of these minerals.

Opal is the chief mineral in the veins and makes up from 75 to 100 percent of all veins. The opal is white, greenish white, pale green, or bluish white and in places is found as botryoidal bands. The opal occurs in two forms: as an opaque white type, which makes up the greater part of the opal, and as transparent pale-green hyalite. Other gangue minerals include calcite and fluorite. Calcite in clear to white crystals is erratically scattered in the various veins; in many places none is found and in some places it makes up as much as 20 percent of the vein material. Fluorite also is erratically distributed but rarely makes up over a few percent of the vein. It occurs in colorless, pale-purple, or dark-purple crystals, which may be intermixed with the other gangue minerals or perched as small discrete cubes on the opal. The white fluorite is commonly difficult to identify in hand specimen because the crystals are rarely more than one-sixteenth of an inch across and are associated with white opal or calcite.

Although many of the veins show abnormal radioactivity, visible uranium minerals were noted only in the group of veins adjacent to the discovery pit on the Autunite No. 8 property. The uranium mineral at this locality is a yellow fibrous mineral, weeksite (Outerbridge, Staatz, Meyrowitz, and Pommer, 1960, p. 39–52). The abnormal radioactivity noted in the other veins is also due to uranium, as indicated by the analyses (table 22). The uranium may occur in discrete very fine grained minerals included in the opal, or the opal itself may contain the uranium. Opal containing finely divided carnotite and uranium-bearing opal with no visible uranium minerals has been reported in the Virgin Valley opal district, Humboldt County, Nev. (Staatz and Bauer, 1951, p. 2).

Most of the minerals of the disseminated deposits are erratically distributed. In the limestone conglomerates, the chief mineral is also weeksite, and locally this mineral is associated with black manganiferous calcite. No other introduced minerals are known.

In the tuffaceous sandstone the chief uranium mineral is beta-uranophane. This mineral occurs in the pore spaces of the rock. Veinlets of schroeckingerite, a greenish-yellow powdery uranium mineral, were noted in one place. The only gangue mineral specifically noted was fluorite, which occurs as sparse white or pale-purple fine-grained masses; it is quite rare.

CHEMICAL COMPOSITION OF THE ORE

The lack of any visible uranium minerals in many places and the fine grain-size and sparsity of the uranium minerals in other places make it extremely difficult to estimate visually the tenor of the deposits. Thus, the variation in the uranium content is best obtained by chemical analyses.

The uranium content of 6 samples from the veins ranged from 0.009 to 0.20 percent uranium (table 22). The uranium content of 16 samples from the disseminated deposits ranged from 0.001 to 0.65 percent uranium. The vein sample containing 0.20 percent uranium came from the Autunite No. 8 property and consists of selected pieces of the high-grade ore. Other than this one selected sample, the only samples showing more than 0.10 percent uranium are from the main ore body on the Good Will property.

The radioactivity analyses of samples from the veins showed equivalent uranium content from 20 to 30 percent higher than the uranium content shown by chemical analyses of the same samples (table 22). For some samples, the difference is somewhat higher than the possible analytical error. If no thorium is present in the samples, then the uranium is slightly out of equilibrium with its daughter products. The results of radiometric and of chemical analyses are close enough, however, so that a fair measure of the uranium content of samples of this type of deposit can be made from a radiometric analysis.

The radiometric analyses from the disseminated deposits on the Good Will property, however, differ

TABLE 22.—*Analyses of uranium samples from uranium deposits in the southern part of the Thomas Range*

[All analyses by Denver laboratory of the U.S. Geological Survey]

Property	Field sample	Type of sample	Location	Equivalent uranium (percent)	Uranium (percent)
Autunite No. 8	SB-71-50	8.5-ft channel	Across west end of discovery pit	[1] 0.030	[2] 0.026
	SB-72-50	2.2-ft channel	Small pit 80 ft east of sample SB-71-50	[1] .017	[2] .013
	SB-75-50	Selected grab	High-grade sample of selected material from dump at discovery pit.	[1] .25	[2] .20
	SB-73-50	4.0-ft channel	Heavily opalized zone 180 ft west-northwest of discovery pit	[1] .025	[2] .022
	SB-74-50	2.5-ft vertical channel	Tuff ledge in canyon bottom approximately 600 ft west of discovery pit.	[1] .011	[2] .009
Buena No. 1	CS-32-55	6-ft chip	Along side of discovery pit	[3] .024	[4] .023
Good Will	SC-5-55	Chip	From tuffaceous sandstone just below limestone conglomerate in trench at southwest end of main ore body.	[3] .013	[5] .012
	SC-6-55	Grab	From auger hole in tuffaceous sandstone near middle of main ore body.	[3] .030	[5] .021
	SC-7-55	2.8-ft vertical channel	From small surface trench in main ore body, 35 ft south-southeast of sample SC-6-55.	[3] .59	[5] .65
	SC-11-55	30-ft horizontal chip	Across central part of main ore body in first bulldozer cut	[3] .47	[5] .51
	SC-12-55	Chip	Across yellowish band noted in part of pit. This sample represents a small part of sample SC-11-55.	[3] .055	[5] .047
	CS-33-55	3-ft vertical channel	Sample across bedding in tuffaceous sandstone a few feet south of main ore body near surface.	[3] .062	[4] .001
	CS-34-55	4.7-ft vertical channel	Sample across bedding in tuffaceous sandstone in south central part of main ore body.	[3] .091	[4] .049
	CS-35-55	4.7-ft horizontal channel	Sample along horizon in bottom of cut at base of sample CS-34-55	[3] .15	[4] .12
	DW-18-56	5-ft vertical channel	From west-trending tunnel in main ore body, 67 ft horizontally and 18 ft vertically below original surface.	[3] .044	[6] .038
	DW-19-56	4.9-ft vertical channel	From northwest-trending tunnel in main ore body, 8 ft in tunnel from opencut.	[3] .11	[6] .097
	SC-8-55	4-ft vertical channel	In tuffaceous sandstone from 10-ft square pit to the southeast of the main ore body.	[3] .034	[5] .006
	CS-36-55	1.8-ft vertical channel	From small pit in tuffaceous sandstone, 10 ft below limestone conglomerate; about 1,000 ft south-southwest of main ore body.	[3] .062	[4] .007
	SC-2-55	4.6-ft vertical channel	In tuffaceous sandstone near southwest corner of discovery pit	[3] .005	[5] .003
	SC-3-55	2-ft horizontal channel	In limestone conglomerate at northwest corner of discovery pit	[3] .012	[5] .005
	SC-1-55	Grab	From auger hole in tuffaceous sandstone, 180 ft S. 25° W. of the discovery pit.	[3] .009	[5] .004
	SC-4-55	Chip	From small pit in tuffaceous sandstone, 158 ft N. 55° E. from discovery pit.	[3] .13	[5] .004

[1] Radiologist, J. N. Rosholt, Jr.
[2] Analyst, G. W. Boyes, Jr.
[3] Radiologist, C. G. Angelo.
[4] Analysts, R. P. Cox and Mary Finch.
[5] Analysts, J. P. McClure, R. L. Daywitt, and James Wahlberg.
[6] Analyst, J. P. Schuch.

from the chemical analyses by from 8 to more than 6,000 percent. Seven of the 16 samples show 25 percent or less variation, and the analyses are comparable in agreement with those obtained from the veins. The variation in the rest of the Good Will samples is so large that a radiometric analysis is obviously of little value for determining the grade of the ore. Radiochemical analyses on the two samples showing the greatest variation indicate that the discrepancy is not due to the presence of parental thorium (Th^{232}) but to the daughter products of the uranium. The big difference in equilibrium of the uranium between the disseminated deposits on the Good Will property and the numerous veinlets may be due to the disseminated deposits' being in a permeable sandstone and the other deposits' being in a relatively impermeable rhyolite or tuff. In the permeable sandstone, ground water can circulate and separate the uranium from its daughter products.

ORIGIN OF THE URANIUM DEPOSITS

The uranium-bearing fluids that formed the uranium deposits are believed to have been derived from the same source as those that formed the uraniferous fluorspar deposits; for example, a hydrothermal fluid formed during differentiation of the younger volcanic group. Uranium content of the rocks of the younger volcanic group is roughly three times that of the average rhyolitic volcanic rock in the western United States, and the magma that formed them would contain the necessary uranium needed to form these deposits. The traces of fluorite found in these deposits could easily be formed by fluorine derived from the fluorine-rich volcanic rocks.

The same original source of the uranium deposits and the uraniferous fluorspar deposits is still suggested, however, by both types of deposits' containing the same rather limited suite of elements, and both types of deposits' being formed at approximately the same time (after most of the younger group of volcanics and before Lake Bonneville sediments).

On the Good Will property the uranium-bearing fluids migrated upward, probably along the fault that lies to the east of the main workings (pl. 8). The migration of these fluids into the adjacent country rock was dependent on the porosity and permeability of the particular rock unit. In the upper part of the disseminated deposits, uranium is concentrated in some of the limestone cobbles in a conglomerate. Although this conglomerate is more permeable than the nearby tuffs, it has rather dense matrix which probably restricted circulation. As a result, replacement of the limestone cobbles has been limited and erratic.

In the lower part of the disseminated deposits, uranium is concentrated in a tuffaceous quartz-sanidine sandstone whose high permeability permits uranium-bearing fluids to pass more or less freely through it; the moderately high porosity of this sandstone furnishes space in which uranium minerals can be deposited. The well-sorted water-laid crystal tuff that underlies the tuffaceous sandstone is slightly better sorted than the sandstone and is made up of the same minerals in approximately the same proportions. This tuff, however, has considerably more fine material, chiefly ash; its porosity is approximately half that of the sandstone and its permeability is many times less. The porosity and permeability of the sandstone control the deposition of the uranium.

SUGGESTIONS FOR PROSPECTING

Uranium deposits consisting of veins probably occur in several places other than those now known. The small size of the veins and the wide spacing between them, the limited size of the areas in which groups of veins occur, and the small proportion of uranium in the veins, suggest that deposits of this type are likely to be of little economic importance. Hence, prospecting for uranium deposits in this area should be concentrated on the disseminated deposits.

The disseminated deposits in the limestone conglomerate on the Good Will property are of little economic value because the uranium occurs only as a partial replacement in parts of some of the limestone cobbles.

The disseminated deposits in tuffaceous sandstone or other equally porous rock afford the best opportunity of finding new, economically important uranium deposits in this region. Tuffs, which are so common in the Thomas Range, contain considerable fine ash, and have a low permeability and porosity. Probably only sandstone or tuffaceous sandstone is porous enough to contain economically significant deposits of uranium. Tuffaceous sandstone in the Thomas Range is known at three localities: (1) a quartz-sanidine sandstone that contains the uranium deposits is on the Good Will property, (2) a calcareous sandstone is at the base of the steep western escarpment of the main part of the Thomas Range at the north end of The Dell, and (3) a pyroxene-plagioclase sandstone is in the Black Rock Hills. Although the number of sandstone exposures are quite limited, these rocks, owing to their friable character, are commonly covered by slopewash where the relief is not great. For example, the sandstone on the Good Will property is nowhere exposed except in the workings and along the roads.

Because the most favorable site for the disseminated deposits is in the sandstones and the most likely areas for sandstone are generally covered, prospecting can best be carried out in the low areas surrounding the main part of the Thomas Range by carefully crisscrossing the area with a radiation counter. One of the more favorable areas to search would be The Dell, where two of three known sandstones occur. The best radiation counter for this type of work would be a scintillation counter because its greater sensitivity allows the user to scan a greater area and detect radiation beneath a thicker cover of overburden.

HISTORY AND PRODUCTION

The first uranium deposit discovered in the mapped area was in 1950 on the Autunite group of claims on the east side of the Thomas Range. Enthusiasm for this property was high because of the mistaken belief that the fluorescence produced by the opal gangue was largely due to autunite and because of several analyses which were in error by factors of 10 or more. Interest in this property died out largely in the fall of 1950 when the true grade of the deposit was found. Only sporadic development work was done from 1950 through 1956.

During 1953 and 1954 another statewide search for uranium deposits was spurred by the discovery of rich deposits on the Colorado Plateau. Several hundred claims for uranium were located in the Thomas Range. Many of these claims are entirely underlain by great thicknesses of Lake Bonneville sediments and show no abnormal radioactivity.

In April 1954 uranium was found on the Good Will claim. In the next two years work was mainly exploratory bulldozing of long trenches, digging of pits, and drilling of vertical holes. Through 1956 a total of 129 tons of ore had been shipped to the U.S. Atomic Energy Commission's buying station in Marysvale, Utah, and to Vitro Corp. in Salt Lake City.

In August 1954 the Buena No. 1 claim was located on the east side of The Dell, east of the Bell Hill property. This property is of minor importance and exploration has been confined to a small discovery pit.

INDIVIDUAL DEPOSITS

Although the disseminated deposit on the Good Will property is the only producer of uranium in the Thomas Range, a description of the vein deposits on the Autunite No. 8 and Buena No. 1 claims is also included here because of widespread interest in these deposits by the miners and prospectors.

AUTUNITE NO. 8

The Autunite No. 8 claim is on the east side of the Thomas Range near its south end in the SW¼ sec. 10, T. 13 S., R. 11 W. (pl. 1). The deposit occurs on the north side of a small canyon near its mouth at an altitude of approximately 5,620 feet, and is reached by 2,200 feet of private road that joins the dirt road along the east side of the Thomas Range.

The Autunite No. 8 claim was located on July 15, 1950, by W. W. Sorenson, C. S. Boyle, and G. E. and C. F. Wilson. The mine workings consist of two pits, one about 40 feet long, 15 feet wide, and 10 feet deep, and the other 6 feet long, 4 feet wide, and 4 feet deep (fig. 55). No ore has been produced from the Autunite No. 8.

Volcanic rocks of both the older and younger groups

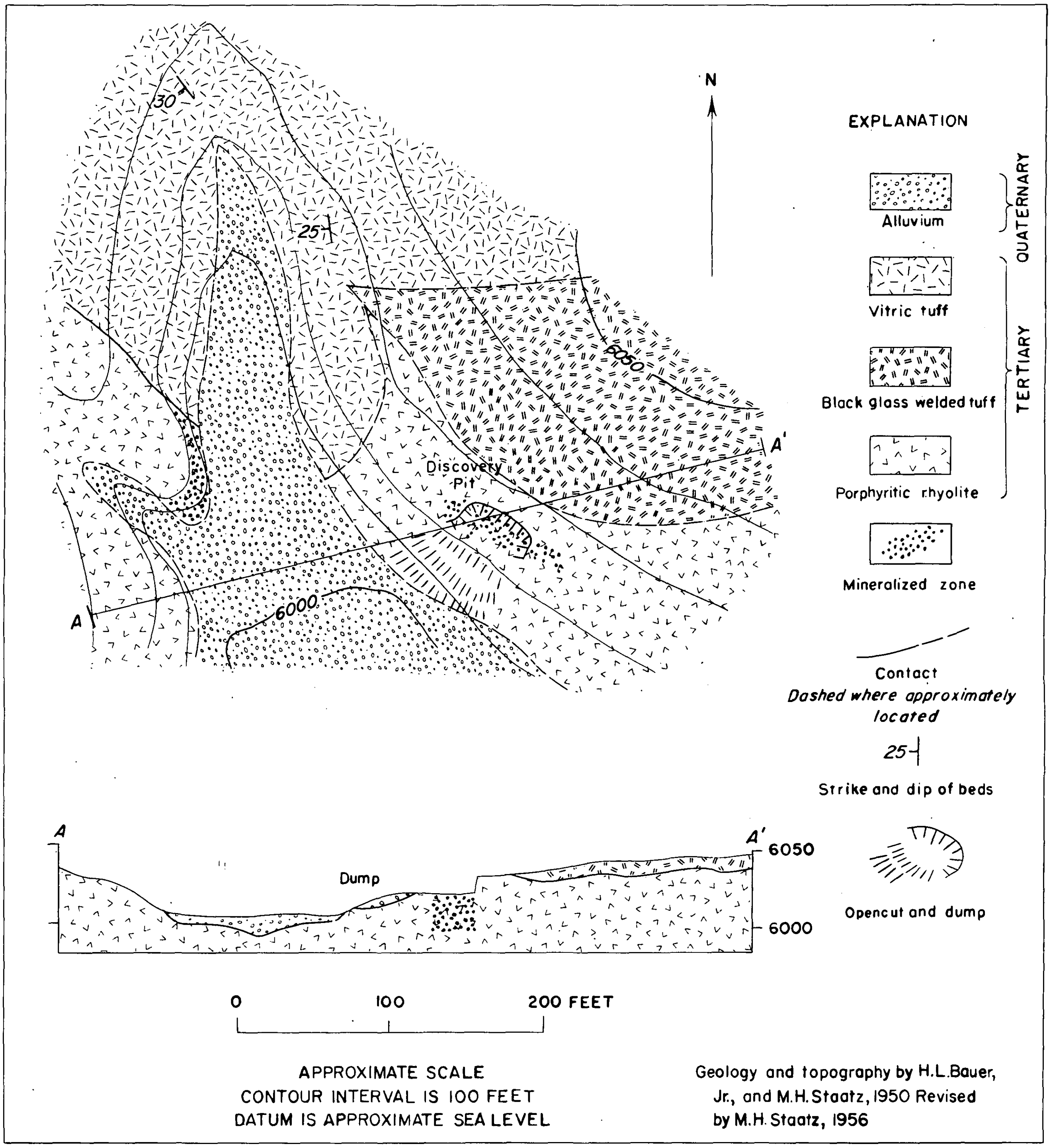


FIGURE 55.—Geologic sketch map and section of part of the Autunite No. 8 claim.

are well exposed on the Autunite No. 8 claim. The oldest rock is porphyritic rhyolite that contains numerous phenocrysts of sanidine and quartz. The quartz grains adjacent to the uranium deposits are smoky. The porphyritic rhyolite is overlain irregularly by black glass welded tuff (fig. 55). Following the emplacement of these older volcanic rocks a period of erosion occurred. The area was then covered by a white vitric tuff. Beds in this tuff are generally horizontal except along the sides of canyons where initial dip in this rock may be as steep as 30°. Approximately 500 feet west of the main workings of the Autunite No. 8 the white vitric tuff is overlain conformably by about 800 feet of rhyolite (pl. 1).

One of the few faults that cut volcanic rocks in the Thomas Range has been traced from the east branch of Topaz Valley northeastward to a point about 700 feet northwest of the Autunite No. 8 discovery pit. This fault, 1,200 feet west of the discovery pit, has a vertical displacement of approximately 60 feet.

The deposits on the Autunite No. 8 claim consist of numerous steep-dipping small veins of uraniferous opal. Most of these veins have a general north to northwest trend and a few have a northeast trend. The veins are from one-thirty-second to one-quarter of an inch thick.

The largest and best exposed area of uraniferous opal veins is in the vicinity of the discovery pit on the east side of a small canyon (fig. 55); the area in which these veins are exposed is about 100 feet long and has a maximum width of about 25 feet. The chief mineral in the veins is opal, which in some places is botryoidal. The uranium occurs in the rather rare mineral weeksite, which was originally described from specimens collected by the senior author on this property (Outerbridge, Staatz, Meyrowitz, and Pommer, 1960, p. 39–52). This mineral is yellow and occurs in finely fibrous rosettes similar in appearance to uranophane. These rosettes are 0.2 to 1 mm across and are found both encrusted and interlayered with the opal. In a few places weeksite is found along fracture walls free of opal. The indices of refraction of weeksite are:

$$N\alpha = 1.596$$
$$N\beta = 1.603$$
$$N\gamma = 1.606$$

Weeksite is faintly pleochroic and does not fluoresce under either short- or long-wave ultraviolet light. Its chemical formula is $K_2(UO_2)_2\ (Si_2O_5)_3 \cdot 4H_2O$.

Other vein minerals are calcite and fluorite. The calcite is common only in parts of some veins and occurs as clear crystals as much as a quarter of an inch across. The fluorite is less common than the uranium mineral; although some of it occurs as purple crystals, most occur as small colorless crystals.

Two samples from the mineralized area, one from an 8-foot horizontal channel cut across the west end of the discovery pit and the other from a 2.2-foot vertical channel 80 feet east of the first sample, contained 0.026 and 0.013 percent uranium, respectively (table 22). Inasmuch as the veins are generally separated by as much as 2 to 3 inches of barren rhyolite, the grade of the individual veins is much higher. A sample of carefully selected material containing a high proportion of vein material with visible weeksite contained 0.20 percent uranium.

A second abnormally radioactive area is in the porphyritic rhyolite on the west side of the small canyon (fig. 55), 180 feet west-northwest of the discovery pit. This area contains numerous small vertical veins with a northerly strike. The veins are in an area approximately 70 feet long by 12 feet wide. Opal is the only mineral noted. A 4-foot channel sample of the rhyolite with numerous opal veins contained 0.022 percent uranium (table 22).

A third abnormally radioactive area occurred in the vitric tuff of the younger volcanic group, approximately 600 feet west of the discovery pit. The tuff at this locality strikes N. 10° E. and dips 5° NW. The mineralized zone is in the bottom of a narrow canyon and has an exposed length of only 10 feet and a width of 2.5 feet. Numerous small fractures in the tuff are filled with pale bluish-green opal. A 2.5-foot vertical channel sample across this ledge contained 0.009 percent uranium (table 22).

BUENA NO. 1

The Buena No. 1 claim lies across a low ridge approximately a half mile north of Searle Canyon in the E½ sec. 11, T. 13 S., R. 12 W. (fig. 50). The discovery pit is at an altitude of about 5,450 feet on a saddle in a low ridge approximately 200 feet west of the steep western escarpment of the main part of the Thomas Range.

The Buena No. 1 was located August 19, 1954, by Van Fenley of Garden Grove, Calif. The workings in 1955 consisted of one pit 6 feet long by 2 feet wide by 3.5 feet deep.

The country rock is the gray facies of the rhyolite of the younger volcanic group. Numerous small vesicles indicate that the rhyolite is from the upper part of a flow. A number of steeply dipping irregular fractures which have a general N. 35° E. trend and northwest dip are in the discovery pit and a small area adjacent to the pit. The fractures are coated with vein material an eighth to half inch thick. Opal, which makes up more than 70 percent of the veins, occurs as white opaque botryoidal masses and as clear colorless to pale-green hyalite. The opal shows a bright-green fluorescence under ultraviolet light. Calcite is the next most common mineral and occurs in white tabular crystals from one-thirty-second to one-eighth inch across and as much as 1½ inches long. The only other mineral noted was fluorite, in tiny light- to dark-purple cubes approximately 0.5 mm across perched on the opal. Most of the fluorite appears to be later than the opal; in a few places, however, the two were found intergrown.

Although uranium minerals were not seen, the veins were abnormally radioactive. A chip sample taken along the entire length of the trench and including several veinlets exposed in the trench contained 0.023 percent uranium (table 22).

GOOD WILL AND YELLOW CHIEF

The Good Will and Yellow Chief uranium claims are in a small valley on the east side of the central part of The Dell about 0.6 mile east of Eagle Rock Ridge (fig. 50). If the township were subdivided, the area would be in the NW¼ sec. 36, T. 12 S., R. 12 W.

The Good Will claim was located April 20, 1954, by Bernard and Joseph Christensen of Delta, Utah; the Yellow Chief and Yellow Chief Nos. 1 to 4 were located on April 10, 1954, by Leland Sanderson and Bernard and Joseph Christensen. Even though the principal workings are on the Good Will claims, the property is commonly called the Yellow Chief group.

The area can be reached by a dirt road, approximately 6,800 feet long, that branches from the main haulage road at the south end of Eagle Rock Ridge.

Exploration and development work on the property in the fall of 1956 include an opencut with three tunnels started from one of its faces on the main ore body, nine long bulldozer trenches, several small trenches, a number of auger holes, and more than 100 vertical churn-drill holes. The results of the drilling are not available.

A total of 129 tons of ore had been shipped from the Good Will property by the end of 1956. According to Leland Sanderson, this total includes a test lot of about 10 tons shipped to Vitro Uranium Co. in Salt Lake City during April 1954, 33 tons of ore containing 0.11 percent uranium shipped to the U.S. Atomic Energy Commission's depot in Marysvale, Utah, during May 1955, and 31 tons of ore containing 0.25 percent uranium and 55 tons of ore containing 0.22 percent uranium shipped to Vitro Uranium Co. during the summer and fall of 1956.

A planetable map of the property was made (pl. 8), and 14 samples from the various workings were analyzed for uranium.

Geology.—The rocks in which the ore deposits at the Good Will property occur represent one of the few water-laid Tertiary sedimentary rocks in the Thomas Range. These sedimentary rocks were deposited in a pond at least several thousand feet long by about a thousand feet wide. The pond was formed in a depression underlain on all except the southwest side by poorly sorted crystal tuff; on the southwest side is a plug of porphyritic rhyolite. The rocks of the Good Will property can be divided roughly into (1) those that are older and underlie the water-laid sedimentary rocks, (2) the water-laid sedimentary rocks, and (3) those that are younger and overlie the water-laid sedimentary rocks.

The older rocks include rhyodacite, porphyritic rhyolite, and poorly sorted crystal tuff. Poorly sorted quartz-sanidine crystal-vitric tuff underlies most of the water-laid sedimentary rocks and is one of the best exposed rocks in the area (pl. 8).

The water-laid sedimentary rocks consist of well-sorted crystal tuff, rhyodacite conglomerate, tuffaceous quartz-sanidine sandstone, and limestone conglomerate. (The term "well-sorted" is used here, not to imply a high degree of sorting, but to distinguish it from land-laid tuff (poorly sorted crystal tuff) of similar mineralogy which has only slightly poorer sorting.) The only volcanic rock younger than the water-laid sedimentary rocks is a vitric tuff, which overlies the limestone conglomerate.

Many of these rock types have been previously described in the section on volcanic rocks. Some rocks, such as the limestone conglomerate and the well-sorted crystal tuff, because their exposures are not large enough to show on the regional map, have not been previously described. These two rocks along with the tuffaceous quartz-sanidine sandstone will be discussed here because the differences in lithology of these rocks has an important bearing on the emplacement of the ore bodies. Uranium minerals are found in both the limestone conglomerate and the tuffaceous quartz-sanidine sandstone.

The uppermost of the water-laid sedimentary rocks is a limestone conglomerate, which is best exposed in a band approximately 900 feet long on the northwest side of the main valley (pl. 8). It also is exposed on the small ridge 350 feet east of the main workings and on the southeast side of the main valley 1,050 feet south of the main workings. The conglomerate rests on an irregular surface and in places fills channels in the underlying tuffaceous sandstone. The upper contact is also irregular. The conglomerate ranges in thickness from a few inches to about 10 feet, and consists of subangular to well-rounded pebbles and cobbles in a fine-grained matrix. The pebbles and cobbles are mainly very fine grained tan, gray, pink or red-brown limestone. In places the limestone has been partly or wholly replaced by silica, and many specimens show diffusion rings of iron oxide staining. In addition to the limestone, pebbles and cobbles of rhyodacite, quartz, and chalcedony have been noted. The matrix is greenish gray, and appears to be largely volcanic ash.

Three types of rock (poorly sorted crystal tuff, well-sorted crystal tuff, and tuffaceous quartz-sanidine sandstone) of almost identical mineralogical and chemical composition occur on the Good Will property. Yet, only one of these rock types contains or is likely to contain any ore deposits. The poorly sorted crystal tuff is similar to the quartz-sanidine crystal tuff described on pages 80 to 88. The poorly sorted crystal tuff is a compact rock; the well-sorted crystal tuff is a friable rock, which in hand specimen more closely resembles the tuffaceous quartz-sanidine sandstone than the poorly sorted crystal tuff.

The well-sorted crystal tuff, from its main exposure on a ridge in the north-central part of the mapped area (pl. 8), grades southward into poorly sorted crystal tuff. Poor exposures on the ridge along the south edge of the map area suggest that these units are interlayered here. The general sequence in the best exposed north-central part of the Good Will property is well-sorted crystal tuff containing a bed of rhyodacite conglomerate in its upper part, overlain by tuffaceous sandstone, which is in turn overlain by the limestone conglomerate. The poorly sorted crystal tuff, the well-sorted crystal tuff, and the tuffaceous sandstone are distinguished chiefly on the basis of sorting, grain size, and the amount of ash in the matrix.

The well-sorted crystal tuff is a white to greenish-yellow, moderately indurated but locally friable rock. It contains a little less than 50 percent sand-size grains, and the rest is ash. The sand-size grains are chiefly angular fragments of sanidine and quartz with lesser amounts of plagioclase, biotite, and magnetite. A thin section of this rock was examined and the ashy matrix was seen to consist of devitrified brown glass with many small cavities, some of which were filled or lined with tridymite and possibly cristobalite.

The tuffaceous quartz-sanidine sandstone is a porous white to yellowish-green, poorly indurated or very friable rock, whose grain size, on the whole, is slightly coarser than that of the well-sorted crystal tuff and about the same as that of the poorly sorted crystal tuff. The mineralogy of the sand grains is similar to that of the well-sorted crystal tuff but much smoky quartz occurs in the vicinity of the ore bodies. A few pieces of rhyodacite or rhyolite fragments are found in some places.

In thin section of the tuffaceous quartz-sanidine sandstone the larger grains were seen to consist of rounded to subangular quartz and sanidine with a little plagioclase, biotite, and rounded lithic fragments, and traces of hematite and limonite. The matrix makes up about 30 percent of the rock and consists of one-fourth fine-grained calcite in irregular patches, and three-fourths clay, mostly montmorillonite, which is apparently an alteration of glass fragments. No distinct shards were seen. Small cavities made up about 10 percent of the rock.

Although the poorly sorted crystal tuff, the well-sorted crystal tuff, and the tuffaceous sandstone all contain the same minerals, they are readily distinguishable in hand specimen because the well-sorted crystal tuff is slightly better sorted and somewhat finer grained than either the poorly sorted crystal tuff or the tuffaceous sandstone; the tuffaceous sandstone contains much less clay and silt-size material than either the poorly sorted or well-sorted crystal tuffs. In order to obtain quantitative data on these three rocks, mechanical analyses were made on the sand-size fraction of four samples; the results are given in table 23 and figure 56. The two samples from the tuffaceous sandstone and one from the poorly sorted crystal tuff have quite similar cumulative curves (fig. 56). These curves are closest in the coarser sizes, as indicated by similarities in the 15th percentile (table 23). The variation between the two samples of tuffaceous sandstone is greater than that between tuffaceous sandstone and the poorly sorted crystal tuff. The curve for the well-sorted crystal tuff, on the other hand, is slightly flatter on its left side and slightly

TABLE 23.—*Mechanical-analysis data of poorly sorted crystal tuff, tuffaceous sandstone, and well-sorted crystal tuff from the Good Will property*

	Poorly sorted crystal tuff (1)	Tuffaceous sandstone (2)	Tuffaceous sandstone (3)	Well-sorted crystal tuff (4)
Sand ... percent	52.7	62.9	66.2	47.4
Clay and silt ... do	47.3	37.1	33.8	52.6
Median sand size ... millimeter	.379	.349	.432	.185
Coefficient of sorting	1.93	1.96	1.65	1.57
15th percentile [1] ... millimeter	.86	.87	.82	.45

[1] A 15th percentile of 0.86 mm means that 15 percent of the sand in the sample is coarser than 0.86 mm.

1. From end of ridge 800 feet southeast of main workings.
2. From lower part of main workings.
3. From upper part of main workings.
4. From end of ridge 600 feet south of main workings.

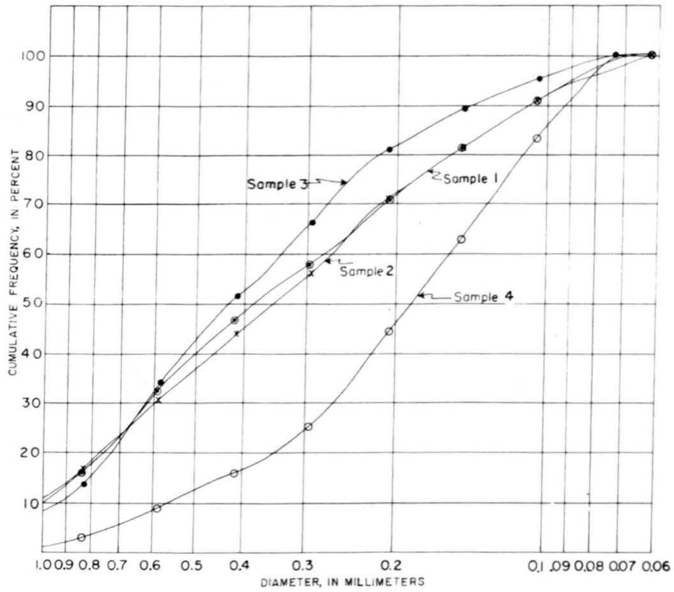


Figure 56.—Cumulative curves of sand from rocks at the Good Will property. Sample 1 from poorly sorted crystal tuff, end of ridge 800 feet southeast of main workings; sample 2, tuffaceous sandstone from lower part of main ore body; sample 3, tuffaceous sandstone from upper part of main ore body; sample 4, well-sorted crystal tuff, end of ridge 600 feet south of main workings.

steeper on its right than the curves for the other rocks. This difference indicates less sand in the coarser fractions and better sorting.

A significant difference can be seen, however, in the clay- and silt-size fraction, where the tuffaceous sandstone contains 10 to 20 percent less of this fine material than the two crystal tuffs (table 23). Because the finer material tends to fill the pore spaces in the rock, the rocks with less fine material will tend to be both more porous and more permeable. Three samples of these rocks were tested for porosity and permeability by R. F. Gantnier of the U.S. Geological Survey. The results are given in table 24. The porosity of the poorly sorted crystal tuff is not directly comparable to the porosity of the other two rocks because it represents effective porosity or the amount

Table 24.—*Porosity and permeability of tuffaceous sandstone, well-sorted crystal tuff, and poorly sorted crystal tuff from the Good Will property*

[Measurements by R. F. Gantnier]

	Tuffaceous sandstone (1)	Well-sorted crystal tuff (2)	Poorly sorted crystal tuff (3)
Porosity percent	[1] 23.1	[1] 13.0	[2] 15.0
Permeability, air [3] millidarcies	782	24.5	3.5

[1] Total porosity.
[2] Effective porosity.
[3] Rate of transfer of air through material.

1. From lower part of main workings.
2. From end of ridge, 600 feet south of main workings.
3. From side of valley, 1,100 feet southeast of main workings.

of connected pore space in the sample, and in the other two samples the porosity measured is the total pore space in the rock. The figures do, however, give an order of magnitude and show that the porosity of the sandstone is almost twice that of either of the two tuffs. The permeabilities show a much greater variation: The permeability of the tuffaceous sandstone is more than 30 times greater than the permeability of the well-sorted crystal tuff, which is 7 times greater than that of the poorly sorted crystal tuff.

Following the deposition of the rocks in this area, the region was tilted generally to the west. Most of the tuff and sandstone beds show a northerly strike and dip from 8° to 58° to the west; locally, however, some beds show a southerly or even easterly dip.

One fault was noted 180 feet east of the main workings. It has a north-northwesterly trend and offsets the limestone conglomerate approximately 370 feet horizontally.

Ore deposits.—Uranium minerals occur on the Good Will property in the tuffaceous sandstone and the overlying limestone conglomerate.

In the conglomerate the yellow uranium mineral weeksite (Outerbridge, Staatz, Meyrowitz, and Pommer, 1960, p. 41–43) irregularly replaces a band about one-quarter of an inch thick around the outside of part of the limestone pebbles or cobbles more than an inch across; in the smaller pebbles the center may be replaced. The pebbles and cobbles containing weeksite are erratically scattered through the conglomerate and have been found along the exposure of the limestone conglomerate on the northwest side of the valley; a few also have been found in the exposures on the southeast side of the valley, but none are known from the exposures on the ridge 350 feet east of the main workings. A sample of limestone conglomerate (SC–3–55) collected at the discovery pit contained only 0.005 percent uranium (table 22). Weeksite replaces only a small part of the pebbles and these pebbles are too widely separated to be of economic interest.

The tuffaceous sandstone contains the only significant uranium deposits found on the Good Will property through 1956. The main deposit is on the northwest side of the valley in the northern part of the mapped area (pl. 8), but abnormally high radioactive areas have been found on the southeast side of the main valley about 1,000 feet south-southwest of the main ore body and erratically scattered through the sandstone south of the main ore body. The size of the ore bodies is difficult to determine because the tuffaceous sandstone is everywhere mantled with slope wash and is exposed only in the workings; the outline of the ore bodies is impossible to determine visually because the uranium minerals are rarely visible.

The main ore body has maximum exposed dimensions of 120 feet parallel to the bedding and 65 feet at right angles to it. This ore body lies in the sandstone just below the limestone conglomerate; the downslope boundary is imperfectly known because it is covered by slopewash and dump. Inasmuch as uranium minerals are exposed in a pit down slope from the main exposure, the ore body may be 100 rather than 65 feet wide. The depth of the deposit is not known; Bernard Christensen (oral communication, 1957) reported, however, "high grade ore" in a vertical hole at a depth of more than 150 feet.

Certain layers in the tuffaceous sandstone are considerably richer than others in uranium minerals. Beta-uranophane (hydrous calcium uranyl silicate) is yellow and fine grained, and occurs in pore spaces in the sandstone. Schroeckingerite (essentially uranyl carbonate) was found only in steeply dipping veinlets, $\frac{1}{16}$ to $\frac{1}{8}$ of an inch thick in the 10-foot square pit, downhill from the main ore body. This mineral is powdery and greenish yellow, and fluoresces a bright yellowish green. Trace amounts of white and purple fluorite were found in samples of the tuffaceous sandstone and well-sorted crystal tuff.

The grade of the uranium in the main ore body is erratic; some beds are considerably richer than others. Ten samples were taken from and directly adjacent to this ore body (table 22), with those listed first in the table were taken at the surface and the later ones from deeper in the ore body. These samples ranged from 0.001 to 0.65 percent uranium.

Several other areas, most of them small, showed abnormally high radioactivity. Samples from five localities were analyzed both radiometrically and chemically for uranium (table 22). A number of these samples, as well as some from the main ore body, were out of equilibrium and gave much higher equivalent uranium than uranium values. Rosholt (1959, p. 21) ran radiochemical analyses on two of the samples showing the greatest inequilibrium (SC-4-55 and SC-8-55). The results showed that the uranium-equivalent uranium inequilibrium was not due either to the presence of parental thorium (Th^{232}) in the sample or to the loss of radon (Rn^{222}) during grinding. The cause was the inequilibrium between the uranium and its daughter products, chiefly ionium (Th^{230}) and radium (Ra^{226}), and to a lesser extent protactinium (Pa^{231}), radon (Rn^{222}), and lead (Pb^{210}). In other words, the parent uranium has probably been selectively leached out of some places and has left behind the radioactive daughter products. As Garrels and Christ (1959, p. 87) pointed out, in ores containing little or no arsenic, phosphorus, or particularly, vanadium, "chemical uranium values may differ markedly and erratically from equivalent uranium" in the zone of oxidation, "inasmuch as the daughter products of radioactive disintegration are generally less soluble, and uranium tends to move differentially." The Good Will ores are believed to be almost entirely free of arsenic, phosphorus, and vanadium, three elements which seem to stabilize uranium and prevent its migration. If the leaching was a result of surface water when the ground-water level was low, then the uranium has probably been selectively leached in places, has moved downward, and its disintegration products have been left behind.

Frondel (1945, p. 432) has shown that smoky quartz generally results from radiation, and in connection with the migration of uranium at the Good Will property, an interesting discontinuity between the distribution of smoky quartz and uranium mineralization was noted. Those samples lacking smoky quartz grains were generally nonradioactive, but a moderately radioactive sample from the upper part of the main ore body contained only a small amount of pale smoky quartz. In another place a sample with no abnormal radioactivity contained numerous smoky quartz grains. Thus, if it is assumed that a sample which contains no smoky quartz has not contained radioactive minerals for any appreciable length of time, one can conclude that the uranium has moved laterally, at least in some places, or that the minerals have been deposited relatively recently in other places so that the radiation has not had time to affect the quartz.

The concentration of uranium minerals in limestone pebbles in the conglomerate is probably a result of the limestone's being the most favorable host of any rock on the property. The concentration of the uranium minerals in the tuffaceous sandstone, however, cannot be explained on the basis of composition, for this rock has almost the same composition as the barren well-sorted tuff, the poorly sorted tuff, and the vitric tuff. The concentration in the sandstone appears to be related to this rock's porosity and permeability, which is considerably greater than that of the tuffs (table 24).

LEAD-ZINC-COPPER-SILVER DEPOSITS

CLASSIFICATION OF DEPOSITS

A classification of the ore deposits of the Dugway district is difficult because many of the older mine workings are not accessible. The deposits within this district show an overall similarity, but distinction may be made between two broad groups: fissure veins in quartzite, and fissure veins and replacements in limestone and dolomite. The latter group may be further divided in a general way into those deposits of dominantly pyritic copper ore and those of dominantly lead-zinc ore.

Fissure veins in quartzite.—Fissure veins in quartzite make up about one-third of the ore bodies in the district and are chiefly producers of lead and silver. These veins are either tabular or roughly lens-shaped. At the Lauris claim (fig. 57), which is on one of the larger fissure veins in quartzite, the exposed ore zone measures about 60 feet long, a maximum of 5 feet wide, and 80 feet deep. Larger veins may occur on the neighboring Bryan claim where a vein in the upper workings has a maximum width of at least 10 feet and an exposed length of 35 feet. The various ore bodies at the Lauris and Bryan claims lie along the same fault zone, which is traceable for 1,500 feet. At the Confidence claim (fig. 57), the south vein is at least 63 feet long and about 2.5 feet wide, and the north vein is at least 100 feet long and from less than an inch to 1.5 feet wide. In other deposits the veins are generally 1 to 2 feet wide.

Fissure veins and replacements in carbonate rocks.—These deposits have been mined chiefly for lead, zinc, silver, or copper. The Four Metals mine, a member of this group, has been the source of more than half the total production of the district.

Three deposits in this group, the Metal States, Bertha, and Surplus (fig. 57), are of pyritic copper ore and are more restricted in their general characteristics than the rest of the group. All three occur in shattered dolomitized limestones—the Surplus and Metal States in the Ochre Mountain limestone, and the Bertha in the Ochre Mountain or the Fandangle limestone. These pyritic copper ore bodies are generally of small size although their exact size is not well known. At the Bertha mine, the exposed part of the ore body is 32 feet wide and 80 feet long. The actual dimensions may be much larger. The Metal States workings are known to have developed ore bodies of comparable dimensions. The northernmost adit on the Metal States property contains copper minerals in thin seams less than an inch wide and in pockets as much as several feet across scattered through a zone 5 to 10 feet wide. Similar copper seams and pockets occur near the surface on the Bertha claim.

The greater part of this group consists of fissure and small replacement lead-zinc-silver deposits. Some of the more important properties of this type are the Four Metals, Francis, Yellow Jacket, and Buckhorn (fig. 57). The size of these ore bodies varies greatly. Many of the deposits probably measure only a few feet in any direction. At the Four Metals mine, which had the largest lead-zinc ore bodies known in the district, the main ore shoot had a maximum length of about 70 feet, a maximum width of 7 feet, and was followed down the dip at least 280 feet. At the Francis claim, the northwestern vein has a maximum width of about 5 feet at the surface and is explored by trenching for about 50 feet along the strike. The vein pinches to only a few inches in width 43 feet below the outcrop, and the grade of ore also decreases sharply downward.

Replacement of the country rock is confined to minor pods and pockets, which as a rule do not extend far along the bedding.

These ore bodies consist of small but rich near-surface pockets of oxidized ore. The stringers of primary sulfides that commonly occur below are in many places too narrow to mine.

RELATION OF ORE DEPOSITS TO COUNTRY ROCK

Veins containing lead, zinc, or copper have been found in the Dugway district in the Cambrian Prospect Mountain quartzite, Shadscale formation, Trailer limestone, Fandangle limestone, and Lamb dolomite; the Ordovician Garden City formation; the Devonian Gilson dolomite and Hanauer formation; the Mississippian Madison limestone equivalent; Woodman formation, and Ochre Mountain limestone; and at one place in Tertiary rhyodacite breccia. All the producing ore deposits, however, occur in the Prospect Mountain, Trailer, Fandangle, Madison limestone equivalent, and Ochre Mountain formations.

Most of the deposits in carbonate rocks occur in dolomitized limestone. The ore bodies in the main workings at the Raymond-Bald Eagle claims and those at the Francis claim, however, occur in unaltered limestone. In places rocks such as the Madison limestone equivalent and Fandangle limestone are both silicified and dolomitized. In the Dugway district, dolomitized Devonian and Mississippian limestones appear to be related spatially to the ore bodies, although in other parts of the Dugway Range dolomitized limestones of other ages contain no ore deposits. Within the district one of the most common types of country rock is a shattered brown dolomite. This type of dolomite occurs, for example, at the Bertha and Four Metals mines. In some places the limestone may be altered even further, as at the Four Metals mine where one bed of the Madison limestone equivalent is dolomitized, bleached, and then almost completely silicified. In the area northwest of the Bertha mine much of the Woodman formation has been altered to a greenish-gray silicified shaly material.

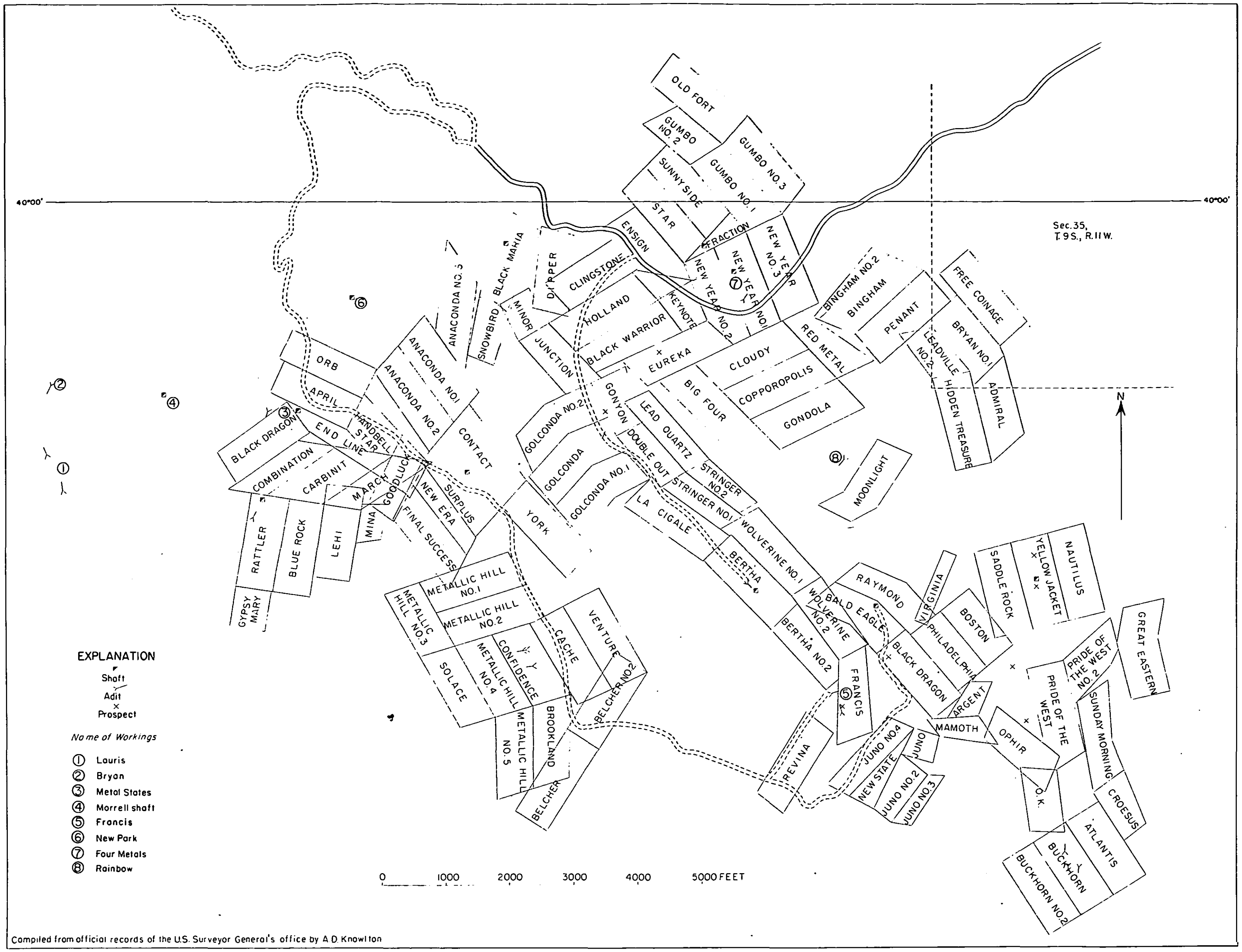


FIGURE 57.—Map of the Dugway mining district, Tooele County, Utah, showing patented claims and some of the mine workings.

RELATION OF ORE DEPOSITS TO STRUCTURAL FEATURES

The lead-zinc-copper-silver deposits of the Dugway Range are found along faults. The two chief types of faults that localize the ore bodies are the major northwest-trending faults, including the Buckhorn thrust, and subsidiary faults related to the major ones. The pyritic copper deposits are in the shattered wall rock adjacent to the major northwest-trending faults, and the fissure veins are in quartzite and in carbonate rocks formed along the subsidiary faults. The northwest-trending Buckhorn thrust fault appears to be the major controlling structure, inasmuch as no significant deposits are known that are more than half a mile from it.

The ore bodies that occur in the fissure veins in the quartzite commonly are in a zone in which the largest fault or faults are complicated by minor faults that intersect the main fracture or fractures (figs. 59, 60, and 62). Ore bodies occur in quartzite both in faults near the central part of the quartzite outcrop, as at the Lauris, Bryan, and Rattler claims, and near the edge of the outcrop in faults subsidiary to the major faults that separate the quartzite from the carbonate rocks, as at the Confidence, Rainbow, and Black Maria claims. At the Confidence and Rainbow properties the mineralized faults trend nearly at right angles to the major fault, and at the Black Maria property the mineralized fault is parallel to a major fault. All the mineralized faults in the quartzite trend north or northeast and dip eastward, and they probably formed as a result of shearing along the major northwest-trending normal faults bounding Kellys Hole and the other fault troughs to the east. Most of the known mineralized faults in the quartzite are on the east sides of the three quartzite blocks. This fact, together with the strike of the faults, suggests that a relative southeastward movement of the west or quartzite side of the major faults may have formed shear zones in the quartzite. Alternatively, inasmuch as the quartzite is the lower plate of a thrust fault, these faults may be a series of reverse faults formed in the overridden plate. Where irregularities in the fault planes formed, podlike ore bodies were noted.

The lead-zinc deposits that are fissure fillings and replacement bodies in the carbonate rocks occur in small faults or shears, or in the gouge between branching faults. About half these faults strike northeast, and half strike northwest. In some areas, however, the mineralized faults have one common trend, such as in the Buckhorn area south of Bullion Canyon where most of these faults strike northwest. Small pipelike bodies are formed in some places at the juncture of two sets of fractures, as on the 95-foot level of the Four Metals mine and on the Fraction claim.

The pyritic copper deposits in general are irregular bodies which occur adjacent to major northwest-trending faults. The Metal States and the Surplus ore bodies occur adjacent to and in the hanging wall of the large fault bounding the southwest side of the graben that forms Kellys Hole. The Bertha ore body occurs at the northeast end of the Bertha graben between the two faults that bound the sides of this graben. Because these ore bodies are poorly exposed, little detailed structural information is available.

Ore deposits at the Bertha and Metal States properties and at a few other places may be close to the Buckhorn thrust fault. The heavy gouge at the Bertha suggests the proximity of this thrust plane. The attitudes of mineralized structures do not form a regional pattern. Even attempts at generalizing the pattern meet with numerous exceptions.

MINERALOGY OF THE ORE

The mineral assemblage of the Dugway district ore deposits is fairly simple. The common primary ore minerals are galena, sphalerite, chalcopyrite, and pyrite. Small quantities of tetrahedrite or tennantite were noted at one deposit. The main gangue minerals are quartz, chalcedony, fluorite, and barite. Lesser amounts of siderite, calcite, aragonite, and chlorite are present at some deposits. The primary sulfide minerals have been oxidized near the surface to produce secondary lead, zinc, and copper minerals. The principal secondary minerals are limonite, hematite, cerussite, smithsonite, hemimorphite, chrysocolla, malachite, azurite, and copper pitch. Other secondary minerals, some of which have been noted at only one deposit, are chalcocite, covellite, cuprite, hydrozincite, anglesite, gypsum, chalcanthite, jarosite, and wulfenite. The secondary minerals occur in earthy or hard nondescript masses in the oxidized zone of most deposits, and would commonly pass unnoticed but for their high specific gravity. Crystals of most of the minerals except fluorite and barite are less than one-quarter of an inch across.

PRIMARY ORE MINERALS

Galena.—Galena occurs in most of the deposits and is the principal ore mineral. It commonly occurs as irregular veinlets or as small individual crystals scattered through a gangue of quartz or fluorite. Specimens from the upper parts of the deposits are generally altered, with the result that the outlines of the grains are irregular owing to embayment by such minerals as cerussite. Galena appears to be one of the earliest minerals formed in these deposits.

Sphalerite.—Sphalerite appears to exceed galena in abundance only at the Four Metals mine. It is also found in the ores from the Bryan, Bertha, Surplus, and Francis claims and from a small prospect just north of the Ophir claim. Inasmuch as the sphalerite alters more easily than galena, the sphalerite may have been more abundant in the original ores than is now apparent. Sphalerite is rare in surface exposures. It occurs in small veinlets or isolated crystals and ranges from dark brown or nearly black to amber yellow. At the Bryan claim sphalerite is yellow to gray brown. In general the sphalerite in the Four Metals mine is dark brown and closely associated with, but probably slightly later in formation than, galena; in places it appears to be contemporaneous with pyrite.

Chalcopyrite.—Chalcopyrite occurs as tiny inclusions along the cleavage of galena at a prospect in the central part of the Bertha graben and in trace amounts on the dumps at the Bertha, New Park, Surplus, and a few other mines. It is probably more common, particularly in the pyritic copper deposits, than is indicated by the observed occurrences on the dumps and in the upper parts of the ore bodies.

Pyrite.—Pyrite seems to be abundant in some areas in the district, absent in others. In the major deposits pyrite is most common at the Four Metals, Metal States, Surplus, and Bertha properties; at all four, it occurs as cubes as much as three-quarters of an inch across, scattered through a dark gray-green gougelike material. A specimen from the Surplus claim contained numerous small pyrite cubes in quartz. At the Four Metals mine the pyrite appears to be the latest sulfide formed, for some of the crystals have cores of galena or sphalerite. Pyrite also occurs in small amounts at several properties in Bullion Canyon but was seen in only one of the veins in the Prospect Mountain quartzite.

Tetrahedrite or tennantite.—Tetrahedrite or tennantite was found at only one locality, a prospect in the central part of the Bertha graben. Here the tetrahedrite or tennantite was noted in small grains that occurred as replacements of galena along the cleavage planes.

GANGUE MINERALS

Quartz.—Quartz is present at nearly every property in the district and is the most common gangue mineral. Comb or vein quartz, fine-grained quartz, and chalcedony are found. Two generations of quartz appear to be present in some deposits, such as in the ore shoot at the Bertha mine. One variety is a fine-grained chalcedony in narrow bands and rings associated with fine-grained hematite; the other is a coarser grained variety that forms crystals as much as 0.5 mm across and occurs in veinlets. Banded crustiform quartz is common in veins in the Prospect Mountain quartzite.

Fluorite.—Fluorite, next to quartz, is the commonest gangue mineral in the district, and is found in the quartzite at the Bryan, Lauris, Rattler, Confidence, Black Maria, Golconda, Eureka, and Rainbow properties and in the Fandangle limestone at the Great Eastern, Pride of the West, and Nautilus claims. In addition, numerous fractures containing fluorite were noted in the Prospect Mountain quartzite north and west of the Bryan claim. Fluorite occurs in two forms in the Dugway district: as colorless to pale-green cubes and octahedra as much as one-half an inch across, and as massive or columnar banded veins from less than an inch to more than 10 feet wide. The latter type of fluorite is commonly pale apple green where fresh broken, but loses its color on prolonged exposure to the sun. Massive pale-purple and orange fluorite was also noted in a few places. The columnar or massive fluorite occurs only in veins in the Prospect Mountain quartzite; cubes and octahedrons may occur at any of the localities. Quartz is the most common associate of fluorite. In some thin sections fluorite was seen to fill in scattered spaces between quartz grains. In a few places galena is found in fluorite.

Barite.—Barite is most common in deposits in carbonate rocks, such as those south of Bullion Canyon and Kellys Hole, and at the Four Metals mine. The only occurrence seen in the veins in quartzite is at the south vein on the Confidence claim. The barite occurs as crested groups of white bladed crystals from microscopic size to crystals 1 inch or more across. One vein made up almost entirely of barite on the Juno claim is as much as 1.5 feet wide. Barite is probably one of the latest minerals formed.

Siderite.—Siderite in crystals large enough to identify is common at only a few places. It was noted at several prospects in the vicinity of the Pride of the West claim and southeast of the Boston claim. It may, however, be a constituent of the brown altered dolomite that occurs around some of the deposits.

Calcite and aragonite.—These carbonates are rather widely distributed in the district, although they are not abundant anywhere. White calcite in rosettes made up of small tabular and scalenohedral crystals occur in the vein at the Bryan claim. Tiny needles of aragonite were noted on cavity walls at a prospect in the Fandangle formation.

Hydromica and chlorite.—Greenish-gray clayey patches and cavity fillings in some of the ores, as at the Bertha property, appear to be a mixture of chlorite and hydromica.

SECONDARY MINERALS

Limonite and goethite.—No attempt was made to distinguish between the amorphous and crystalline varieties of iron oxide, limonite and goethite, but they are common in the oxidized zones of most of the deposits of the district.

Hematite.—Hematite is common in the ore throughout the district. It is associated with pyrite at the Bertha mine, where it occurs as thin lamellar plates and groups of plates. It also makes up the greater part of some veins, as at the south vein on the Confidence property.

Cerussite.—In the Dugway district cerussite is the most common of the secondary lead minerals. It occurs in the oxidized zone of practically every deposit that contains galena. Cerussite is particularly abundant at the Lauris, the Four Metals, the Confidence, a prospect southeast of the Boston, and the lead ore shoot at the Bertha. The cerussite occurs either in clusters of small clear crystals or in irregular masses. The latter occurrence is more common, and at some places, such as the Confidence and the Lauris claims, these masses may be several inches across. The massive mineral is commonly white to gray in color and may be earthy or compact. A fresh surface, however, will generally show an adamantine luster. Cerussite commonly occurs as rims around galena crystals.

Smithsonite.—Smithsonite was found at only a few properties, yet, because of the difficulty of identification, it is probably more common than the known localities indicate. It occurs at the north vein of the Francis claim as apple-green reniform and botryoidal nodules as much as 2 inches across. Elsewhere, as at the south vein of the Francis claim, on the Juno claim, and at the surface at the Four Metals mine, it occurs as earthy masses that are white, gray, or very pale green.

Hemimorphite.—The zinc silicate, hemimorphite, occurs in small amounts at a number of properties. It is not nearly as common as cerussite, but is fairly abundant at the Bald Eagle-Raymond mine, and at the Bryan claim. At both places it occurs as sheaflike clusters of small clear crystals lining cavities.

Chrysocolla.—The blue-green copper mineral chrysocolla is most abundant at the north adit of the Metal States property where it occurs in thin seams and pockets associated with copper oxides and carbonates. This mineral is locally common, in many places especially along or adjacent to some of the larger faults, as at the Belcher and Black Maria claims.

Malachite and azurite.—The two copper carbonates malachite and azurite are common throughout the district. In only a few places, such as the north adit at the Metal States property, the Black Dragon, the Belcher claim, and the Black Maria claim, are they abundant. Malachite is more common than azurite, and both are generally associated with chrysocolla and with copper pitch. Malachite and azurite commonly occur as thin films and veinlets in altered dolomite and quartzite. In a few places small rosettes of malachite crystals were noted. A thin section of material containing malachite from the Black Dragon claim south of the Raymond-Bald Eagle claim showed that some of the fibrous crystals were optically more similar to brochantite and atacamite than malachite.

Copper pitch.—Copper pitch, as used here, includes the black copper oxides such as melaconite and tenorite which are commonly found mixed with chrysocolla. Such material is common at the northernmost adit on the Metal States, the Surplus, and the Belcher properties.

Chalcocite.—A few very small grains of a soft gray mineral, probably chalcocite, were noted in a specimen from the Bertha mine.

Covellite.—Traces of covellite were noted in specimens from the Bertha mine. It is also present in trace amounts at a prospect in the central part of the Bertha graben, at several prospects on the Pride of the West claim, and at a prospect just north of the Ophir claim. The covellite is generally accompanied by and replaces small grains of chalcopyrite or galena.

Cuprite.—The copper oxide cuprite was positively identified at only one place in the district, a small copper prospect on the Black Dragon claim just south of the Bald Eagle claim. A thin section revealed its presence as small irregular stringers in the center of malachite veinlets. Cuprite may be present in small amounts at some of the other copper properties.

Hydrozincite.—Thin coatings and patches of a mineral which fluoresces bluish white to very pale yellow were noted at a few places on ore from the Bryan claim, Morrell shaft, and Four Metals mine. This powdery mineral gave a strong zinc test that indicates it is probably hydrozincite.

Anglesite.—Anglesite is rare in the district. Very thin seams were found around some galena crystals in a few specimens.

Gypsum.—Gypsum occurs at the Four Metals mine, but it is mainly associated with the pyritic copper deposits—the Bertha, Metal States, and Surplus. Most of the gypsum seen was on the dumps at these properties, where some or all of it may have formed from oxidation of pyrite. It occurs in translucent platy crystals generally less than 1 inch across.

Chalcanthite.—Fine blue crystals of copper sulfate are common on the walls of the workings and in the muck at the Bertha property and at the Four Metals mine.

Jarosite.—Reddish-brown and bright-yellow earthy material in oxidized ore at the Four Metals mine and at the south vein of the Confidence claim is mostly jarosite.

Wulfenite.—A few lemon-yellow tabular crystals of the lead molybdate, wulfenite, occur in cavities in altered dolomite at two prospects about 250 feet southeast of the Boston claim.

CHEMICAL COMPOSITION OF THE ORE

Four metals—lead, zinc, silver, and copper—are of importance in the ores of the Dugway district. Only minor amounts of gold are present. Silicon, fluorine, barium, calcium, oxygen, and sulfur are the chief elements of the gangue.

Lead content.—The most widespread ore element is lead, and every sample analyzed contained at least a small amount. Some of the ore contains only lead and a little silver. The assays (table 25) ranged from 0.51 percent, in a sample from the copper deposit in the north adit at the Metal States property, to 45.21 percent, in a sample from the small workings south of the main Four Metals shaft. The average lead content of the ores of the district is probably between 8 and 10 percent.

Although galena is abundant in most of the ore, a large proportion of the lead produced was recovered from cerussite, the secondary lead carbonate. The scarcity of lead sulfate (anglesite) in the district is probably due to the fact that lead carbonate is much less soluble than lead sulfate.

Zinc content.—Zinc is abundant at only a few mines such as the Four Metals and Francis. Assays (table 25) ranged from 0.058 percent in the ore at the upper tunnel on the Lauris claim to 41.48 percent on the 95-foot level at the Four Metals mine. Excluding the Four Metals and Francis properties, the average of the remainder of the assays is a little less than 1 percent.

Inasmuch as most of the samples were collected from workings near the surface and sphalerite is more soluble than galena, the zinc content of some of the veins may increase considerably below the zone of oxidation. Zinc is most common in the fissure veins and replacements in carbonate rock, and least common in deposits of pyritic copper ore, although small lead-zinc veins within these pyritic copper deposits may be comparatively rich in zinc (table 25, DW-12-56).

TABLE 25.—*Analyses of samples from the Dugway mining district in the northern part of the Dugway Range, Tooele County, Utah*

[All analyses by the Denver laboratory of the U.S. Geological Survey. Radiologist, D. L. Schafer (equivalent uranium). Analysts: R. P. Cox (uranium); D. L. Skinner (gold, silver, lead, zinc, copper); L. F. Rader, Jr. (fluorite). Fluorite content calculated from fluorine analyses]

Property	Field sample	Type of sample	Location	Equivalent uranium (percent)	Uranium (percent)	Gold (ounces per ton)	Silver (ounces per ton)	Lead (percent)	Zinc (percent)	Copper (percent)	Fluorite (percent)
Bertha	DW-12-56	2.2-ft horizontal channel	5 ft above floor level over small winze on thickest part of small lead vein.	<0.001	0.0005	0.16	18.32	27.73	3.37	0.12	--------
	DW-13-56	Chip sample	Around room at south end of workings in black pyritic ore.	<.001	.0010	.06	.22	1.22	.50	3.72	--------
Bryan	DW-8-56	3-ft horizontal chip sample.	South end of drift across lead-fluorite vein.	<.001	.0003	.06	4.98	6.83	.41	Tr.	46.5
	DW-7-56	Horizontal chip sample	Around both sides and end of small cross cut in fluorspar.	<.001	.0004	--------	--------	--------	--------	--------	73.4
Confidence	DW-4-56	6-in. horizontal channel sample.	Across small vein, 8 ft above floor in upper adit, 80 ft from portal.	<.001	.0004	.06	1.10	21.63	.67	.22	14.6
	DW-5-56	8-in. horizontal channel sample.	Across small vein 10 ft above floor in lower adit, 85 ft from portal.	<.001	.0002	.02	8.94	39.59	.34	.11	1.7
Eureka	DW-1-56	Grab sample	Ore pile by small pit	.003	.0045	.02	3.96	33.00	1.39	2.94	--------
Four Metals mine.	DW-16-56	2.4-ft chip sample	Across sphalerite-rich vein in stope adjacent to shaft, 6.5 ft below the 95-ft level.	<.001	.0002	.02	1.62	8.89	41.48	.12	--------
	DW-15-56	1.2-ft channel sample	Across sphalerite-rich vein in stope 12 ft above the 185-ft level and 13 ft south of the shaft.	<.001	.0005	Tr.	Tr.	3.17	27.45	.05	--------
	DW-14-56	Chip sample	Back of small stope containing 6 in. vein in small tunnel, 600 ft south-southwest of main shaft.	<.001	.0011	.02	5.34	45.21	3.83	.11	--------
Francis	DW-3-56	4-ft horizontal channel sample.	Across northwest vein 4 ft below surface near top of raise.	<.001	.0010	0	.66	2.60	18.30	.65	--------
	DW-2-56	1.7-ft horizontal channel sample.	Across northwest vein in adit 4 ft above floor.	<.001	.0013	.02	3.04	8.74	7.99	.28	--------
Lauris	DW-10-56	3.2-ft chip sample	Across 3.2-ft vein in stope 6.5 ft below upper level and 44 ft from its northern end.	<.001	.0004	.06	1.10	20.42	.058	Tr.	53.9
	DW-9-56	3.1-ft chip sample	Across 3.1 ft fluorpsar vein in south end of stope just above the lower level.	<.001	.0003	--------	--------	--------	--------	--------	74.2
Metal States mine.	DW-6-56	Chip sample	Scattered ore pockets 17-40 ft down winze in northernmost adit.	.001	.0034	0	0	.51	.63	10.87	--------

At the main Four Metals mine the overall ratio of zinc to lead is about 2 to 1, the average zinc content being between 15 and 20 percent. At the Francis mine a sample from near the surface contained 18.30 percent zinc, a sample from the same vein in the adit below contained 7.99 percent zinc (table 25).

Copper content.—Oxides, carbonates, and silicates of copper are widely distributed in the Dugway district, although only in the pyritic copper deposits are they abundant enough to constitute ore. Copper sulfides are very scarce.

The few analyses available indicate that properties such as the Bertha and Metal States have a moderate tonnage of copper ore containing 2 to 4 percent copper. A chip sample from pockets containing secondary copper minerals at the adit on the Metal States property contained 10.87 percent copper, a chip sample from the main Bertha ore body contained 3.72 percent copper, and a grab sample from an ore pile on the Eureka claim contained 2.94 percent copper (table 25). All other samples assayed contained less than 0.7 percent copper. The mineral in which most of the copper was present in the Bertha ore was not determined, although traces of chalcocite, chalcopyrite, and covellite are visible in hand specimen.

Silver content.—Although no silver minerals were recognized in the ores of the Dugway district, nearly all the deposits contain 1 to 2 ounces of silver per ton. Ore mined in the district in the period 1937 to 1951 (table 26) contained an average of 1.4 ounces of silver per ton. This figure, however, is heavily weighted by the high proportion of ore coming from the Four Metals mine. The highest silver assay obtained by us in the district, 18.32 ounces (table 25), was on a sample from the small lead ore shoot at the Bertha property. Other assays (table 25) range from a trace to 8.94 ounces per ton at the Confidence claim.

Assay data available on primary ore from the Four Metals mine show a fairly close relation of silver to lead, that is, 1 ounce of silver is present for approximately each 5.5 percent lead. Silver content of the ore is not related to the zinc content. Thus, the silver at the Four Metals mine is probably contained mainly in galena. At many of the other deposits in the district, silver has much the same ratio to galena and is probably contained in it. The silver content from the small lead vein at the Bertha property (table 25) and that reported at the Buckhorn property (Butler, Loughlin, Heikes, and others, 1920, p. 462), however, are at least twice as high as might be expected from this lead-silver ratio. Hence, some of the silver probably occurs in undetected silver minerals such as argentite.

Gold content.—The highest gold assay obtained (table 25) was 0.16 ounces per ton in the sample from the lead-ore shoot at the Bertha claim. No gold was present in a sample of copper ore from the north adit of the Metal States property, nor in a sample from the northwestern vein at the Francis claim. The remainder of the samples (table 25) contained from a trace to 0.06 ounces of gold per ton.

Uranium content.—The uranium content of all samples analyzed (table 25) is very low. Most of the important mines and dumps in the district were also tested with a radiation counter; no abnormal radioactivity was noted.

Fluorite content.—Fluorite is a common constituent of the fissure veins in quartzite and rare in other types of deposits. It makes up a good proportion of the vein material in the Lauris, Bryan, Rattler, and Black Maria, and is a possible byproduct at some of these properties. The U.S. Bureau of Mines carried out flotation experiments on ore from the Black Maria property and obtained a concentrate that assayed 93 percent CaF_2 (Snedden, Batty, Long, and Dean, 1947, p. 25).

Six samples from the Bryan, Confidence, and Lauris claims were analyzed for fluorine by the U.S. Geological Survey. From these data the fluorite content is calculated and presented in table 25. The content ranged from 1.7 percent fluorite from a sample taken in the lower adit on the Confidence claim to 74.2 percent from a sample taken in the lower level on the Lauris claim. An additional sample from the Black Maria property was reported by Snedden, Batty, Long, and Dean (1947, p. 21) to contain 24.8 percent fluorite. An acceptable metallurgical-grade fluorspar (70 percent CaF_2) might be obtained by hand picking of ore from the Lauris and Bryan claims.

ORIGIN OF THE LEAD-ZINC-COPPER-SILVER DEPOSITS

Character and source of ore-forming fluids.—The primary minerals of the Dugway district are relatively simple and are those commonly associated with mesothermal and, to some extent, epithermal deposits. As little is known about the composition of the deposits at depth, even a brief description of the nature of the ore-forming fluids is difficult. That the fluids were of low or moderate temperature and under relatively low pressure is illustrated by the crustiform nature of the ore in some deposits, the presence of chalcedony, barite, and fluorite in most of the veins, and the lack of lime-silicate minerals.

The source of the ore-forming fluids in the Dugway mining district is not apparent. The only rocks of igneous origin in the district are rhyodacite breccias, tuffs, and a few small altered rhyodacite dikes. The character of the ore strongly suggests, however, that the source of the fluids which formed the deposits was different from that which formed the uraniferous fluorspar and the uranium deposits in the Thomas Range. The elements lead, zinc, copper, iron, silver, barium, and sulfur, common in the deposits of the Dugway district, are absent in those in the Thomas Range; uranium, on the other hand, is absent in the Dugway district. Furthermore, the rocks adjacent to the fluorspar deposits in the Thomas Range show no alteration; the rocks adjacent to the ore deposits in the Dugway Range are commonly altered to dolomitized, bleached, or silicified limestone. This altered rock is thought to have formed here, as in the East Tintic district, Utah (Lovering, 1949, p. 21–22), by an initial wave of hydrothermal fluids that preceded the formation of the mineral deposits.

The ore deposits and country rock (Butler, Loughlin, Heikes, and others, 1920, p. 467–469) of the Fish Springs mining district, about 15 miles southwest of the Dugway district, are similar to those of the Dugway district, except that the ore bodies in the former district are associated with some small dikes of granite porphyry.

In view of the similarity of the Dugway deposits to those of the Fish Springs district and the proximity of a large granitic intrusive body in the Granite Mountains 3 miles northwest of the Dugway district, it seems reasonable to postulate that this mineralized area may be underlain at unknown depth by a stock or dikes of granitic rock from whose magma the ore solutions emanated. The depth of such intrusions, if present, cannot be predicted from present knowledge of the area, although the lack of contact metamorphism and prevalence of low-temperature minerals and textures suggest that an igneous source will not be found at depths of less than a thousand feet.

Age of mineralization.—The age of ore formation in the Dugway district can only be approximated by inference. At the northeast corner of Kellys Hole small quartz veinlets containing chalcopyrite and galena are present in rhyodacite breccia. This rhyodacite breccia is no older than that of the older volcanic group farther south in the Thomas Range (see p. 116), as seems likely, then the mineralization is probably Miocene or younger in age. The ore also appears to have been formed after the major faulting, for some ore minerals have been found along most sets of faults.

SUGGESTIONS FOR PROSPECTING

The Dugway mining district covers an area roughly 4 miles long in a northwest-southeast direction and 2½ miles wide. Almost all the known ore deposits are within half a mile of the big northwest-trending faults. Both quartzite and carbonate rocks are favorable hosts for ore deposits, but those in quartzite are likely to be small lead-rich shoots and fluorspar veins. The most favorable area for discovery of new veins in the quartzite is within 100 yards of the southwest side of large northwest-trending faults. Ore bodies in the carbonate rocks may be either small- to medium-sized veins of lead or lead-zinc ore or irregular pyritic copper deposits. The former are in limestone or dolomitized limestone, but areas of dolomite (especially those containing chocolate-brown, bleached, or silicified dolomite) should be favored over areas of unaltered limestone. The pyritic copper deposits are in fault troughs, such as the Kellys Hole and Bertha grabens, adjacent to major northwest-trending faults. Areas covered by alluvium in these troughs should be especially favorable for prospecting.

HISTORY AND PRODUCTION

The Dugway district was discovered in 1869 and organized in 1872 (Butler, Loughlin, Heikes, and others, 1920, p. 462). The first discovery in the district was made by Sam Gilson on the Buckhorn claim (Engineering and Mining Journal, 1891, p. 503), and the ore from this property is said to have contained as much as 1,800 ounces of silver per ton. The town of Buckhorn, which no longer exists, was near the head of Buckhorn Canyon on the flats to the east of the Buckhorn mine. The Engineering and Mining Journal (1891, p. 704), reporting on development within the district, stated that "Dugway district has 2 stores, 3 saloons, some 30 tents and a big boarding house. Water has to be brought 18 miles and sells for $2.50 per 40 gallons." The isolation of the district, the scarcity of water, and the lack of timber hampered development of this area from the beginning. A small smelter near the mouth of Bullion Canyon was completed in 1876, but apparently treated only a small amount of ore.

Little is known of the production of the district prior to 1934. The Buckhorn had the largest production of the mines worked in the early days. Heikes (Butler, Loughlin, Heikes, and others, 1920, p. 463) estimated that prior to 1903 about 1,000 tons of ore, mostly lead ore, was shipped from the district. The few records that are available for the period between 1903 and 1936 indicate that mining was sporadic and only a little ore was produced. Heikes (1921, p. 200) reported that in 1917 "there were three properties producing ore, of which two * * * shipped copper ore, and Laurel (Lauris) shipped a car of 50 percent lead ore." According to Heikes (1922, p. 447), in 1919 "lead ore containing silver from the Laurel (Lauris) mine comprised the principal part of the Dugway district's output made by four producers and aggregating 83 tons." Also according to Heikes (1928, p. 437), in 1925 the Francis claim produced 159 tons of lead ore containing 2.54 ounces of gold, 688 ounces of silver, 1,500 pounds of copper, 97,637 pounds of lead, and about 19,000 pounds of zinc.

Production of metals from the district in 1934 and from 1937 through 1951 is shown in table 26. The Four Metals mine produced about 7,000 short tons of ore during this period. The largest production from this district was attained in 1945 when nearly 2,000 tons of ore valued at $56,679 was shipped. After the end of World War II activity declined, and no production was recorded in 1952 or 1953; since 1951 there has been only sporadic development work and a few small shipments of ore. Some of the properties worked in the last ten years include the Bryan, Lauris, Four Metals, Francis, Confidence, Raymond-Bald Eagle, Bertha, and Metal States. In 1946 the Francis, leased to the New Park Mining Co. and operated by Tom P. Costas, shipped oxidized lead-zinc ore. In 1948 and 1949 R. G. Lee and Willis Smith leased the Four Metals mine and shipped a total of 322 tons of lead-zinc ore. In 1955 lessees Hollinger and MacFarland shipped copper ore from the Bertha. There was no mining in the district in 1956.

Using (1) the estimate by Butler, Loughlin, Heikes, and others (1920, p. 462) of 1,000 tons of ore produced in the Dugway district prior to 1903 and (2) the average production of the 2 years reported from 1903 to 1934 as a yearly average for this period, the authors estimate the total production of the district from 1869 through 1956 to have been about 12,000 short tons of ore. The Four Metals-Smelter Canyon group of mines has been responsible for by far the largest amount, probably about 60 percent, of the district's production.

The figures in table 26 indicate that the average recovered metal content per ton of ore mined from 1934 through 1951 has been about 0.01 ounces of gold, 1.4 ounces of silver, 1.3 pounds of copper, 153.6 pounds of lead, and 202.7 pounds of zinc. The average value of a ton of ore was about $35. Ores mined early in the district's history were much richer, particularly in silver. Most of the ore shipped in recent years has gone to smelters at Bauer and Tooele, Utah.

INDIVIDUAL DEPOSITS

Descriptions of mines in the Dugway district are limited to those workings that were readily accessible in 1956. Most of these deposits have had at least some development work in the last 10 years. Thus, an

TABLE 26.—*Total production of gold, silver, copper, lead, and zinc from the Dugway district, Tooele County, Utah, 1934, 1937–51*

[No production recorded in 1935 and 1936. Data from Minerals Yearbooks: Gerry and Miller (1935, p. 331); Miller (1938, p. 440, 446); Miller and Luff (1939, p. 470; 1940, p. 454, 461); Woodward and Luff (1941, p. 454, 461; 1943a, p. 465, 473; 1943b, p. 492, 501; 1945, p. 471, 481; 1946, p. 448, 460); Needham and Luff (1947, p. 467, 476; 1948, p. 1539, 1546; 1949, p. 1519; 1950, p. 1610, 1615; 1951, p. 1583, 1588); Luff (1953, p. 1596, 1602; 1954, p. 1600, 1606).]

Year	Mine	Ore shipped or sold (short tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Total value (dollars)
1934	1, unspecified	5	1	----	----	----	----	35
1937	Four Metals	1,500	2	2,031	6,000	217,593	430,000	43,155
1938	3, unspecified	129	----	396	----	44,609	14,896	3,023
1939	Four Metals	63	----	84	----	8,489	16,192	1,298
1940	do	248	2	533	363	52,600	62,587	7,063
1941	do	317	3	675	800	73,000	24,800	6,700
1942	do	330	2	391	100	30,300	56,300	7,626
1943	Smelter Canyon	489	2	675	500	78,600	42,500	11,100
1944	Smelter Canyon	948	17	1,717	2,200	198,300	127,000	32,455
	Final Success	22						
1945	Smelter Canyon [1] and Four Metals	1,955	12	1,536	416	153,211	512,887	56,679
	Cannon property [1]	31	----	----	----	----	----	
1946	Smelter Canyon and Four Metals	483	2	365	2,500	33,000	103,500	16,994
	Cannon property	8						
1947	2, unspecified	9	----	21	40	2,600	2,200	667
1948	Four Metals group	172	10	1,864	2,200	207,000	62,900	47,933
	Cannon property	173						
	3 others, unspecified	335						
1949	Smelter Canyon and Four Metals	163	1	336	100	38,300	44,500	11,928
	1 other, unspecified	31						
1950	Four Metals	245	1	242	400	29.400	51,000	11,548
	Francis							
	Raymond							
	1 other, unspecified	16						
1951	Four Metals	77	----	168	100	32,200	30,900	11,371
	Cannon property	39						
	1, unspecified	18						
	Totals (1934, 1937–51)	7,806	55	11,034	15,719	1,199,202	1,582,162	269,575

[1] Content of metals as given by Needham and Luff (1947) on their page 476. These figures exceed those given for gold, lead, and zinc by the same authors on their page 467.

adequate description of the Buckhorn, the chief silver producer, cannot be given because the workings on the original ore body are completely filled in. The following mining properties are described below: the Bertha, Bryan, Confidence, Four Metals, Francis, Lauris, and Metal States mines. Several properties between the Buckhorn thrust and the Castle Mountain fault in the vicinity of the old Buckhorn mine are also described, under "Mines and prospects of the Buckhorn area." These deposits are all of a similar type and are discussed together because not enough geologic information is available to warrant discussing them separately.

BERTHA

The Bertha claim is in the southeast or upper end of a narrow valley in the north-central part of the Dugway Range. This property is approximately 1 mile due south of the Four Metals mine and 3,000 feet east of the southern part of Kellys Hole (fig. 57). A steep dirt road leading to the property branches from the road through the northern end of the Dugway Range one-quarter of a mile west of the Four Metals mine.

The Bertha claim was located in the 1890's and patented on May 16, 1900, by J. B. Thompson and associates. A little copper ore was shipped to a smelter near Stockton, Utah, around the turn of the century. Some work has been done at various times since then, the most recent being in 1955 when the property was leased to Hollinger and MacFarland who shipped 78 tons of ore to the American Smelting and Refining Co. In 1956 the property was owned jointly by J. F. and T. Q. Cannon and J. C. Orme.

The workings on the Bertha consist of a shaft, a prospect pit, and an adit. The pit is only about 8 feet deep; the shaft is inclined at 41° in a N. 24° E. direction and is approximately 95 feet deep. This shaft connects with the main adit by a 14-foot crosscut. The adit has approximately 400 feet of workings and is extremely irregular. A map of this adit on the scale of 1 inch to 40 feet was made by tape and compass (fig. 58). At the base of the shaft another level was present, but it has been back-filled.

Geology.—The Bertha property is in dolomite of unknown age in the southeast end of a graben between two upfaulted blocks of Prospect Mountain quartzite. The faults bounding the downfaulted block join about 800 feet southeast of the portal of the adit; to the northwest, however, they diverge (pl. 1). These faults are from 200 to 400 feet apart near the Bertha workings and appear to dip towards the center of the graben; a segment of the Buckhorn thrust fault probably underlies this area. The rock in the vicinity of the workings is a coarse-grained chocolate-brown-weathering dolomite that is locally silicified. This dolomite lies between the Ochre Mountain limestone of Mississippian age to the northwest and the Fandangle limestone of Cambrian age to the southeast but because the area between the two limestones is poorly exposed, the relation between the dolomite and limestone formations is not known.

Ore deposits.—The main ore deposit on the Bertha claim is a large irregular body of pyritic copper ore formed by replacement of the brown dolomite along fractures that in general parallel the two main boundary faults. The pyritic copper ore body is outlined in part by the adit (fig. 58), but neither the southeast nor the northwest end of the ore body is exposed. The ore body has a minimum length of 80 feet and a width of 32 feet on the adit level. Short crosscuts above the adit level expose the ore body for an additional 21 feet to the southeast and for 15 feet to the south. Near the surface the ore body has been oxidized to a brown limonitic gossan, which is well exposed near the adit mouth and around the shaft on the adit level (fig. 58). If the secondary limonite-rich part of the ore body is added to the primary pyritic part, then the minimum length of the exposed ore body is 180 feet.

The ore consists of a dark greenish-gray fine-grained clayey material through which are scattered numerous pyrite cubes from 0.4 mm to 20 mm across and in places small patches of covellite and malachite. A polished section shows that the ore consists chiefly of pyrite and hematite in dark-green to black claylike material. Hematite occurs in flat plates and clots which may replace the pyrite. Thin seams of chalcopyrite, in part altered to covellite, are present in the pyrite. A few very small grains of a mineral resembling chalcocite were noted, but not positively identified. Shears in the ore body and the adjoining dolomite are commonly coated with malachite or azurite. Chalcanthite was noted on the walls of the adit in several places. The only other recognizable mineral is gypsum, which although abundant on the dump, is only rarely found in the underground workings, where it occurs along fractures.

A chip sample taken around the edge of the stope at the southeast end of the adit (fig. 58) contained 3.7 percent copper and 1.2 percent lead (table 25). The copper content of this sample agrees closely with the 3.6 percent reported by Billingsley and Lyons (1926, written communication) from this same deposit. The lead content is surprising, because lead minerals were not seen in any of the hand specimens.

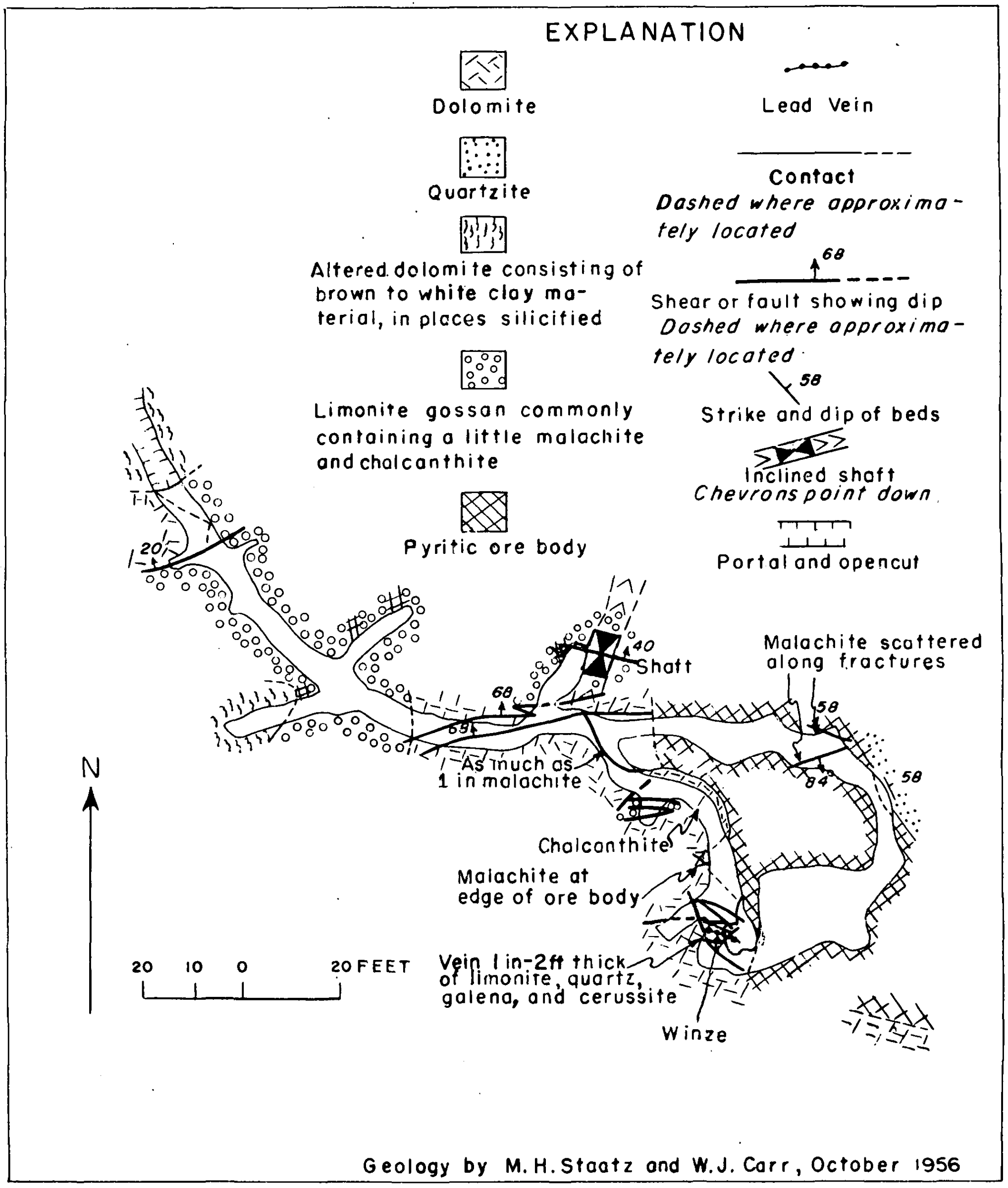


FIGURE 58.—Geologic map of adit on Bertha property.

A few small pieces of lead vein similar to that described below may have been taken in the sample.

In addition to the main pyritic copper ore body, a lead vein occurs along a small fault in the adit 6 feet west of the main ore body (fig. 58). The vein is about 4 feet long and from 1 inch to 2.2 feet thick. A winze sunk on this vein is approximately 30 feet deep. A polished section of the vein material is made up of about 35 percent galena, 20 percent cerussite, 10 percent limonite, and 35 percent quartz. Cerussite is commonly pseudomorphic after the galena. A little calcite was also noted in the vein. A thin section of a specimen from the dump, probably from this same lead vein, consisted of 60 percent quartz, some of it chalcedonic, 20 percent hematite, 10 percent galena, 5 percent cerussite, 1 percent hemimorphite, and 4 percent a dark brownish-green, nearly isotropic mineral that is probably sphalerite partly altered to smithsonite.

A channel sample (table 25) taken across this vein at its widest point contained 27.7 percent lead, 3.4 percent zinc, and 18.3 ounces of silver per ton. The silver content is the highest of any samples given in table 25.

BRYAN

The Bryan claim is on the north-facing slope of the steep quartzite mountain in the northwest corner of the Dugway Range. Its south end is 4,000 feet west of the Metal States shaft (fig. 57). The upper workings on the property are reached by a rough steep road about 5,000 feet long which branches off the main road at the divide on the north end of Kellys Hole.

The Bryan claim is unpatented and was first located about 75 years ago. It was relocated by Margaret and George Willis Smith of Stockton, Utah, in October 1955.

Two sets of workings are on the Bryan claim. The lower group, at an altitude of 4,720 feet, is at the north end of the claim and the portal is on the adjoining Harding claim. These lower workings consisted of an adit about 300 feet long with several crosscuts. In 1956 the portal of the adit was caved. The upper group, at an altitude of 5,100 feet, consists of 2 small adits 15 feet apart vertically. The portals of both adits are in unconsolidated Lake Bonneville gravels. The upper adit is caved at the portal; the lower adit, which is 108 feet long, is partially caved (fig. 59).

Geology and ore deposits.—The Bryan claim is entirely underlain by white massive Prospect Mountain quartzite. A conspicuous fault zone having an easterly dip and a north-northeast trend traverses the claim. The ore occurs in veins along this structure. Surface exposures of this fault zone are poor, but in a cut near the portal of the upper workings a fault surface is exposed which dips 65° E. In the lower adit (fig. 59), fractures that dip steeply to the east and west were noted in the quartzite but the main fault along the footwall side of the ore body dips 32° to 45° E. The hanging-wall side of this ore body is not exposed but it has been stoped for as much as 35 feet along the fault and as much as 10 feet away from the fault (fig. 59). Vein material consists chiefly of pale-green fluorite in colloform layers ¾ to 3 inches thick. The fluorite shows no crystal faces and its

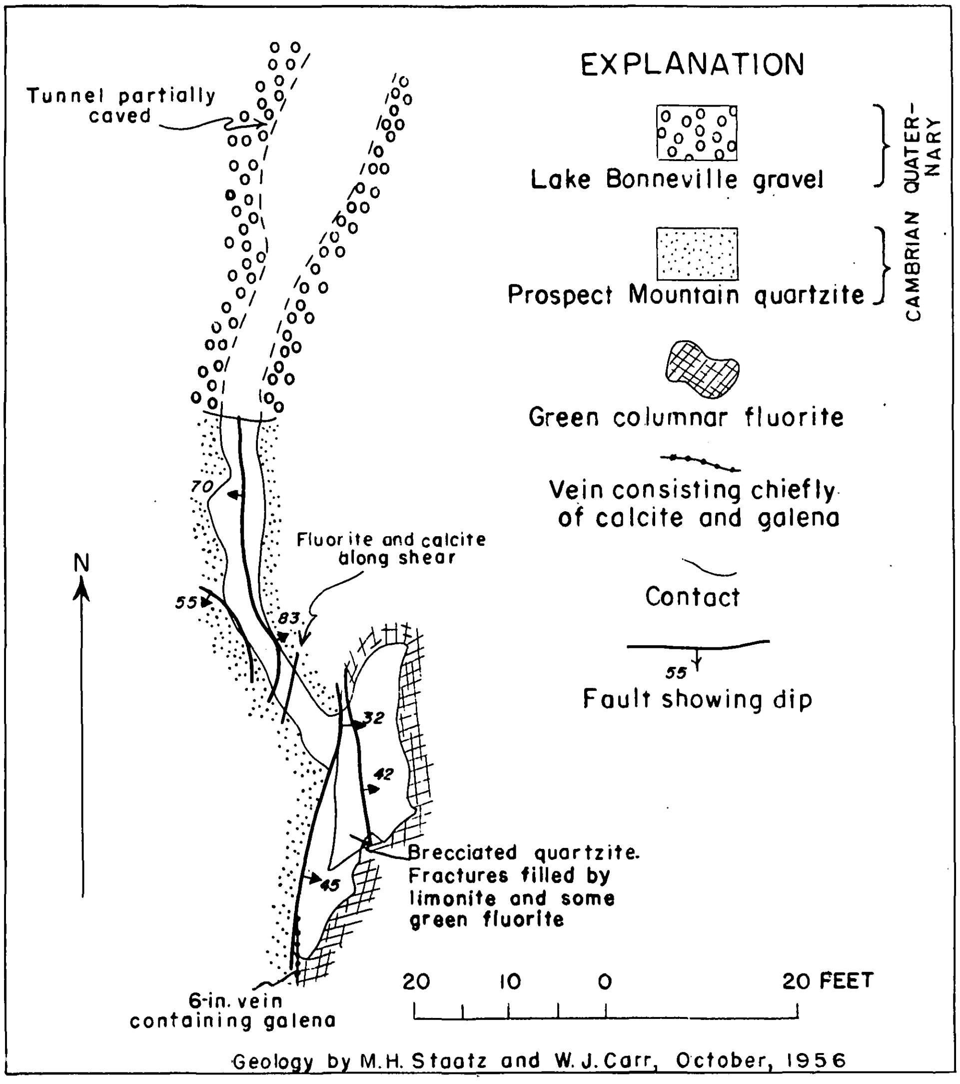


FIGURE 59.—Geologic map of the lower adit of the upper group of workings, Bryan claim.

structure is columnar at right angles to the layering. Some of the thinner layers are iron-stained.

At the south end of the adit a 6-inch vein occurs on the west side of the fluorspar body. This vein contains irregular stringers of galena 1 to 10 mm wide, rosettes of small tabular and scalenohedral crystals of white calcite, and a little quartz and fluorite. Specimens of vein material from the dump contained tiny crystals of hemimorphite as much as 2 mm long in cavities, some cerussite and quartz, small amounts of dark-brown sphalerite, and traces of chrysocolla, anglesite, limonite, chlorite, and hematite. Some specimens showed patches and thin films of fluorescent hydrozincite. Galena and gray-brown altered sphalerite occurred in 0.5- to 1.0-mm broken ragged crystals. The cerussite and anglesite are present mainly as alteration of galena along cleavage planes and the edges of crystals. Hemimorphite in crystals 0.5 mm long forms radial groups or aggregates in cavities and on sphalerite. Quartz occurs both as a fine-grained variety whose grains average about 0.1 mm in diameter, and as a coarser grained variety whose grains average about 0.6 mm. The probable order of crystallization of the major primary minerals in this vein was galena, sphalerite, fluorite, and quartz.

A chip sample across the lead-fluorite vein in the lower adit of the upper workings assayed 4.98 ounces of silver per ton, 6.83 percent lead, 0.41 percent zinc, and 46.5 percent fluorite (table 25). A chip sample of the fluorite vein material alone from the east-central part of the exposed ore body contained 73.4 percent fluorite.

The dump at the lower workings contained pieces of massive iron-stained fluorite and a little chrysocolla, but no sulfides.

CONFIDENCE

The Confidence property is on the southwest side of Kellys Hole near its southeast end. The main workings are 5,400 feet southeast of the Metal States shaft, near the base of a steep quartzite mountain. The property is reached from the Four Metals mine (fig. 57) by a steep rough road which climbs over the northwest rim of Kellys Hole and traverses its length. Although the Confidence is only 1¼ miles S. 20° W. from the Four Metals mine, the road distance is 3¾ miles.

The Confidence claim was patented on June 28, 1905, by the Metallic Hill Mining Co. In 1956 the property was owned jointly by J. F. and T. Q. Cannon and June Cannon Orme of Salt Lake City. Some ore has been removed from several small stopes on this property, but the amount is not known.

Two northeast-trending veins approximately 250 feet apart are on the Confidence property. On the south vein, workings consist of a short open crosscut to the vein, which is explored by a 63-foot trench about 2.5 feet wide and 10 to 12 feet deep. On the north vein are two adits (fig. 60); the lower is 124 feet long, the upper is 100 feet long. The upper adit is 47 feet vertically above the lower one, and in places the two are joined by a narrow stope.

Geology and ore deposits.—The veins on the Confidence property lie wholly within massive white fine- to coarse-grained Prospect Mountain quartzite. The veins are in the upthrown block on the west side of the Kellys Hole graben from 100 to 400 feet southwest of the main fault along the southwest side of the graben. The two veins occur in smaller faults which intersect the main fault.

The south vein is 0.5 to 2.5 feet thick and is on a fault that strikes N. 19° E., dips 82° SE., and has a minimum horizontal displacement of 200 feet. The vein material is dark reddish-brown quartz and hematite, with locally plentiful thin rectangular crystals of barite and masses of calcite, and some thin incrustations of a yellow mineral resembling jarosite. Malachite and azurite are rare and occur as thin coatings on the adjacent wall rock.

The north vein, the one of chief economic importance, is on a fault that strikes N. 73° E. and dips from 65° NW. through vertical to 80° SE. The vein is best exposed in the two adits, where it is explored along strike for 101 feet and down dip for 60 feet. Its thickness ranges from less than 1 inch to 1½ feet, but most of the vein is from 3 to 8 inches thick. The vein selvage commonly consists of about half an inch of colorless fluorite octahedra. The central part of the vein consists of crumbly brown to brownish-white fine-grained oxidized ore. The chief ore mineral is cerussite; a little malachite, azurite, and chrysocolla are found in some places. Gangue minerals besides fluorite are quartz, calcite, hematite, and limonite.

Two channel samples taken across the north vein (table 25) contained 21.6 and 39.6 percent lead and 1.10 and 8.94 ounces per ton of silver, and indicate that although the vein is small, it is quite high grade. Small amounts of zinc and copper are also indicated.

FOUR METALS MINE

The Four Metals mine lies on a group of hills in the central part of the Dugway Range just south of the northern border of the mapped area (pl. 1). The

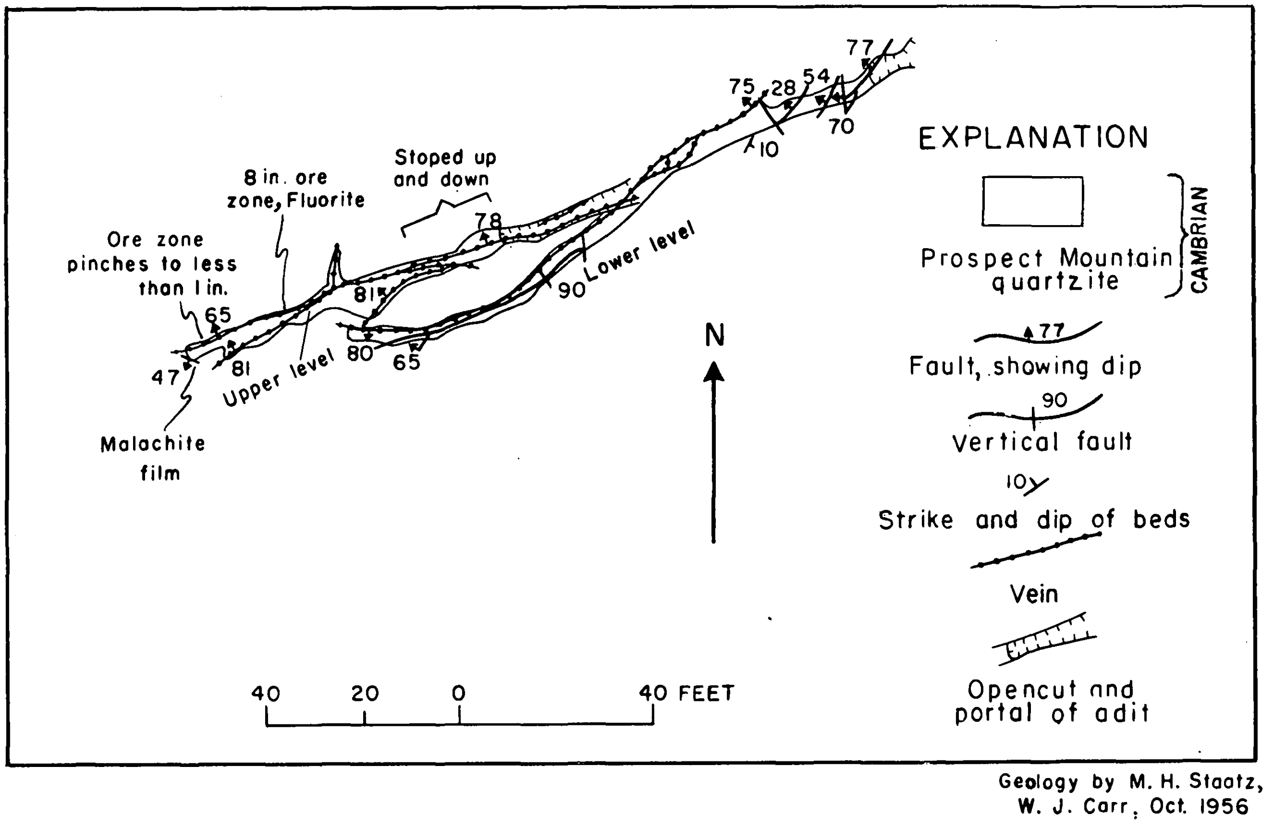


FIGURE 60.—Geologic map of north adits of the Confidence claim.

property is at the end of the graded part of the road along the east side of the Dugway Range. The distance along this road from the east-west Callao-Vernon road to the Four Metals mine is 14.2 miles.

This property was first located in the 1870's and was then known as the Silver King. Later the property was relocated as the New Year No. 1, New Year No. 2, New Year No. 3, and Fraction claims, which were patented on June 3, 1909, by R. E. L. Frymier. The main Four Metals shaft and most of the workings are on the New Year No. 1 claim. In 1956 this property was owned by Donald B. Warren of 247 Culiver Road, Rochester, N.Y.

The history and production record of the Four Metals mine are poorly known. During the 1890's, however, William Mills shipped considerable silver-lead ore to a smelter at Stockton, Utah. The mine was operated for a short time in the early 1910's when several carloads of lead-zinc sulfide ore were shipped by G. W. Snyder to the Combined Metals Reduction Co., after which the mine was again shut down. Between 1937 and 1951 the Four Metals mine and the adjoining Smelter Canyon mines produced approximately 7,000 short tons of ore or about 60 percent of the total production of the Dugway mining district (table 26). Little ore was produced between 1951 and 1957.

Several veins occur on the New Year Nos. 1, 2, and 3 and the Fraction claims. Small pits and trenches are numerous. The main vein was developed from an inclined shaft dipping 72° to the southwest; it was reported by Heikes (Butler, Loughlin, Heikes, and others, 1920, p. 463) to be 400 feet deep. From the shaft a number of levels were driven, but at the time of our visit only five levels (the 50-foot, 95-foot, 185-foot, 220-foot, and 270-foot) were above water, which stood at an elevation of approximately 4,750 feet, or 2 feet below the 270-foot level. Parts of the five levels above water are inaccessible owing to caving, bulkheads, or stoped out floors. The accessible parts of these levels, a total of 1,450 feet of workings, were mapped with Brunton compass and tape on a scale of 1 inch to 40 feet (pl. 9). The ore bodies exposed on these levels have been practically stoped out.

The south end of another conspicuous vein crops out 65 feet northeast of the shaft on the main vein. This second vein was mined from a trench; at the north end of this trench an inclined shaft dips 70° E. (pl. 9).

Several other tunnels are on the New Year No. 1 claim. On the west side of a small canyon approximately 500 feet south of the main shaft, an adit about 100 feet long was driven in barren ground. Trenches have been dug along several small veins exposed 600 feet south-southeast of the main Four Metals shaft. Early in 1955 a shaft inclined 20° to the north was sunk to develop these veins. From the bottom, where the shaft flattens out to 12 degrees, a drift about 30 feet below the surface was driven northwestward along a vein (pl. 9, small insert). The drift and inclined shaft total 195 feet of workings. A small amount of stoping has been done above the drift level.

On the Fraction claim (fig. 57) a shaft and a series of inclined stopes were noted. The shaft is about 25 feet deep and apparently struck no ore. The opening to the stopes lies 45 feet north of the shaft, and ore was evidently mined from a series of gently dipping pockets 10 to 15 feet across and quite irregular in shape.

Geology.—The Madison limestone equivalent can be traced from a prominent ridge in the southern part of the Dugway Proving Ground SW quadrangle southward to the Four Metals mine. In the vicinity of the mine, however, this formation has been dolomitized and silicified. The main rock type, and the one in which the ore deposits occur, is a chocolate-brown, moderately coarse grained dolomite. The rocks at the tops of the hills in the area are commonly silicified and generally consist of a lower bed of white fine-grained rock that resembles quartzite and of a thicker upper bed of dull-gray cryptocrystalline rock that resembles chalcedony.

To the east the altered Madison limestone equivalent is underlain conformably by quartzite and dolomite of the Hanauer formation, and although no veins were noted in this formation at the surface, the main Four Metals vein is in it on the 270-foot level (pl. 9). To the west the rocks of the Madison limestone equivalent are in fault contact with the Woodman formation. In the vicinity of the mine the rocks strike north-northwest and dip 18° to 29° SW.

Ore deposits.—The ore deposits occur as replacements of the dolomite and as fissure fillings along fractures or small faults. The fractures commonly have a little gouge along them. The veins occur along a system of braided fractures in which the braided pattern occurs both horizontally and vertically. The fractures may be curved, but generally strike from N. 9° to 30° W. Dips are generally steep in either direction. Most of the fractures associated with the main Four Metals vein dip to the southwest. Cross fractures are not common in the Four Metals mine, but several are present at the north end of the 95-foot level. A small ore body occurs along them. These fractures strike about N. 77° E. and dip 48° to 69° NW. The fracture system in which the main vein system of the Four Metals mine occurs has been traced on the 220-foot level for a distance of 260 feet.

The fracture system of the vein 65 feet to the east of the main vein system can be traced on the surface for 235 feet, and it dips steeply to the northeast. The fracture system associated with the veins 600 feet south-southwest of the Four Metals shaft can be traced in the adit (pl. 9, small insert) for 80 feet; most of the fractures in which the veins occur dip to the northeast. Undoubtedly the fracture systems on which the various veins occur are considerably longer, but much of the surface is covered and the underground workings were not driven to the end of the fracture systems.

Ore and gangue minerals occur throughout most of the fractures exposed in the mine workings. Commonly, however, these minerals consist only of a little pyrite scattered in a few inches of gouge or a narrow calcite stringer.

Three ore shoots are found in the main Four Metals fracture system: the south shoot, seen only on the upper two levels (pl. 9), the middle shoot which is the main ore body on which the shaft was sunk, and the north shoot which trends northeast and is exposed only in the 95-foot level. The south shoot, which ranges in width from 1 inch to 3 feet, is the smallest of the ore bodies. Only about 10 feet of this ore body is wide enough to warrant mining. The extension of this ore body below the 95-foot level is unknown because the south ends of the three lower levels (pl. 9) are caved. The middle shoot, where mined, is from 1 to 7 feet thick; the thickest part is on the poorly exposed 185-foot level, and its length on the other levels ranged from about 45 feet to 90 feet. The northern shoot is from 1 to about 11 feet thick and 55 feet long; it widens near its western end and has within it a pipelike body of high grade ore 6 to 9 feet in diameter. This pipe was stoped upward for approximately 60 feet; it has a plunge of 30° S. 56° W. These three ore shoots have fractures along both sides and were probably formed by replacement of the intervening crushed rock.

The size of the ore shoots in the fracture system 65 feet east of the main Four Metals shaft is not readily discernible because the trench is partly caved and the bottom is covered. The varying dimensions of this trench, however, suggest considerable variation in the width and richness of the vein. The stope width suggests that this vein was from 1 to 3 feet thick. It has been worked to a depth of about 25 feet in some places in the trench, and probably does not extend far below these workings, inasmuch as a long crosscut driven on the 95-foot level under this vein failed to intersect the ore body.

The veins in the workings approximately 600 feet south-southeast of the main Four Metals shaft are much smaller than those in the two vein systems described above. Ore is scattered along the fractures at irregular intervals and the shoots range in thickness from ¼ to 6 inches (pl. 9).

The mineralogy of all the veins is similar and fairly simple. The primary ore consists of galena, sphalerite, and pyrite in a gangue chiefly of quartz, but contains also some calcite and clay and a little barite. Chlorite was noted in one specimen. No primary copper minerals were noted, but the presence of chalcanthite along a shear on the 220-foot level, and the small amounts of copper noted in the chemical analyses (table 25) indicate that some copper minerals are present. The relative amounts of pyrite, galena, and sphalerite vary from place to place, but sphalerite is generally more common than galena, except in the working 500 feet south of the main Four Metals shaft (pl. 9, small insert). Pyrite is found not only in the ore shoots but also in clay along the fractures. Galena was apparently the first mineral formed, inasmuch as in polished sections it is surrounded by sphalerite and pyrite. In general, sphalerite was deposited next and then pyrite, which commonly occurs as small (0.1 to 2 mm) striated cubes perched on the other sulfides. In one place, however, the three sulfide minerals appear to have been deposited together. The grain size of the sphalerite and galena is variable, but most crystals are between 0.5 and 1 mm across. After the sulfides the gangue minerals quartz and calcite were formed, and they fill the interstices between the sulfide minerals.

The upper parts of the veins are oxidized. Part of the ore on the 50-foot level, and probably most of the ore above this level, is oxidized; the greater part of the ore mined from the trench 65 feet east of the Four Metals shaft was oxidized. In the oxidized ore zone, the pyrite has been changed to limonite and hematite, the sphalerite to smithsonite, and the galena to cerussite. Alteration of the galena to cerussite appears to have been slower than the oxidation of the other sulfide minerals, as the cerussite commonly surrounds cores of galena in places where no other sulfide minerals are present.

The grade of the ore varies markedly. By 1956 considerable ore had been stoped from the ore bodies on most levels and little ore was visible. Two samples were cut from pillars in sphalerite-rich parts of the main ore shoot (table 25). The zinc content of these samples is probably higher and the lead content lower than in most parts of this ore body. All available assays of ore from the Four Metals mine indicate that the overall ratio of zinc to lead is about 2 to 1. A series of tonnage-grade figures on ore shipped by R. G. Lee and Willis Smith to the smelter in 1948 and 1949 was obtained through the courtesy of Mr. L. K. Requa and is given in table 27. The lead content of these shipments ranged from 5.7 to 12.6 percent and the zinc content from 5.4 to 23.6 percent. The relation of lead to silver (table 25) suggests that the galena is probably argentiferous.

TABLE 27.—*Tonnage and grade of ore shipments made from the Four Metals mine by Willis Smith and R. G. Lee in 1948 and 1949*

[Information from L. K. Requa and published with permission of R. G. Lee]

Date shipped	Amount (short tons)	Copper (percent)	Lead (percent)	Zinc (percent)	Silver (ounces per ton)	Gold (ounces per ton)
12-1-48	27.5	0.2	11.2	9.5	1.69	0.010
12-7-48	42.4	.1	12.6	5.4	2.5	.007
12-15-48	32.3	Tr.	6.9	19.0	1.3	.007
12-28-48	25.9	.2	7.6	11.7	1.85	.010
1-7-49	12.1	.1	9.0	5.8	1.99	.010
1-19-49	28.8	.1	9.8	23.6	1.33	.005
4-22-49	42.8	Tr.	5.7	14.5	.95	.005
5-6-49	44.9	.3	6.8	16.3	1.20	.015
5-26-49	49.6	.3	9.3	19.0	1.66	.011
6-21-49	25.5	.3	12.3	17.1	2.05	.011

FRANCIS

The Francis property lies across the top of a small ridge near the middle of the Dugway Range, approximately 2,000 feet southeast of the shaft on the Bertha property (fig. 57). This property is reached by a steep dirt road from the southeast end of Kellys Hole.

The Francis claim was patented July 17, 1894, by John F. Delaney and associates. According to the county treasurer's records, the owner in 1956 was George B. Curley of Salt Lake City, Utah. Two veins, approximately 350 feet apart, occur on or near this property. Inasmuch as the veins are similar in nature and are both referred to by the miners as the Francis, they are herein discussed together.

The earliest work was on the southeast vein, which had a tunnel open on both ends and approximately 160 feet long that followed the vein along a fairly flat ridge. This tunnel reached a maximum depth of about 20 feet below the surface, and the ore, mainly secondary lead and zinc carbonates, was stoped out above the tunnel. No workings are below the tunnel level. Although some ore has evidently been produced from this deposit, no record on the amount or grade is available.

On the second or northwest vein two trenches 48 and 30 feet long (fig. 61) were dug. These trenches have a maximum depth of 8 feet. The portal of a 105-foot adit is 68 feet southwest of the vein. This adit tends northeastward and meets the vein 43 feet below the trench. An inclined shaft driven along the vein connects the southwest end of one of the trenches with the adit. A second shaft 15 to 20 feet deep is 15 feet south of the first shaft.

Geology.—The veins on the Francis property are in the Trailer and Fandangle limestones, 300 to 600 feet south and west of the Prospect Mountain quartzite. The northwest vein is in the Trailer limestone just beneath its contact with the Fandangle, and the southeast vein is in the Fandangle limestone within 20 feet of its contact with the Trailer limestone.

Ore deposits.—Ore has been produced from two veins on the Francis property. The northwest vein trends northwest at the surface and dips steeply, but in the adit it trends northeast and dips 63° SE. (fig. 61). This vein is exposed for 100 feet along strike and splits into two branches near its southeast end. On the surface it ranges from about 2 to 6 feet in thickness; in the back of the adit, however, it is only 1 foot thick, and at the floor only several inches thick.

The vein material appears to be made up largely of limonite and clay with some malachite. Smithsonite is present locally in irregular gray, greenish-gray, or brown masses that are difficult to distinguish from the rest of the vein. Near the north end of the northernmost trench, however, a few pieces of green botryoidal smithsonite were found. No sphalerite was noted. Lead also occurs in the veins, chiefly as cerussite. This mineral is generally found in irregular gray patches; it also occurs in tiny (as much as 1 mm across) clear crystals in small vugs. One piece of galena was found on the dump. The gangue minerals, in addition to iron oxide minerals and clay, include calcite and a little barite.

Analyses of two channel samples taken across this vein, one from the adit, the other from the inclined shaft 4 feet below the surface, are given in table 25. They indicate that zinc is probably the chief constituent of the ore, although lead is important.

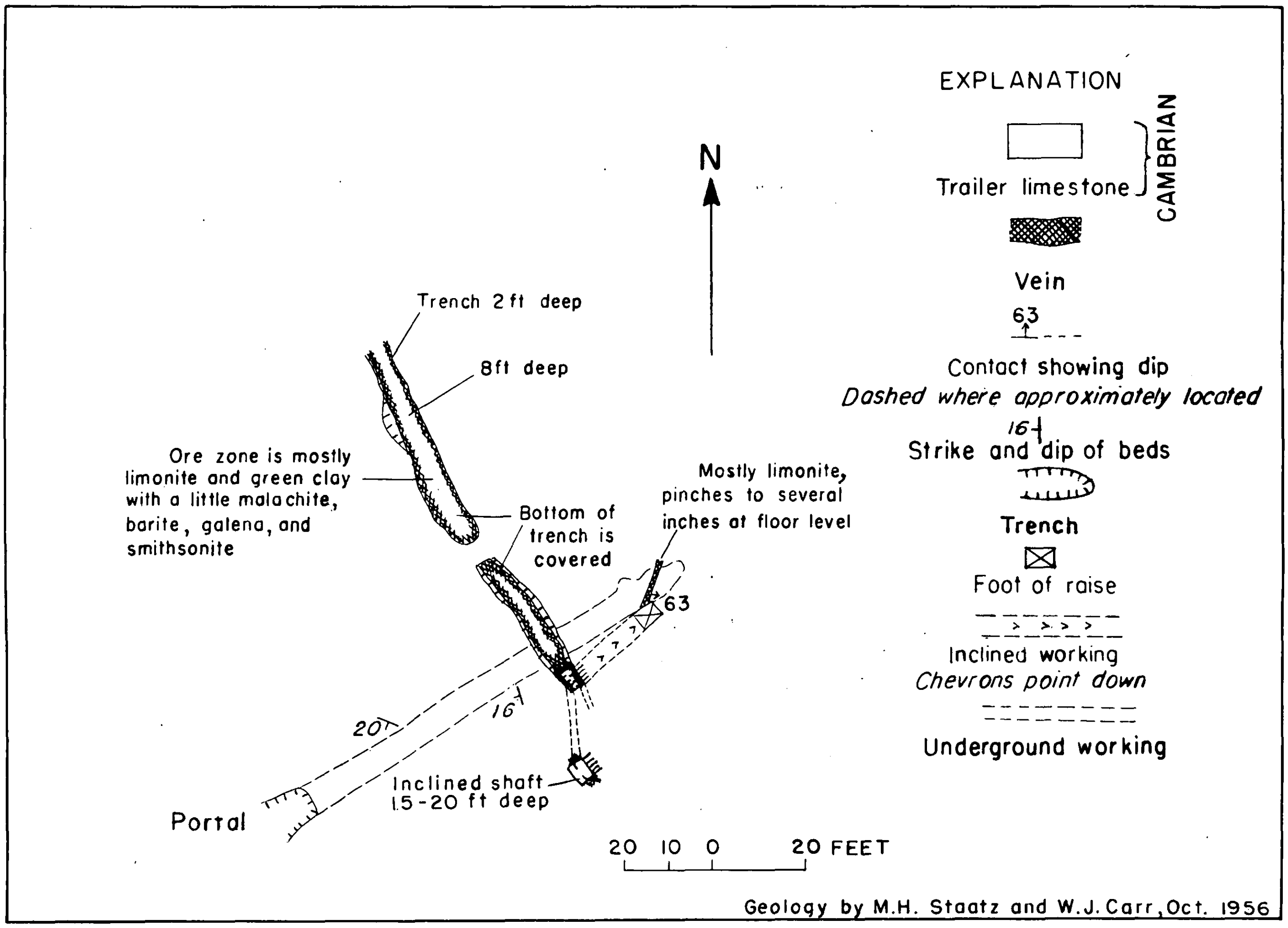


FIGURE 61.—Geologic map of surface and underground workings of the northwest vein at the Francis claim.

The southeast vein trends north-northeast and dips irregularly. The vein is exposed for approximately 185 feet along its strike. Most of the vein has been stoped out to a width of 1½ to 3 feet.

The ore from the southeast vein is similar to that of the northwest vein. Vein material consists chiefly of hematite and limonite; locally thin films of green malachite and a little calcite are present. No ore minerals are readily visible in hand specimen, but in thin section approximately 10 percent cerussite and 10 percent smithsonite were noted in one specimen.

LAURIS

The Lauris claim is on the south-facing slope of a steep quartzite mountain in the northwest corner of the Dugway Range. This claim adjoins the Bryan claim on the south; (fig. 57) the ore bodies on the two properties lie on the same fault zone. The southern end of the Lauris claim is about 2.1 miles S. 72° W. of the Four Metals mine, and 0.7 mile S. 4° W. of the Metal States shaft. The lower adit of the property is reached by a rough road about 1 mile long which joins a dirt road on the flats along the northwest side of the Dugway Range.

The deposits, now called the Lauris, were first located about 1880. This area has formerly been called both the Laurel tunnels and the Louis claim. The Lauris claim is unpatented and was relocated October 29, 1955, by Margaret and George Willis Smith of Stockton, Utah.

Production has been intermittent from this property. Records of early production are not available, but according to Heikes (1921, p. 200; 1922, p. 447), "* * * the Laurel (Lauris) shipped a car of 50 percent lead ore" in 1917 and "lead ore containing silver from the Laurel (Lauris) mine comprised the principal part of the Dugway district's output made by four producers and aggregating 83 tons in 1919."

The claim is developed by two separate workings: at 4,760 feet altitude, a lower adit that is 430 feet long and has a few small overhead stopes, and, at an altitude of 4,912 feet, an upper adit that is 100 feet long and has stopes extending upward about 25 feet to the surface and downward about 55 feet (fig. 62). Most of the production has come from the smaller upper workings.

Geology and ore deposits.—The Lauris claim lies along a fissure vein entirely within the Prospect Mountain quartzite (fig. 62). In the vicinity of the adits the beds strike north-northeast and dip about 25° NW. The fault zone in which the vein occurs strikes north and consists of several bifurcating shears that dip from 60° to 84° E. There are also a few minor northwest-trending shears that offset the larger faults in some places.

No sulfide ore was seen in the lower adit, or on the dump, although numerous veins of light-green massive banded fluorite are present. These veins of fluorspar are from ½ inch to 6 feet wide and generally occur as lenses along the faults. The largest fluorspar vein is about 60 feet from the portal of the adit. This vein has a maximum thickness of 6 feet above the adit in a stope, but it pinches rapidly downward to less than a foot at the adit level. The only other minerals noted in the fluorspar vein were quartz, hematite, and limonite.

The ore body exposed in the upper workings is almost completely mined out. It lies between two faults that dip eastward 68° and 69° at the adit level (fig. 62). The size of the stope indicates the ore body had a maximum length of about 60 feet and a maximum width of about 5 feet, and extended down dip from the surface for about 80 feet. A pillar of ore exposed above the adit level contained 2.7 feet of ore consisting of bands of galena and secondary lead minerals and 1-inch bands of fluorite. A few inches to 1.4 feet of fluorite can be seen along faults at the south end of the ore body and at the bottom of the stope.

The ore from the upper adit is made up of bands, which in one polished section consisted of a ½-inch band containing about 60 percent massive galena, 35 percent cerussite replacing the galena, and 5 percent quartz scattered through the cerussite. Bordering this is a 2- to 3-mm band consisting almost entirely of cerussite and an outer band containing white fibrous fluorite and a little hematite, quartz, and cerussite along cracks. A thin section of a fluorite-rich band contained 15 percent quartz, in anhedra ranging from 0.5 mm to less than 0.1 mm, that filled cracks and locally replaced the fluorite. Colorless fluorite made up 70 percent of the section and occurred as angular brecciated and rectangular pieces as much as one-quarter of an inch across. Other minerals included 10 percent hematite as opaque to dark-red clots and small plates, a possible trace of barite in small veinlets, a few percent clay, and small amounts of cerussite as an interlacing network in the other minerals. A few bands of colloform quartz as much as half an inch wide and some green copper staining were noted in pieces of material on the dump. Much of the fluorite, which when fresh is normally a pale apple green, bleaches white on prolonged exposure to sunlight.

The ore from the upper and lower adit is principally fluorite (table 25). The fluorspar in the lower adit is of metallurgical grade without beneficiation.

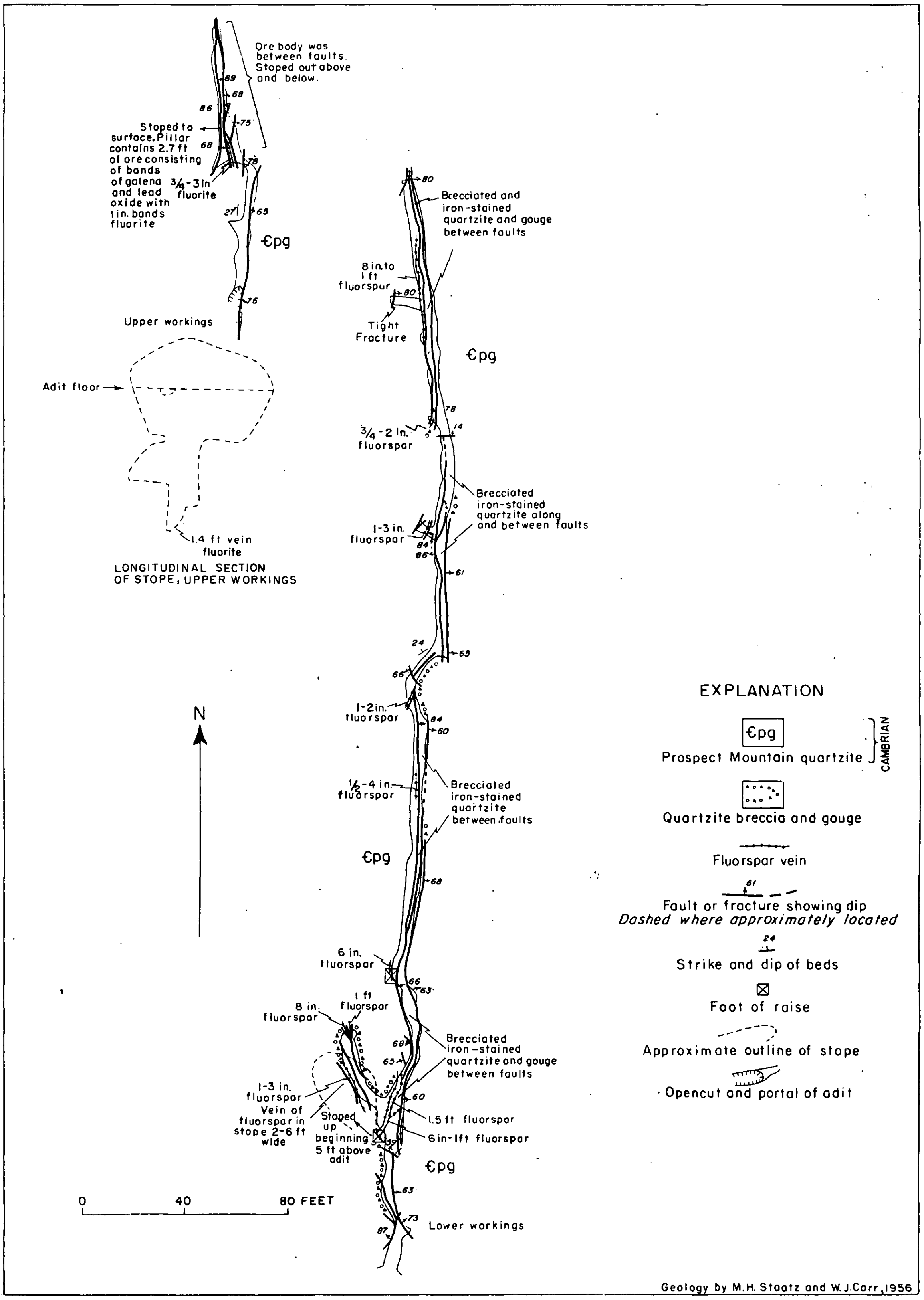


Figure 62.—Geologic map of workings on the Lauris claim.

METAL STATES

The Metal States or Cannon mine is the name here applied to three sets of workings, a total of 350 feet apart, on the southwest side of Kellys Hole near its northwest end (fig. 48*A*). Whether the name Metal States was originally applied to all three is not known, but because they are adjacent to each other on the same fault and are similar in character they will be described together. This property is 1.4 miles S. 71° W. of the Four Metals mine and is reached from this mine by a steep dirt road 2.7 miles long.

The workings are on the patented Endline and Black Dragon claims and on an unpatented area lying directly northeast of these claims (fig. 57). The Black Dragon was patented on May 12, 1892, and the Endline on February 23, 1897, by Angus M. Cannon. In 1956 these two claims were owned by J. F. and T. Q. Cannon and J. C. Orme of Salt Lake City.

The principal workings were on the west end of the Endline claim, where a caved shaft inclined 60° in a N. 20° E. direction was reported by L. S. Brechon (1934, written communication) to be 250 feet deep with a 250-foot drift at the 120-foot level and a 160-foot drift at the 200-foot level. An adit approximately 80 feet long with a short crosscut is about 160 feet southwest of the shaft behind a small cabin on the northwest end of the Black Dragon claim. A third set of workings is approximately 210 feet west-northwest of this adit, where a Y-shaped adit (fig. 63) has been driven in the fault zone between the quartzite and dolomite. A 68-foot winze inclined at 32° N. 41° W. has been sunk at the western end of this adit.

Geology.—The Metal States property lies along a major fault forming the southwest side of a graben (fig. 48*A*). This fault has a northwest strike and dips 30° NE. Massive white Prospect Mountain quartzite forms the steep mountain on the footwall side of the fault, and black medium-grained dolomite crops out in the workings on the hanging-wall side. This dolomite was formed by hydrothermal alteration and can be traced northward into unaltered light-gray Ochre Mountain limestone.

Ore deposits.—The ore deposits occur mainly in the dolomite along the fault zone, where according to Billingsley and Lyons (1926, written communication) it has been intensely fractured. The caved shaft exposed a pyritic copper-bearing ore body in the hanging wall parallel to the fault. The dump contains abundant pyrite and some copper carbonates. A grab sample taken from the dump of this property by L. S. Brechon (1934, written communication) was reported to contain 3.8 percent copper.

The adit southwest of the shaft is in barren quartzite.

The Y-shaped adit (fig. 63) to the west starts in dolomite and then turns and follows the contact between the dolomite and a gossan. The winze is along this same contact. The maximum thickness of the gossan is not known, but it has a minimum thickness of 15 feet.

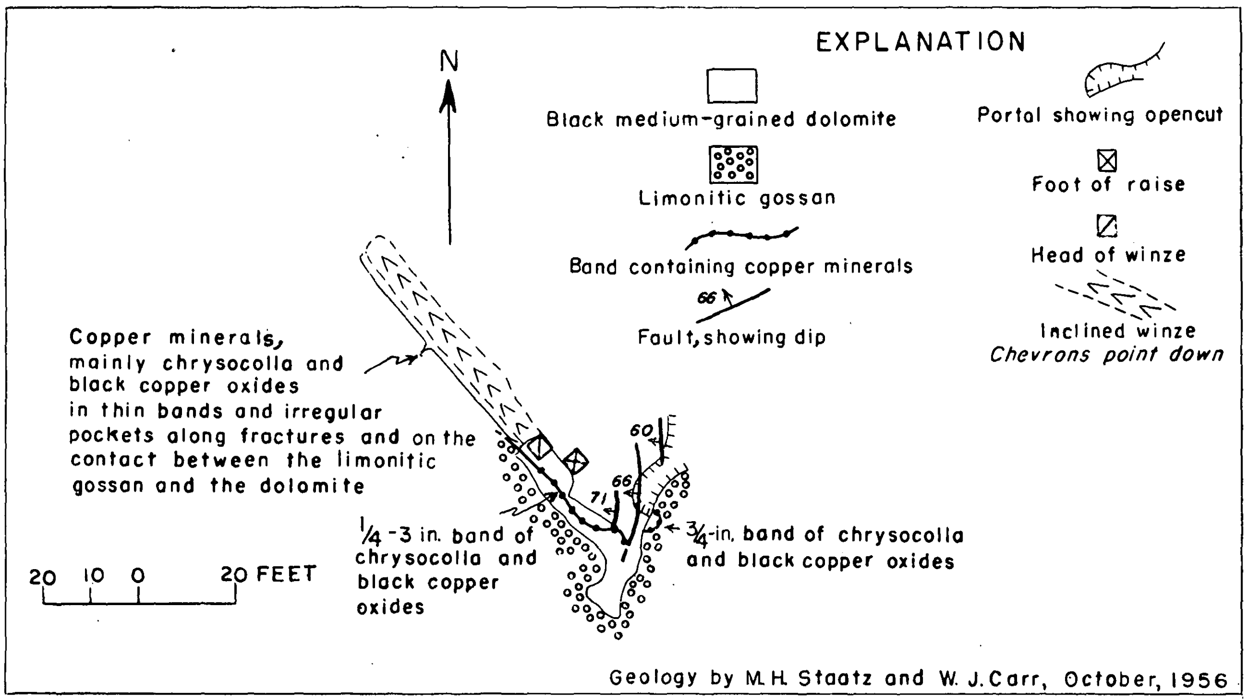


FIGURE 63.—Geologic map of adit on western end of Metal States property.

The gossan is made up largely of brown to orange limonite with some clay, and may be either hard and compact or soft and porous. Copper minerals occur chiefly in an irregular band ¼ to 3 inches thick in pockets along the contact between gossan and dolomite and in minor amounts in the gossan. The most common copper minerals are chrysocolla and the black copper oxides; malachite, azurite, and chalcanthite were noted in smaller amounts.

A chip sample was taken across scattered ore pockets from 17 to 40 feet down the winze (table 25). This sample, which contained 10.9 percent copper and small amounts of lead and zinc, represents some of the best ore exposed in these workings.

MINES AND PROSPECTS OF THE BUCKHORN AREA

A number of small mines and prospects are in the area west of the Buckhorn thrust fault (pl. 1), east of the main divide of the Dugway Range, and for about 1 mile south of the head of Bullion Canyon. There are 20 patented claims in this area, including the Virginia, the first (1879) patented claim in the Dugway mining district. Most of the other claims in the Buckhorn area were patented about 1897 and have not been worked for many years. The workings are now in poor condition, and the names of many are unknown. Because they are all geologically similar they are discussed here together.

Although some of these small mines were undoubtedly worked in the 1870's the peak of activity in this part of the district occurred in the 1890's. The Buckhorn mine is reported (Heikes, *in* Butler, Loughlin, Heikes, and others, 1920, p. 462) to have produced in 1891 sixty tons of silver-lead ore worth about $68,000. Some of the ore was reported to contain as much as 1,800 ounces of silver per ton. Probably little or no ore has been produced from this mine since that time. Production records are not available for any of the other mines in this part of the district.

Most of the workings in the area are small and inaccesible, and few were examined in detail. There are several vertical shafts having dumps, the size of which indicate several hundred feet of workings, but many of the workings must be classified as prospects consisting of short adits and small opencuts. Some of these doubtless produced small amounts of rich lead-silver ore.

Probably the three most productive mines in the Buckhorn area were the Yellow Jacket, Raymond-Bald Eagle, and Buckhorn. The Yellow Jacket workings, on the Yellow Jacket claim (fig. 57) at the head of Bullion Canyon, consist of several opencuts, short adits, and a vertical shaft. A poor road about 1.2 miles long branches from the main road serving the Dugway district and leads up Bullion Canyon to the workings. The Raymond-Bald Eagle workings are on claims of the same names just east of the central divide of the Dugway Range, 5,800 feet southeast of the Four Metals mine and 1,600 feet northeast of the northwestern vein on the Francis claim. A road in poor condition leads up to the mine from Kellys Hole, the total road distance from the Four Metals mine being about 5 miles. The workings at the Raymond-Bald Eagle claims consist of an opencut about 25 feet long, 15 feet wide, and 10 feet deep, with a shaft of unknown depth at the bottom. About 200 feet west of the opencut are several trenches and short adits. Some work has been done on this deposit in recent years, although it is not known if any ore was shipped. The Buckhorn mine, which has not been worked for many years, is located 4,500 feet southeast of the northwest vein at the Francis claim. The nearest road to the mine is the one to the Raymond-Bald Eagle property. This road crosses the crest of the Dugway Range 3,500 feet northwest of the Buckhorn mine. The workings consist of two branching adits having a total length of about 500 feet, several short adits, a shaft, and an opencut, now mostly filled. The opencut is about 28 feet across, 42 feet long, and a maximum of 12 feet deep as presently exposed. Most, if not all, of the ore came from this pit.

Geology and ore deposits.—Nearly all the deposits in this area are in the Fandangle limestone, principally in the lower massive part. In most places the Fandangle, normally a gray limestone, has been altered to a brownish-gray dolomite, and near many of the mineralized areas the dolomite is chocolate brown. Nearly all the deposits appear to be small replacement pockets of argentiferous lead ore. Only one prospect in this area, the Black Dragon, showed significant copper mineralization. The workings on most properties were confined to the near-surface oxidized ore. The Raymond-Bald Eagle and Black Dragon are close to the major faults separating the Prospect Mountain quartzite from the limestones. The rocks of the area are considerably broken, however, by numerous small and a few moderate-size faults having a northerly or northeasterly trend, and there are also a few faults with an east-west trend. All these structural features are cut off by the northwest-trending Buckhorn thrust fault which bounds the area on the east. Few, if any, of the faults just mentioned contain ore bodies. Most of the ore pockets appear to be along small shears related to these faults; some are at or near the intersection of two such shears. No consistent trend to the ore-bearing shears was discerned, although a northwest-trending set appears to be the most common.

The Yellow Jacket property is supposed to have produced lead carbonate ore from replacement bodies in dolomite near the intersection of two fissures which strike about N. 15° W. and N. 80° W. and dip about 45° SW. and 80° NE., respectively. The deposit is in highly dolomitized and iron-stained Fandangle limestone and is only about 400 feet west of the Buckhorn thrust fault. No ore minerals were seen on the dumps, although there is much limonite and a little copper staining.

The opencut at the Raymond-Bald Eagle property is in the footwall of a reverse fault which trends N. 68° E. and dips 68° SE. The country rock is highly dolomitized Fandangle limestone. The hanging wall of the fault is thin-bedded gray Trailer limestone. Iron oxides and a little galena and secondary lead and zinc minerals were noted on the dump. A thin section of a piece of ore from the opencut contained 50 percent of small hemimorphite crystals in radial clusters, 20 percent hematite as clots and opaque aggregates, 20 percent cavities, 5 percent cerussite in small scattered patches, and 5 percent very fine grained quartz. The ore also contains some galena and considerable green clayey material.

The workings at the Buckhorn mine are all in gray to brown locally dolomitized limestone in the upper part of the Fandangle limestone. No ore-bearing structures were noted, although there are several fractures with a few inches of gouge exposed in the longest of the western adits. The pit from which most of the ore came is partially backfilled. The only vein minerals noted were barite and calcite which occur in lumps of chocolate-brown dolomite. Pieces of a gray-brown fine-grained igneous rock, probably a rhyodacite dike, were found on the dump by the opencut and at several places uphill from the cut.

A deposit, though very small, which illustrates the geology and is rather typical of the deposits in the Buckhorn area, occurs on the unpatented area southeast of the Boston claim and about 0.3 mile south of the Yellow Jacket workings and the head of Bullion Canyon. This deposit is developed by a pit about 10 feet wide and 6 feet deep in brown dolomite and gray limestone of the Fandangle limestone. A small shear dipping at a low angle crosses the pit and separates limestone in the footwall from the dolomite in the hanging wall. The mineralized area was a pocket that occupied most of the pit, but did not extend much below the shear into the limestone. The deposit is completely mined out, but material on the dump indicates that the ore consisted of (1) nodulelike masses as much as 1.5 feet across of brown vuggy silicified dolomite commonly having a thin silicified rim with a little galena and (2) a softer core of brown locally pulverulent material. Vugs in the outer part of these masses contain earthy yellow iron oxide, some secondary lead minerals including a little yellow wulfenite in tabular crystals as much as one-quarter of an inch across, and rosettes of tiny white acicular crystals of aragonite. A little calcite and small white blades of barite are present in cavities and scattered through the rock. Under the microscope the outer part of one of the nodular masses is seen to consist chiefly of chalcedonic quartz with lesser amounts of a red-brown fine-grained mineral resembling siderite, calcite, dolomite, and a few scattered barite crystals. Ore minerals consist of galena and hemimorphite. Limonite and hematite compose the remainder of the gangue minerals. The galena occurs in irregular anhedral crystals 1 to 2 mm across, surrounded by and embayed by cerussite. The hemimorphite is found in small sheaflike clusters lining cavities. The textural relations suggest that galena replaced a brecciated limestone or dolomite, the galena was altered to cerussite, and finally the rock was silicified and barite was introduced as the latest gangue mineral.

Colorless or pale-green fluorite cubes and octahedra as much as half an inch across are commonly associated with comb quartz and a little galena at several mines and prospects on the Great Eastern, Pride of the West, and Nautilus claims (fig. 57). Fluorite is scarce, however, in ores of the rest of the Buckhorn area. Barite is a gangue mineral which is almost universally present in the Buckhorn area. It occurs as scattered microscopic blades and in some places as large crested masses in veins as much as 1.5 feet wide.

The Black Dragon claim, which lies about 1,000 feet northeast of the northwestern vein at the Francis claim, is unique in the Buckhorn area in that it shows some strong, although restricted, copper mineralization. The copper minerals are exposed in a small trench on a fault that strikes N. 30° W. and dips 55° NE. This fault separates a block of the Shadscale formation from the Fandangle limestone. Much hematite and limonite are present along this fault. A thin section of a piece of limonitic copper-bearing material from the trench contained 35 percent malachite in emerald-green rosettes of slender crystals as much as 0.5 mm long. The malachite fills scattered pockets and occurs as thin veinlets; the central parts of some veinlets have stringers of brilliant red cuprite. The remainder of the slide is a dark-brown to nearly opaque material that is probably a mixture of copper oxides and limonite. Chrysocolla, although not present in the slide, also occurs in places as thin veinlets.

REFERENCES CITED

Alling, A. N., 1887, On the topaz from the Thomas Range, Utah: Am. Jour. Sci., 3d ser., v. 33, p. 146–147.

Anderson, C. A., 1941, Volcanoes of the Medicine Lake highland, California: California Univ., Dept. Geol. Sci. Bull., v. 25, p. 347–422.

Baker, A. A., Huddle, J. W., and Kinney, D. M., 1949, Paleozoic geology of north and west sides of Uinta Basin, Utah: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 1161–1197.

Bloecher, F. W., Jr., 1952, Uranium recovery from Thomas Range, Utah, fluorspar: American Cyanamid Co., Atomic Energy Div., ACCO-16, 23 p., Watertown, Mass.

Bryan, Kirk, 1919, Classification of springs: Jour. Geology, v. 277, p. 522–561.

Buranek, A. M., 1947, Notes on topaz and associated minerals of Topaz Mountain and adjacent areas, Utah: Utah Mineralog. Soc. Bull., v. 7, p. 36–43.

Butler, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts, Utah: U.S. Geol. Survey Prof. Paper 80, 212 p.

Butler, B. S., Loughlin, G. F., Heikes, J. C., and others, 1920, The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111, 672 p.

Calkins, F. C., and Butler, B. S., 1943, Geology and ore deposits of the Cottonwood-American Fork area, Utah: U.S. Geol. Survey Prof. Paper 201, 152 p.

Callaghan, Eugene, 1936, Geology of the Chief district, Lincoln County, Nevada: Nevada Univ. Bull., v. 30, no. 2, 32 p.

———1937, Geology of the Delamar district, Lincoln County, Nevada: Nevada Univ. Bull., v. 31, no. 5, 72 p.

Christiansen, F. W., 1951, A summary of the structure and stratigraphy of the Canyon Range, *in* Intermountain Assoc. Petroleum Geologists, Geology of the Canyon, House and Confusion Ranges, Millard County, Utah: Guidebook to the geology of Utah, no. 6.

Coats, R. R., 1953, Geology of Buldir Island, Aleutian Islands, Alaska: U.S. Geol. Survey Bull. 989–A, p. 1–26.

Cohenour, R. E., 1958, Precambrian rocks of the Sheeprock Mountains, Tooele County, Utah [abs.]: Geol. Soc. America Bull., v. 69, no. 12, p. 1726.

———1959, Sheeprock Mountains, Tooele and Juab Counties: Utah Geol. and Mineralog. Survey Bull., 63, 201 p.

Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert, 1934, Bixbyit von Patagonia: Centralbl. Mineralogie, pt. A, p. 129–135.

Cox, D. C., 1945, General features of Colorado fluorspar deposits: Colorado Sci. Soc. Proc., v. 14, p. 263–285.

Crittenden, M. D., Jr., Straczek, J. A., and Roberts, R. J., 1961, Manganese deposits in the Drum Mountains, Juab County, Utah: U.S. Geol. Survey Bull. 1082–H, p. 493–544.

Cross, Whitman, 1886, On the occurrence of topaz and garnet in lithophyses of rhyolite: Am. Jour. Sci., 3d ser., v. 31, p. 432–438.

Daly, R. A., 1933, Igneous rocks and the depths of the earth: New York, McGraw-Hill Book Co., 598 p.

Deiss, Charles, 1938, Cambrian formations and sections in part of Cordilleran trough: Geol. Soc. America Bull., v. 49, p. 1067–1068.

Doss, Bruno, 1892, Ueber eine zufallige Bildung von Pseudobrookit, Hamatit, und Anhydrit als Sublimations produkte, und uber die systematische Stellung des erstern: Zeitschr. Kristallographie, v. 20, p. 569–584.

Drewes, Harald, and Palmer, A. R., 1957, Cambrian rocks of the southern Snake Range: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 104–120.

Eardley, A. J., 1944, Geology of the north-central Wasatch Mountain, Utah: Geol. Soc. America Bull., v. 55, p. 819–894.

Eardley, A. J., and Hatch, R. A., 1940, Proterozoic(?) rocks in Utah: Geol. Soc. America Bull., v. 51, p. 795–843.

Eastern Nevada Geological Association Stratigraphic Committee, 1953, Revision of stratigraphic units in Great Basin: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 143–151.

Emmons, R. C., and others, 1953, Selected petrogenic relationships of plagioclase: Geol. Soc. America Mem. 52, 142 p.

Eng. and Min. Jour., 1891, Mining news: v. 51, p. 503, 704.

Fitch, C. A., Quigley, James, and Barker, C. S., 1949, Utah's new mining district: Eng. and Min. Jour., v. 150, p. 63–69.

Ford, W. E., 1915, A study of the relations existing between the chemical, optical, and other physical properties of the members of the garnet group: Am. Jour. Sci., 4th ser., v. 40, p. 33–49.

Fries, Carl, Jr., Schaller, W. T., and Glass, J. J., 1942, Bixbyite and pseudobrookite from the tin-bearing rhyolite of the Black Range, New Mexico: Am. Mineralogist, v. 27, p. 305–322.

Frondel, Clifford, 1945, Effect of radiation on elasticity of quartz: Am. Mineralogist, v. 38, p. 432–436.

Gabriel, A., and Cox, E. P., 1929, A staining method for quantitative determination of certain rock minerals: Am. Mineralogist, v. 14, p. 290–292.

Galloway, J. J., and Kaska, H. V., 1957, Genus *Pentremites* and its species: Geol. Soc. America Mem. 69, 104 p.

Garrels, R. M., and Christ, C. L., 1959, Behavior of Colorado Plateau uranium minerals during oxidation *in* Garrels, R. M., and Larsen, E. S., 3d, 1959, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, p. 81–89.

Garrels, R. M., and Dreyer, R. M., 1952, Mechanism of limestone replacement at low temperatures and pressures: Geol. Soc. America Bull., v. 63, no. 4, p. 325–380.

Geikie, Archibald, 1897, Ancient volcanoes of Great Britain: v. 2, 492 p., London, McMillan and Co., Ltd.

George, W. O., 1924, Physical properties of natural glasses: Jour. Geology v. 32, p. 353–372.

Gerry, C. N., and Miller, T. H., 1935, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1935, p. 317–342.

Gilbert, G. K., 1875, Report on the geology of portions of Nevada, Utah, California, and Arizona examined in the years 1871 and 1872: U.S. Geog. and Geol. Surveys W. 100th Meridian Rept., v. 3, p. 17–187.

———1890, Lake Bonneville: U.S. Geol. Survey Mon. 1, 438 p.

Gilluly, James, 1928, Basin Range faulting along the Oquirrh Range, Utah: Geol. Soc. America Bull., v. 39, p. 1103–1130.

———1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173, 171 p.

Goddard, E. N., 1946, Fluorspar deposits of the Jamestown district, Boulder County, Colorado: Colorado Sci. Soc. Proc., v. 15, p. 5–47.

Granger, A. E., 1953, Stratigraphy of the Wasatch Range near Salt Lake City, Utah: U.S. Geol. Survey Circ. 296, 14 p.

Grout, F. F., 1932, Petrography and petrology: New York, McGraw-Hill Book Co., 522 p.

Hague, Arnold, 1883, Abstract of the report on the geology of the Eureka district, Nevada: U.S. Geol. Survey 3d Ann. Rept., p. 237–290.

———1947, Topaz areas of the Thomas Range: Rocks and Minerals, v. 22, p. 1003–1010.

Hansen, G. H., and Bell, M. M., 1949, The oil and gas possibilities of Utah: Utah Geol. Mineralog. Survey, 341 p.

Harker, Alfred, 1900, Igneous rocks series and mixed igneous rocks: Jour. Geology, v. 8, p. 389–399.

———1909, The natural history of igneous rocks: New York, Methuen and Co., 384 p.

Heikes, V. C., 1921, Gold, silver, copper, lead, and zinc in Utah: U.S. Geol. Survey, Mineral Resources U.S., pt. 1, 1917, p. 167–202.

———1922, Gold, silver, copper, lead, and zinc in Utah: U.S. Geol. Survey, Mineral Resources U.S., pt. 1, 1919, p. 417–449.

———1928, Gold, silver, copper, lead, and zinc in Utah: U.S. Bur. Mines, Mineral Resources U.S., pt. 1, 1925, p. 409–439.

Hewett, D. F., 1928, Dolomitization and ore deposition, Econ. Geology, v. 23, p. 821–863.

Hillebrand, W. F., 1905, Red beryl from Utah: Am. Jour. Sci., 4th ser., v. 19, p. 330–331.

Hintze, L. F., 1951, Lower Ordovician detailed stratigraphic sections for western Utah: Utah Geol. and Mineralog. Survey Bull. 39, 99 p.

———1952, Lower Ordovician trilobites from western Utah and eastern Nevada: Utah Geol. and Mineralog. Survey Bull. 48, 249 p.

Intermountain Association of Petroleum Geologists, 1951, Geology of the Canyon, House, and Confusion Ranges, Millard County, Utah: Guidebook to the geology of Utah, no. 6, 113 p.

Ives, R. L., 1946a, Minerals of Kelly's Hole, Utah: Rocks and Minerals, v. 21, p. 839–844.

———1946b, The Dugway geode placers, Utah: Rocks and Minerals, v. 21, p. 411–415.

———1947, Topaz areas of the Thomas Range: Rocks and Minerals, v. 22, p. 1003–1010.

Johnson, J. B., Jr., and Cook, K. L., 1957, Regional gravity survey of parts of Tooele, Juab, and Millard Counties, Utah: Geophysics, v. 22, p. 48–61.

Jones, A. J., 1895, Topaz crystals of Thomas Mountain, Utah: Iowa Acad. Sci. Proc. 2, p. 175–177.

Kunz, G. F., 1885, Precious stones: U.S. Geol. Survey, Mineral Resources U.S., 1883–1884, p. 756–781.

———1893, Precious stones: U.S. Geol. Survey, Mineral Resources U.S., 1892, p. 723–782.

Larsen, E. S., Jr., Keevil, N. B., and Harrison, H. C., 1952, Method for determining the age of igneous rocks, using accessory minerals: Geol. Soc. America Bull., v. 63, p. 1045–1052.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., 1910, Ore deposits of New Mexico: U.S. Geol. Survey Prof. Paper 68, 361 p.

Lindgren, Waldemar, and Loughlin, G. F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S. Geol. Survey Prof. Paper 107, 282 p.

Lintz, Joseph, Jr., and Lohr, L. S., 1958, Two new invertebrates from the Mississippian of Nevada: Jour. Paleontology, v. 32, p. 977–980.

Lovering, T. S., 1949, Rock alteration as a guide to ore—East Tintic district, Utah: Econ. Geology Mon. 1, 64 p.

Luff, Paul, 1953, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1950, p. 1586–1603.

———1954, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1951, p. 1589–1606.

Mansfield, G. R., 1920, Geography, geology, and mineral resources of the Fort Hall Indian Reservation, Idaho: U.S. Geol. Survey Bull. 713, 152 p.

———1927, Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 453 p.

———1929, Geography, geology, and mineral resources of the Portneuf quadrangle, Idaho: U.S. Geol. Survey Bull. 803, 110 p.

Merriam, C. W., 1940, Devonian stratigraphy and paleontology of the Roberts Mountains Region, Nevada: Geol. Soc. America Spec. Paper 25, 114 p.

Merriam, C. W., and Anderson, C. A., 1942, Reconnaissance survey of the Roberts Mountains, Nevada: Geol. Soc. America Bull., v. 53, p. 1675–1728.

Miller, T. H., 1938, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1937, p. 431–447.

Miller, T. H., and Luff, Paul, 1939, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1938, p. 461–477.

———1940, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1939, p. 445–463.

Minakami, Takeshi, Ishikawa, Toshio, and Yagi, Kenzo, 1951, The 1944 eruption of volcano Usu in Hokkaido, Japan: Bull. Volcanologique, ser. 2, v. 11, p. 45–161.

Montgomery, Arthur, 1934, A recent find of bixbyite and associated minerals in the Thomas Range, Utah: Am. Mineralogist, v. 19, p. 82–87.

———1935, Minerals of the Thomas Range, Utah: Rocks and Minerals, v. 10, p. 161–168.

Morris, H. T., and Lovering, T. S., 1961, Stratigraphy of the East Tintic Mountains, Utah: U.S. Geol. Survey Prof. Paper 361, 145 p.

Muessig, Siegfried, 1951, Eocene volcanism in central Utah: Science, v. 114, p. 234.

Muller, K. J., 1956, Taxonomy, nomenclature, orientation, and stratigraphic evaluation of conodonts: Jour. Paleontology, v. 30, p. 1324–1340.

Needham, C. E., and Luff, Paul, 1947, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1945, p. 456–477.

———1948, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1946, p. 1530–1548.

———1949, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1947, p. 1508–1524.

———1950, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1948, p. 1599–1616.

Needham, C. E., and Luff, Paul, 1951, Gold, silver, copper, lead, and zinc in Utah, review by counties and districts: U.S. Bur. Mines Minerals Yearbook, 1949, p. 1573–1589.

Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177, 172 p.

———1943, The Basin and Range province in Utah, Nevada, and California: U.S. Geol. Survey Prof. Paper 197–D, p. 141–196.

Nolan, T. B., Merriam, C. W., and Williams, J. S., 1956, The stratigraphic section in the vicinity of Eureka, Nevada: U.S. Geol. Survey Prof. Paper 276, 77 p.

Norton, J. J., Griffitts, W. R., and Wilmarth, V. R., 1958, Geology and resources of beryllium in the United States, *in* United Nations 2d Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1959, Proc.: v. 2, p. 21–34.

Olson, R. H., 1956, Geology of the Promontory Range: Utah Geol. Soc. Guidebook to the geology of Utah, no. 11, p. 41–75.

Osmond, J. C., 1954, Dolomites in Silurian and Devonian of east-central Nevada: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 1911–1956.

Outerbridge, W. F., Staatz, M. H., Meyrowitz, Robert, and Pommer, A. M., 1960, Weeksite, a new uranium silicate from the Thomas Range, Juab County, Utah: Am. Mineralogist, v. 45, p. 39–52.

Pabst, Adolph, 1938, Orientation of bixbyite on topaz: Am. Mineralogist, v. 23, p. 342–347.

Palache, Charles, 1934, Minerals from Topaz Mountain, Utah: Am. Mineralogist, v. 19, p. 14–18.

Pardee, J. T., Glass, J. J., and Stevens, R. E., 1937, Massive low-fluorine topaz from the Brewer mine, South Carolina: Am. Mineralogist, v. 22, p. 1058–1064.

Parks, J. M., Jr., 1951, Corals from the Brazer formation (Mississippian) of northern Utah: Jour. Paleontology, v. 25, p. 171–186.

Patton, H. B., 1908, Topaz-bearing rhyolite of the Thomas Range, Utah: Geol. Soc. America Bull., v. 19, p. 177–192.

Peacock, M. A., 1931, Classification of igneous rock series: Jour. Geology v. 39, p. 54–67.

Peale, A. C., 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U.S. Geol. Survey Bull. 110, 56 p.

Penfield, S. L., and Foote, H. W., 1897, On bixbyite, a new mineral, and notes on the associated topaz: Am. Jour. Sci., 4th ser., v. 4, p. 105–108.

Penfield, S. L., and Minor, J. C., 1894, On the chemical composition and related physical properties of topaz: Am. Jour. Sci., 3d ser., v. 47, p. 387–396.

Poldevaart, Arie, 1949, Three methods of graphic representation of chemical analyses of igneous rocks: South Africa Royal Soc. Trans., v. 32, p. 177–188.

Powers, H. A., 1932, The lavas of the Modoc lava bed quadrangle, California: Am. Mineralogist, v. 17, p. 253–294.

Przibram, Karl, 1956, Irradiation colours and luminescence: London, Pergamon Press, 332 p.

Raymond, P. E., 1925, A possible factor in the formation of dolomite [abs.]: Geol. Soc. America Bull., v. 36, p. 168.

Richardson, G. B., 1913, The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., v. 36, p. 406–416.

———1941, Geology and mineral resources of the Randolph quadrangle, Utah-Wyoming: U.S. Geol. Survey Bull. 923, 54 p.

Rittman, Alfred, 1952, Nomenclature of rocks: Bull. Volcanologique, ser. 2, v. 12, p. 75–102.

Rogers, A. F., and Kerr, P. F., 1933, Thin-section mineralogy: New York, McGraw-Hill Book Co., 311 p.

Rosholt, J. N., Jr., 1959, Natural radioactive disequilibrium of the uranium series: U.S. Geol. Survey Bull. 1084–A, p. 1–30.

Ross, C. S., and Smith, R. L., 1955, Water and other volatiles in volcanic glasses: Am. Mineralogist, v. 40, p. 1071–1089.

Ross, R. J., Jr., 1951, Stratigraphy of the Garden City formation in northeastern Utah and its trilobite faunas: Peabody Mus. Nat. History Bull. 6, 161 p.

Rush, R. W., 1956, Silurian rocks of western Millard County, Utah: Utah Geol. and Mineralog. Survey Bull. 53, 66 p.

Rust, G. W., 1937, Preliminary notes on explosive volcanism in southeastern Missouri: Jour. Geology, v. 45, p. 48–75.

Shimer, H. W., and Shrock, R. R., 1944, Index fossils of North America: New York, John Wiley and Sons, 837 p.

Simpson, J. H., 1876, Report of exploration across the Great Basin of the Territory of Utah for a direct wagon-route from Camp Floyd to Genoa in Carson Valley in 1859: Engineer Dept. U.S. Army, Washington, 518 p.

Snedden, H. D., Batty, J. V., Long, W. J., and Dean, K. C., 1947, Concentration of Utah fluorite ores: U.S. Bur. Mines Rept. Inv. 4143, 27 p.

Spieker, E. M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geol. Survey Prof. Paper 205–D, p. 117–160.

Staatz, M. H., and Bauer, H. W., Jr., 1951, Virgin Valley opal district, Humboldt County, Nevada: U.S. Geol. Survey Circ. 142, 7 p.

Staatz, M. H., and Osterwald, F. W., 1956, Uranium in the fluorspar deposits of the Thomas Range, Utah, *in* Page, L. R., Stocking, H. E., and Smith, H. B., compilers, 1956, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 131–136.

———1959, Geology of the Thomas Range fluorspar district, Juab County, Utah: U.S. Geol. Survey Bull. 1069, 97 p.

Staatz, M. H., and Trites, A. F., 1955, Geology of the Quartz Creek pegmatite district, Gunnison County, Colorado: U.S. Geol. Survey Prof. Paper 265, 111 p.

Thurston, W. R., Staatz, M. H., Cox, C. D., and others, 1954, Fluorspar deposits of Utah: U.S. Geol. Survey Bull. 1005, 53 p.

Trask, P. D., 1932, Origin and environment of source sediments of petroleum: Houston, Tex., Gulf Publishing Co., 323 p.

Tyrrell, G. W., 1948, The principles of petrology: London, Methuen and Co., 349 p.

Van Houten, F. B., 1956, Reconnaissance of Cenozoic sedimentary rocks of Nevada: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 2801–2825.

Van Tuyl, F. M., 1916, The origin of dolomite: Iowa Geol. Survey Ann. Rept., 1914, v. 25, p. 257–420.

Wahlstrom, E. E., 1947, Igneous minerals and rocks: New York, John Wiley and Sons, 367 p.

Walcott, C. D., 1908, Cambrian sections of the Cordilleran area: Smithsonian Misc. Coll., v. 53, no. 5, p. 167–230.

Walker, R. T., 1928, Mineralized volcanic explosion pipes: Eng. Mining Jour., v. 126, p. 895–898, 939–942, 976–984.

Warner, L. A., Holser, W. T., Wilmarth, V. R., and Cameron, E. N., 1959, Occurrence of nonpegmatite beryllium in the United States: U.S. Geol. Survey Prof. Paper 318, 198 p.

Washington, H. S., 1917, Chemical analyses of igneous rocks, published from 1884 to 1913, inclusive, with a critical discussion of the character and use of analyses: U.S. Geol. Survey Prof. Paper 99, 1201 p.

Webb, G. W., 1956, Middle Ordovician detailed stratigraphic sections for western Utah and eastern Nevada: Utah Geol. Mineralog. Survey Bull. 57, 77 p.

Wentworth, C. K., and Williams, Howel, 1932, The classification and terminology of the pyroclastic rocks: Rept. Comm. Sedimentation 1930–1932, Natl. Research Council Bull. no. 89, p. 19–53.

Westgate, L. F., and Knopf, Adolf, 1932, Geology and ore deposits of the Pioche district, Nevada: U.S. Geol. Survey Prof. Paper 171, 79 p.

Wheeler, H. E., 1948, Late Precambrian-Cambrian stratigraphic cross section through southern Nevada: Nevada Univ. Bull. v. 42, no. 3, 61 p.

Wheeler, H. E., and Beesley, E. M., 1948, Critique of the time-stratigraphy concept: Geol. Soc. America Bull., v. 59, p. 75–85.

White, D. E., 1957, Thermal waters of volcanic origin: Geol. Soc. America Bull., v. 68, p. 1637–1658.

Wilcox, R. E., 1954, Petrology of Parícutin volcano, Mexico: U.S. Geol. Survey Bull. 965–C, p. 281–353.

Williams, Howel, 1935, Newberry Volcano of central Oregon: Geol. Soc. America Bull., v. 46, p. 253–304.

———1942, The geology of Crater Lake National Park, Oregon: Carnegie Inst. Washington Pub. 540, 161 p.

———1950, Volcanoes of the Parícutin region: U.S. Geol. Survey Bull. 965–B, p. 165–279.

Williams, J. S., 1948, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geol. Soc. America Bull., v. 59, p. 1121–1164.

Winchell, A. N., 1947, Elements of optical mineralogy, pt. 2: New York, John Wiley and Sons, 459 p.

Woodward, G. E., and Luff, Paul, 1941, Gold, silver, copper, lead, and zinc in Utah: U.S. Bur. Mines Minerals Yearbook, 1940, p. 445–462.

———1943a, Gold, silver, copper, lead, and zinc in Utah: U.S. Bur. Mines Minerals Yearbook, 1941, p. 455–474.

———1943b, Gold, silver, copper, lead, and zinc in Utah: U.S. Bur. Mines Minerals Yearbook, 1942, p. 481–502.

———1945, Gold, silver, copper, lead, and zinc in Utah: U.S. Bur. Mines Minerals Yearbook, 1943, p. 461–482.

———1946, Gold, silver, copper, lead, and zinc in Utah: U.S. Bur. Mines Minerals Yearbook, 1944, p. 437–461.

Wright, W. I., 1938, The composition and occurrence of garnets: Am. Mineralogist, v. 23, p. 436–449.

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