Geology of the Beryllium Deposits in the Thomas Range Juab County, Utah

By MORTIMER H. STAATZ

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A study of the surface geology of the beryllium deposits, which occur in tuffs of Tertiary age

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CONTENTS

ILLUSTRATIONS

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GEOLOGY OF THE BERYLLIUM DEPOSITS IN THE THOMAS RANGE, JUAB COUNTY, UTAH

By MORTIMER H. STAATZ

ABSTRACT

Beryllium deposits containing bertrandite ($2Be_2 SiO_4 \cdot H_2O$) occur in tuffs on the flats surrounding Spor Mountain in the western part of the Thomas Range in western Juab County, 46 miles northwest of Delta, Utah. The first beryllium deposit was found in December 1959, and others were found in 1960 and 1961. The beryllium-bearing tuff is located by trenching and drilling, because the tuff is generally covered by sediments.

Both fluorspar and uranium mines have been worked in this area. Fluorspar mining started in 1944, and ore has been produced from at least 20 pipes and a few veins in dolomites of Ordovician and Silurian age on Spor Mountain. Uranium mining started in the fall of 1956 in a small body of lacustrine sandstone interbedded in volcanic rocks at the Yellow Chief property in the flat on the east side of Spor Mountain.

The rocks exposed in the area range in age from Ordovician to Pleistocene. Spor Mountain is made up chiefly of Paleozoic sedimentary rocks, which are cut in places by Tertiary volcanic rocks. The eastern part of the Thomas Range and the flats surrounding Spor Mountain consist chiefly of Tertiary age volcanic rocks divided into an older and a younger group separated by an angular unconformity. Alluvial deposits cover much of the lowlands and below a level of 5,200 feet most of these unconsolidated sediments are of the Lake Bonneville Group and were deposited in Lake Bonneville during Pleistocene time. Rocks of the older group occur in poorly exposed outcrops in the flats east and south of Spor Mountain. They are divided into six units: dark labradorite rhyodacite, rhyodacite, porphyritic rhyolite, quartz-sanidine crystal tuff, vitric tuff, and intrusive breccia. Interbedded with these units in a small area on the east side of Spor Mountain is a water-laid sandstone and thin limestone pebble conglomerate. The greater part of the exposed volcanic rocks belongs to the younger group which is made up of several overlapping, identical sequences of rock. These sequences consist of vitric tuff, breccia, and rhyolite, with rhyolite making up at least 95 percent of the rock in any sequence. The beryllium deposits are found in tuffs of both groups.

The Paleozoic sedimentary rocks have a northeast strike and a moderate northwest dip. The attitude of the rocks of the older volcanic group in part results from initial dip and in part from some of the tilting that affected the

Paleozoic rocks. The attitude of the younger volcanic rocks conforms to initial dip. The area is cut by numerous faults belonging to three general groups: (a) small northeast-trending thrusts, (b) moderate-sized diversely oriented normal and reverse faults, and (c) large north-trending Basin-and-Range-type faults. Most of the faults belong to the second group, which may be subdivided by age and trend into: northeast-trending normal and reverse strike faults, northwest-trending transverse faults, and east-trending transverse faults. All faults cut the Paleozoic sedimentary rocks. The east-trending moderate-sized faults and the Basin-and-Range-type faults cut rocks of the older volcanic group. Only a few small faults cut rocks of the younger volcanic group.

Beryllium deposits are chiefly in tuff that is associated with small amounts of fluorite. On the east side of Spor Mountain, these deposits are in quartz-sanidine crystal tuff of the older volcanic group, and on the west side, they are found in the vitric tuff, which commonly contains dolomite pebbles, of the younger volcanic group. The tuff is believed to be favored as the host rock because of its high porosity and permeability. In addition, small beryllium-bearing veins have been found in the Paleozoic dolomite in a few places adjacent to volcanic rocks.

Although the beryllium is erratically distributed, certain layers in the tuff appear more favorable than others. One beryllium-rich layer in the tuff on the Hogsback property is roughly 6 feet thick and can be traced around a hill 900 feet long by 400 feet wide. Several other layers have been traced at least several hundred feet, although in most places lack of exposures makes tracing difficult.

Beryllium-bearing tuff has been altered, so that much of the glass, especially any pumice, and any dolomite pebbles have been replaced by fluorite, montmorillonite, at least one manganese oxide mineral, opal, chalcedony, and bertrandite. The replaced tuff is a white soft, friable rock containing unreplaced crystal fragments. The new minerals are very fine grained; crystals of bertrandite are about 1 micron in size. Bertrandite, opal, chalcedony, and some of the montmorillonite are white, and because of similar color and small grain size cannot be visually separated. Bertrandite is found only in altered tuff with its typically associated minerals; on the other hand, similar-appearing altered tuff that contains all the associated minerals commonly contains no bertrandite. Some of the deposits contain ellipsoidal nodules 1/16 inch to 1 foot in length consisting chiefly of opal and fluorite. Commonly these nodules are much richer in bertrandite than the enclosing tuff. Samples of unsorted altered tuff contain as much as 1.1 percent beryllium; the nodules contain as much as 3.2 percent beryllium.

The beryllium deposits, together with the neighboring fluorspar and uranium deposits, are believed to have formed during the waning stages of volcanism after most of the rocks of the younger volcanic group were erupted. Beryllium-bearing fluids, in which the beryllium was carried as a soluble complex fluoride, were derived from the magma that formed the fluorine-, uranium-, and beryllium-rich rhyolite of the younger volcanic group. These fluids rose along faults. In the vicinity of the major fluorspar deposits, the fluoride content of the fluids remained too high for the beryllium complex to break down. In the outlying regions where the fluoride content was low, beryllium precipitated. The tuffs were favored as a host for the bertrandite because of their high porosity and permeability.

INTRODUCTION

PURPOSE AND SCOPE OF STUDY

The Thomas Range is the first place in which beryllium minerals have been found in tuff. The development of nuclear beryllium detectors for use in the field, such as described by Brownell (1959) and Vaughn, Wilson, and Ohm (1960), made this discovery possible. Although these instruments should aid in finding finely disseminated beryllium deposits in tuff in other areas, a study of the Thomas Range beryllium deposits will give some guidelines in exploring and developing similar deposits elsewhere. This report covers only the geology of the beryllium deposits and is supplementary to previous descriptions of the fluorspar deposits of the Thomas Range (Staatz and Osterwald, 1959) and the general geology of the Thomas and Dugway Ranges (Staatz and Carr, 1963). The previous reports were completed before the discovery of any beryllium minerals in the tuff.

USES, PRODUCTION, AND OCCURRENCE OF BERYLLIUM

Beryllium has a number of important uses in ceramics and special alloys, as well as in the atomic energy field. This metal would have even greater use if it were cheaper and more abundant.

Through 1955, beryl-bearing pegmatites were the only commercial source of beryllium in the United States and most of the world. Beryl is recovered from the pegmatites by hand sorting, generally as a byproduct or coproduct in the mining of feldspar, mica, or lithium minerals. The amount of beryl in any one pegmatite is small because the pegmatites are commonly small, and beryl is generally found only in certain zones within the pegmatite. In recent years, the output of beryl from pegmatites has been declining (Eilertsen, 1960, p. 241). If the United States is to become self-sufficient in beryllium and if beryllium consumption is to continue to expand, large nonpegmatitic sources of beryllium must be found.

In late 1959, a high concentration of beryllium was discovered in tuff in the Thomas Range, Utah. The beryllium mineral was idenfied in May or June 1960 as bertrandite ($2Be_2SiO_4 \cdot H_2O$). Since the original discovery, bertrandite-bearing tuff has been found in several places in the Thomas Range. The largest known deposits are scattered over an area at least 3 miles long by 2 miles wide. The widespread occurrence of beryllium in tuff in the Thomas Range has given rise to the hope that this area may become a major source of the metal.

LOCATION

The Thomas Range is a small desert range near the eastern edge of the Basin and Range province in central Juab County, Utah (fig. 1). The range consists of three distinct topographic units. The largest or eastern part has a north-south trend and an hourglasslike shape. This part of the range is about 14 miles long, has a maximum width of 9 miles, and is composed of Tertiary volcanic rocks. The western part of the range, which is called Spor Mountain, has a north-northwest trend and an oval shape (fig. 1). Spor Mountain is separated from the eastern part of the range by The Dell, an intermontane valley 0.8 to 2 miles wide. Spor Mountain is composed chiefly of complexly faulted middle Paleozoic sedimentary rocks. The northwest part of the Thomas Range, which is called the Black Rock Hills, is circular in shape with a diameter of 4.5 miles, and lies 3.5 miles northwest of Spor Mountain (fig. 1). The Black Rock Hills are composed of Upper Devonian sedimentary rocks and Tertiary rhyodacite.

The area in which beryllium deposits have been found is in Tps. 12 and 13 S., R. 12 W., Salt Lake principal meridian (fig. 2). The nearest town is Delta, in Millard County, approximately 46 miles from the southeast corner of the area shown in figure 2. Delta is also the nearest railhead, and is on the main line of the Union Pacific Railroad between Salt Lake City and Los Angeles. The area is connected to Delta by 15 miles of paved road and 31 miles of graded dirt road.

HISTORY AND PREVIOUS WORK

Fluorspar, uranium, and beryllium deposits were found on or in the vicinity of Spor Mountain (fig. 2). All three types are low-temperature deposits that formed at about the same time and that commonly have the same mineral associations. No copper, lead, zinc, silver, or gold minerals, such as are found in the Detroit mining district 11 miles to the southeast, the Dugway mining district 15 miles to the north, or the Fish Springs mining district 13 miles to the northwest, are known in the vicinity of Spor Mountain. Most of the prospecting on Spor Mountain took place in three periods: 1948–49 for fluorspar (Staatz and Osterwald, 1959, p. 5–6), 1952–54 for uranium (Staatz and Carr, 1963), and 1960 to at least mid-1961 for beryllium.

Beryllium was discovered in the Spor Mountain area in December 1959 when a "rockhound" collected a number of nodules of opal for cutting and polishing. On his way home the collector stopped at Ely, Nev., where the nodules were tested by Beryllium Resources, Inc., with a nuclear beryllium detector. The nodules contained beryllium. This discovery led Beryllium Resources, Inc., to start exploration in the Spor Mountain area. They were followed shortly by

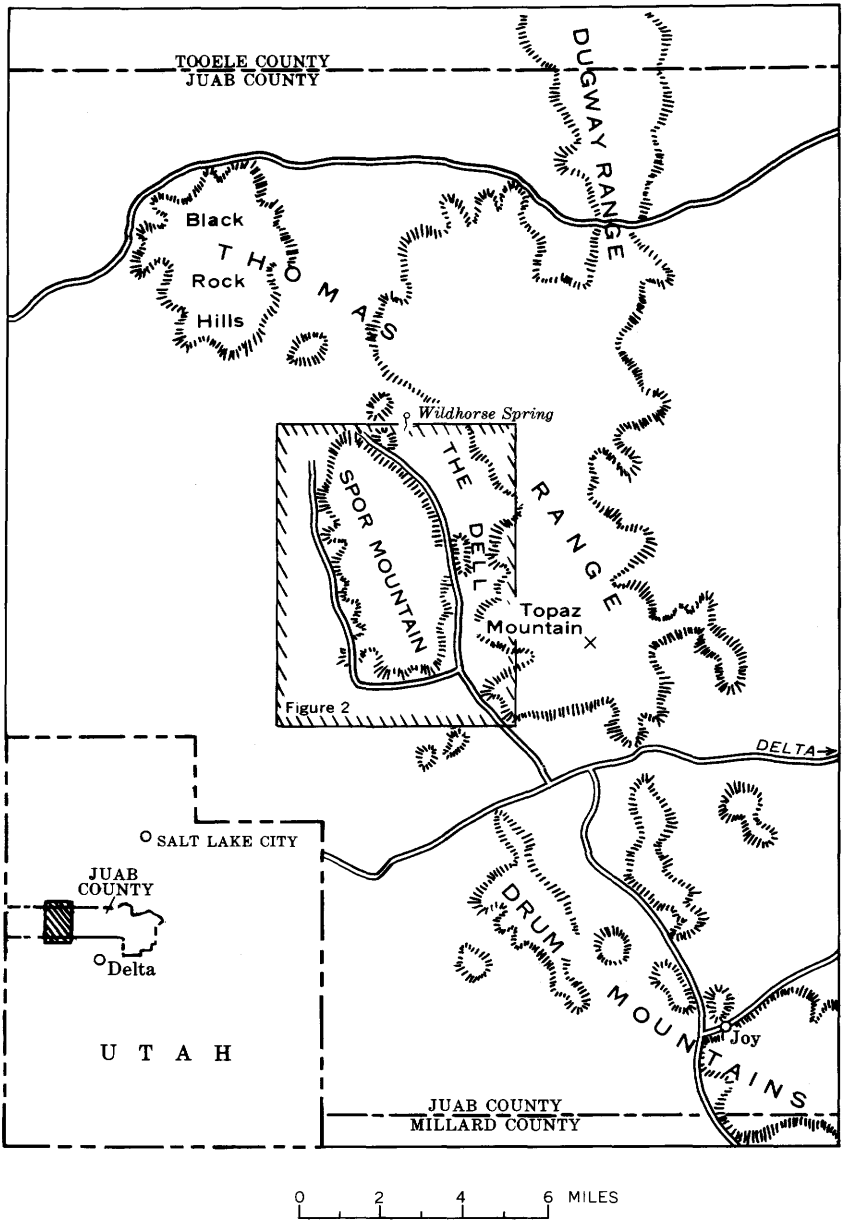
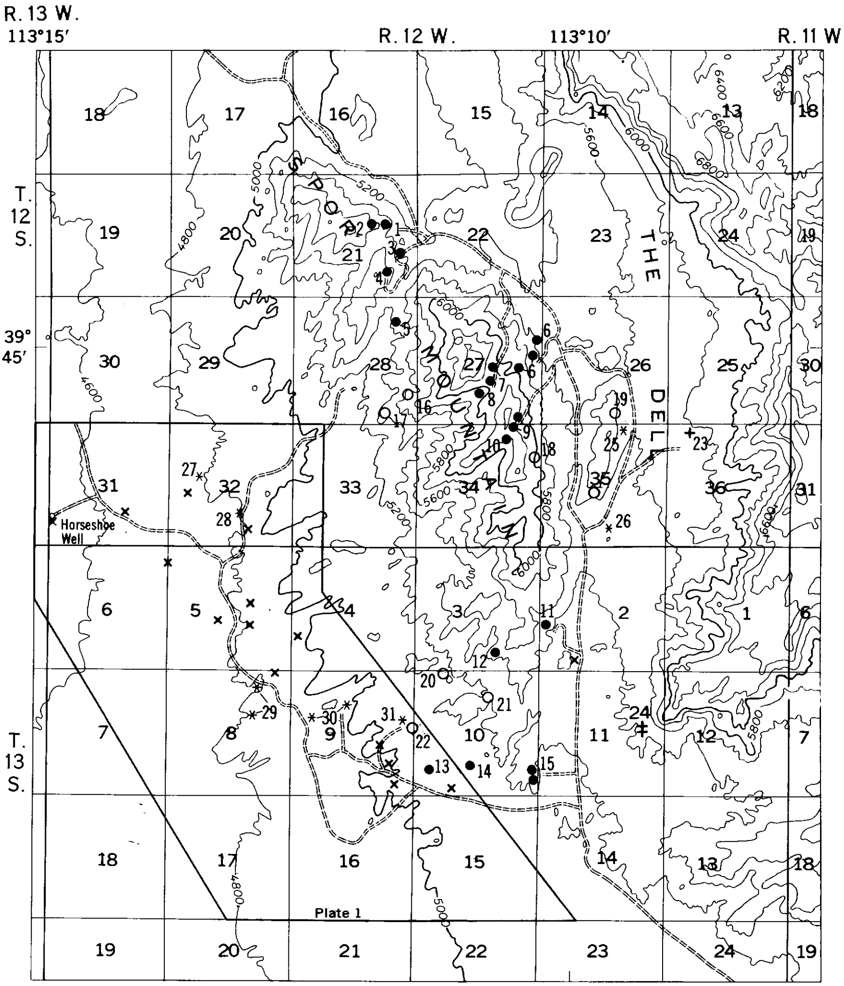


FIGURE 1.—Index map of the Thomas Range, Juab County, Utah.

Vitro Mineral Corp., and a little later by The Combined Metals Reduction Corp. Beryllium-bearing tuff was discovered on both the east and west flanks of Spor Mountain. Numerous claims have been located by companies and individuals. As many of the beryllium-bearing tuff beds are covered, much of the exploration is done



Topography from U.S. Geological Survey Topaz Mountain and Dugway Range quadrangles

0 1 2 3 MILES

CONTOUR INTERVAL 200 FEET
DATUM IS MEAN SEA LEVEL

FIGURE 2.—Distribution of mineral deposits in the Spor Mountain area. Heavy dashed line outlines area covered by plate 1.

EXPLANATION

●
Fluorspar mine in dolomite

1. Oversight
2. Hilltop
3. Lost Sheep
4. Blowout
5. Thursday
6. Dell
7. Dell No. 5
8. Green Crystal
9. Fluoirne Queen
10. Fluorine Queen No. 4
11. Floride
12. Floride No. 5
13. Lucky Louie
14. Harrisite
15. Bell Hill

○
Fluorspar prospect in dolomite

16. Blue Queen
17. Lost Soul
18. Nonella
19. Eagle Rock
20. Evening Star
21. Prospector
22. Blue Chalk

×
Fluorspar occurrence in tuff

+
Uranium mine

23. Yellow Chief or Good Will

ǂ
Uranium prospect

24. Buena No. 1

⧫
Locality of sample from which an assay of at least 0.05 percent Be was obtained

25. Claybank
26. Hogsback
27. North End
28. Tarus
29. Roadside
30. Rainbow
31. Blue Chalk

by drilling. Unlike the exploration for fluorspar and uranium, the exploration for beryllium is done largely by companies rather than individuals.

The earliest geologic report on the Thomas Range was made by Harry Engelmann, geologist for Capt. J. H. Simpson's expedition across the Great Basin in 1859 (Simpson, 1876, p. 325–326). Engelmann briefly discussed topaz from the eastern part of the Thomas Range. Topaz, which occurs in the rhyolite, and its much rarer associated minerals—pink beryl, bixbyite, specularite, garnet, and pseudobrookite—were the subject of many early papers (Allings, 1887; Hillebrand, 1905; Jones, 1895; Kunz, 1885; p. 738, 1893, p. 764; Montgomery, 1934; Palache, 1934, p. 14–15; Patton, 1908; and Penfield and Foote, 1897).

Fluorspar on Spor Mountain was studied between 1944 and 1950 by W. R. Thurston and E. D. Washburn for the U.S. Geological Survey, 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 by Fitch, Quigley, and Barker (1949). Uranium in the fluorspar deposits was studied in 1950 by M. H. Staatz, V. R. Wilmarth, and H. L.

Bauer, Jr. (Thurston and others, 1954). The Spor Mountain area was mapped in detail during 1951 and 1952 by M. H. Staatz and F. W. Osterwald (Staatz and Osterwald, 1956, 1959). H. L. Bauer, Jr.,[1] mapped a part of the northern end of Spor Mountain during the fall of 1951. From 1954 to 1956 M. H. Staatz and W. J. Carr mapped the northern third of the Topaz Mountain quadrangle and the Dugway Range quadrangle. The report of that work (Staatz and Carr, 1963) emphasizes the stratigraphy of the Paleozoic sedimentary rocks of both ranges and the petrology of the volcanic rocks of the eastern part of the Thomas Range. It describes new fluorspar properties and the early development of the Yellow Chief uranium mine. A new uranium silicate mineral from the east side of the eastern part of the Thomas Range and the Yellow Chief property in The Dell was described and named weeksite (Outerbridge and others, 1960).

The beryllium area at Spor Mountain has been studied by many individuals since 1959, including David Snyder, Benjamin Dickerson, Cecil Smith, and Thomas McClary for Vitro Mineral Corp.; Richard Pascoe, Joseph Leisek, Jeffery Jones, and Allen Taylor for Beryllium Resources, Inc.; Morris Trover for United Technical Industries; John Simons for Union Pacific Railroad Co.; Reginald Lee for The Combined Metals Reduction Corp.; Michael Rockwell; Page Jenkins; and Richard Moody. In addition, The Anaconda Co., Dow Chemical Corp., Minerva Oil Co., and New Jersey Zinc Co. have had representatives in the area. With W. R. Griffitts of the U.S. Geological Survey, I examined the beryllium-bearing tuff exposed in June 1960, and wrote the first published description of these beryllium occurrences (Staatz and Griffitts, 1961).

PRESENT WORK AND ACKNOWLEDGMENTS

The present work is a study of the geology of the beryllium deposits and includes a map of an area of approximately 10 square miles that shows all known exposures of beryllium-bearing tuff on the west and southwest sides of Spor Mountain (fig. 2, pl. 1). This area also is shown as part of plate 1 of U.S. Geological Survey Bulletin 1069 (Staatz and Osterwald, 1959). The earlier mapping in the flats to the west of Spor Mountain was reconnaissance, but the area shown on plate 1 was remapped in detail taking advantage of exposures in many new bulldozer trenches. Sampling was done on all known outcrops of altered tuff—both in the southwest part

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

of the Spor Mountain area and in The Dell. Much of the exploration in this area has been done by drilling. As data obtained by individuals or companies are private information, no drilling data are included in this report. Fieldwork for the present report was done intermittently from late February to the middle of April 1961, although some data were obtained from a previous visit in June 1960.

Numerous people and companies involved in exploration for beryllium in the Spor Mountain area have been extremely helpful. Especial thanks are due to Cecil Smith and Tom McClary of Vitro Mineral Corp.; Richard Pascoe, Joe Leisek, Jeff Jones, and Allen Taylor of Beryllium Resources, Inc.; Reginald Lee of The Combined Metals Reduction Co.; Faye Spor; and Richard Moody. W. W. Vaughn and J. M. Ohm, of the U.S. Geological Survey, spent a week in the Spor Mountain area testing a new core hole beryllium detector. With E. E. Wilson, they built the instrument with which all beryllium determinations used in this report were made. Thanks are also due to W. R. Griffitts of the U.S. Geological Survey, who accompanied me to the Spor Mountain area in June 1960, and from whom considerable helpful advice on beryllium deposits was received.

GEOLOGY

GEOLOGIC SETTING

The rocks in the Spor Mountain area range from Early Ordovician to Pleistocene in age. Spor Mountain is made up chiefly of Paleozoic sedimentary rocks; the flats surrounding Spor Mountain and the eastern part of the Thomas Range are made up chiefly of Tertiary volcanic rocks. The sedimentary and volcanic rocks are well exposed in the mountains, but most places in the flats are thinly to thickly mantled with gravels and marls of the Pleistocene Lake Bonneville Group. The Paleozoic sedimentary rocks in this area are approximately 3,950 feet thick, consist of about 270 feet of limestone, 320 feet of shale, 590 feet of quartzite and 2,770 feet of dolomite, and range in age from Early Ordovician to Late Devonian. The greater part of Spor Mountain is underlain by dolomite of Middle Silurian age. However, the Paleozoic rocks exposed on the southwest side of Spor Mountain, near the beryllium-rich tuffs, are principally Devonian in age.

The Tertiary volcanic rocks are made up of an older and a younger group. The older volcanic group is exposed chiefly in low hills in The Dell and as intrusive bodies in the Paleozoic sedimentary rocks on Spor Mountain. In this region the following six lithologic units have been distinguished: dark labradorite rhyodacite, rhyodacite, porphyritic rhyolite, quartz-sanidine crystal tuff, vitric tuff, and intrusive breccia. A small lacustrine sandstone unit overlain by a thin erratic conglomerate is found interbedded with rocks of this older group in the central part of The Dell. The younger volcanic group is exposed along the east side of The Dell and on the southwest side of Spor Mountain. These rocks make up nearly all the eastern part of the Thomas Range, where at least five overlapping sequences of rocks are found. These sequences consist of rhyolite, vitric tuff, and breccia, but rhyolite makes up more than 95 percent of the total rock. Parts of several sequences are exposed along the east side of The Dell; only one sequence is exposed, however, along the southwest side of Spor Mountain.

The structure of the Spor Mountain area, especially the faulting of the Paleozoic sedimentary rocks, has been discussed elsewhere (Staatz and Osterwald, 1959, p. 42–45; Staatz and Carr, 1963), where it is shown that the Paleozoic sedimentary rocks have a consistent northeast strike and a moderate northwest dip. They are cut by faults belonging to three general groups: (a) a few small northeast-trending thrust faults, (b) numerous moderate-sized normal and reverse faults of three general trends, and (c) a few large north-trending Basin-and-Range-type faults. The older group of volcanic rocks are cut by east-trending moderate-sized faults and by the large Basin-and-Range-type faults. The younger group of volcanic rocks is rarely cut by faults, and where cut, the movement is small. The attitude of the rocks of the older volcanic group is due in part to folding that tilted the Paleozoic rocks and in part to original dip. The attitude of rocks of the younger volcanic group is due entirely to original dip. As the volcanic rocks were deposited on a mature topography carved in the older Paleozoic rocks, the original dip can be fairly steep.

PALEOZOIC SEDIMENTARY ROCKS

All the large fluorspar deposits occur in the Paleozoic sedimentary rocks. These rocks have been described in considerable detail (Staatz and Osterwald, 1959, p. 9–34; Staatz and Carr, 1963). For this reason, and because no large concentrations of beryllium have been found associated with them, the Paleozoic sedimentary rocks will not be further discussed in this paper. It should be noted, however, that the Sevy Dolomite of Devonian age is the Paleozoic sedimentary rock most commonly found adjacent to the beryllium-bearing tuff on the southwest side of Spor Mountain.

TERTIARY VOLCANIC ROCKS

Volcanic rocks cover a large part of The Dell, the southwest side of Spor Mountain, and the entire eastern part of the Thomas Range. In addition, small intrusions are found in many places on Spor Mountain. The volcanic rocks may be divided by mode of emplacement into flows, pyroclastics, and intrusions; by composition, into rhyolitic and rhyodacitic rocks; and by age, into an older volcanic group and a younger volcanic group.

A pronounced unconformity, having considerable relief in places, separates the two age groups. Near the center of The Dell, this unconformity is close to the valley floor; half a mile to the east, along the east side of The Dell, it is about 400 feet higher.

Rocks of the younger volcanic group are commonly well exposed, and the relation between individual members is fairly clear. These rocks are best exposed in the eastern part of the Thomas Range. Rocks of the older group are generally poorly exposed, and the age relation between some members of this group is unknown. These rocks are exposed on small hills in and along the sides of The Dell and in some of the deeper valleys in the eastern part of the Thomas Range. Both groups have flow rocks, pyroclastic rocks, and intrusive rocks; the most of the rocks of both groups have a rhyolitic composition. Both have rocks, such as rhyolite and tuffs, that closely resemble similar rocks in the other group. Some general differences occur that are useful in separating the two groups. All rocks with a rhyodacitic composition belong to the older group. The greater part of the tuffs of the older group are crystal tuffs, and many of them are welded. The greater part of the tuffs of the younger group are chiefly vitric tuffs, and only a few are welded. Both groups, however, have crystal tuffs, welded tuffs, and vitric tuffs. The mineralogy of the tuffs and rhyolites of the two groups is commonly identical, although accessory topaz appears to be more common in the rhyolite of the younger group. Flow lines are fairly common in rhyolite of the younger group but are rarely seen in rhyolite of the older group.

The flow and intrusive rocks were classified on their chemical composition according to the method of Rittmann (1952) because classification based on the mineralogy of the phenocrysts may not truly represent the entire rock. This is especially true in rocks like rhyodacite which have a fairly high content of potassium and silica yet have neither potassium feldspar nor quartz phenocrysts. Chemical compositions of the Thomas Range volcanic rocks have been described elsewhere (Staatz and Carr, 1963). The pyroclastic rocks are classified according to Wentworth and Williams (1932, p. 45–53).

A quartz-sanidine crystal tuff of the older volcanic group has been dated as 20 million years, or middle Miocene, by the Larsen method (Larsen, Keevil, and Harrison, 1952) applied to zircon (Jaffe and others, 1959, p. 71). The specimen used was collected from the east-central part of The Dell. Rocks of the younger volcanic group have not as yet been dated. These rocks are most likely Pliocene as they unconformably overlie the older volcanic group, underlie Pleistocene Lake Bonneville sediments, and were deposited after the major part of the Basin and Range faulting.

OLDER VOLCANIC GROUP AND ASSOCIATED SEDIMENTARY ROCKS

The older volcanic group is divided into six units in the areas in which beryllium has been found—The Dell and the southwest side of Spor Mountain. These units are dark labradorite rhyodacite, rhyodacite, porphyritic rhyolite, quartz-sanidine crystal tuff, vitric tuff, and intrusive breccia. Lacustrine sandstone and an overlying conglomerate, which are found interbedded with these rocks in the central part of The Dell, are also discussed here.

DARK LABRADORITE RHYODACITE

Dark labradorite rhyodacite is found in eight scattered outcrops in a northwestward-trending band 1½ miles long, at the southern end of Spor Mountain (pl. 1). The northern end of this band is at the Harrisite mine (14, fig. 2), and outcrops of this rock form low hills rising above the Lake Bonneville sediments. The relation of this rock to other rocks is not known, and previously, this rock, which was identified mainly by thin-section examination, was called an enstatite-augite latite (Staatz and Osterwald, 1959, p. 35–36).

The dark labradorite rhyodacite is a dark-gray to brown porphyritic rock that weathers dark rusty brown. The most abundant phenocrysts are dark-green pyroxene crystals, which make up 15 to 30 percent of the rock; two pyroxenes, enstatite and augite, occur in about equal abundance. Anhedral, commonly embayed quartz phenocrysts may make up as much as 3 percent of the rock. Some specimens contain small irregular labradorite crystals (An_{56}), and magnetite, biotite (generally partly altered to hematite), and hornblende are found in some specimens. The groundmass consists of plagioclase microlites in a brown glass. Composition of the plagioclase, as determined from extinction angles, ranges from An_{50} to An_{72}.

RHYODACITE

Rhyodacite is much more abundant than the dark labradorite rhyodacite and is found on both the east and the west sides of Spor Mountain. This rhyodacite occurs as both intrusive bodies and flows. Along a steep-sided wash 6,200 feet southeast of the Harrisite mine, a small plug of rhyodacite cuts dolomite of Silurian age. Near the south end of the eastern part of the Thomas Range, vesicular rhyodacite with a well-alined flow structure suggests a flow; in most places on the southwest side of Spor Mountain, the position of the rhyodacite immediately on top of the dolomite also suggests a flow (pl. 1). The rhyodacite is older than the porphyritic rhyolite because it is cut by small dikes of the latter at the northern end of Spor Mountain (fig. 3*A*), but the age relation between rhyodacite and other units of the older volcanic group is unknown. Previously, this rock was called a hypersthene latite (Staatz and Osterwald, 1959, p. 36).

Rhyodacite is a dark-brown, dark-gray, or black porphyritic rock containing numerous white rectangular crystals of plagioclase and a few dark-green pyroxene crystals that make up 15 to 50 percent of the rock. Plagioclase is commonly zoned and is generally labradorite. The pyroxene crystals may be either hypersthene or augite, the former being generally more abundant. Accessories include magnetite and apatite. The groundmass consists of light-brown glass containing a felted mass of plagioclase microlites. Maximum extinction angles measured on the plagioclase microlites indicate a composition that ranges from An_{48} to An_{53}.

QUARTZ-SANIDINE CRYSTAL TUFF

Quartz-sanidine crystal tuff is found in the central part of The Dell, where it occurs in low rounded hills (fig. 3*B*). In most places these hills are surrounded by alluvium or sediments of the Lake Bonneville Group. Near the Yellow Chief mine, the quartz-sanidine tuff is overlain by vitric tuff of the older volcanic group and by a lacustrine sandstone. Age relations to other members of the older group are not clear.

The quartz-sanidine crystal tuff is a white, yellowish-brown, or grayish-red rhyolitic rock containing 25 to 75 percent crystal fragments in a compacted ash matrix. Quartz and sanidine in about equal amounts make up the greater part of the crystal fragments (fig. 4*A*). Smaller amounts of biotite, plagioclase, and accessory magnetite are present in most specimens. The groundmass is a light- to dark-brown glass that is partly devitrified, glass shards are common, and small amounts of tridymite occur in a few specimens.

This tuff contains numerous small cavities in some places. Some of the tuff is welded, and in the central part of The Dell, layers of welded brown crystal tuff are interbedded with layers of more friable white crystal tuff.

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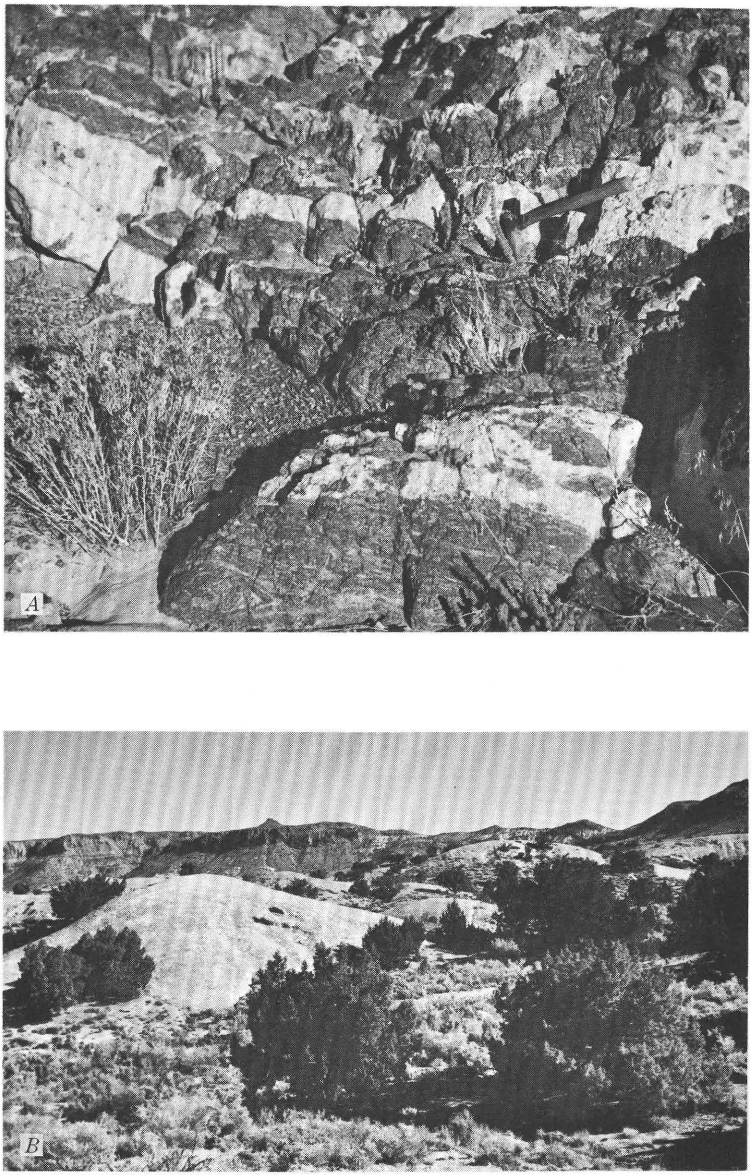

FIGURE 3.—Outcrops of volcanic rocks of the older group. *A*, Rhyodacite (gray) intruded by thin dikes of porphyritic rhyolite (light-gray) in The Dell, near the north end of Spor Mountain; *B*, Typical rounded exposures of quartz-sanidine crystal tuff in The Dell.

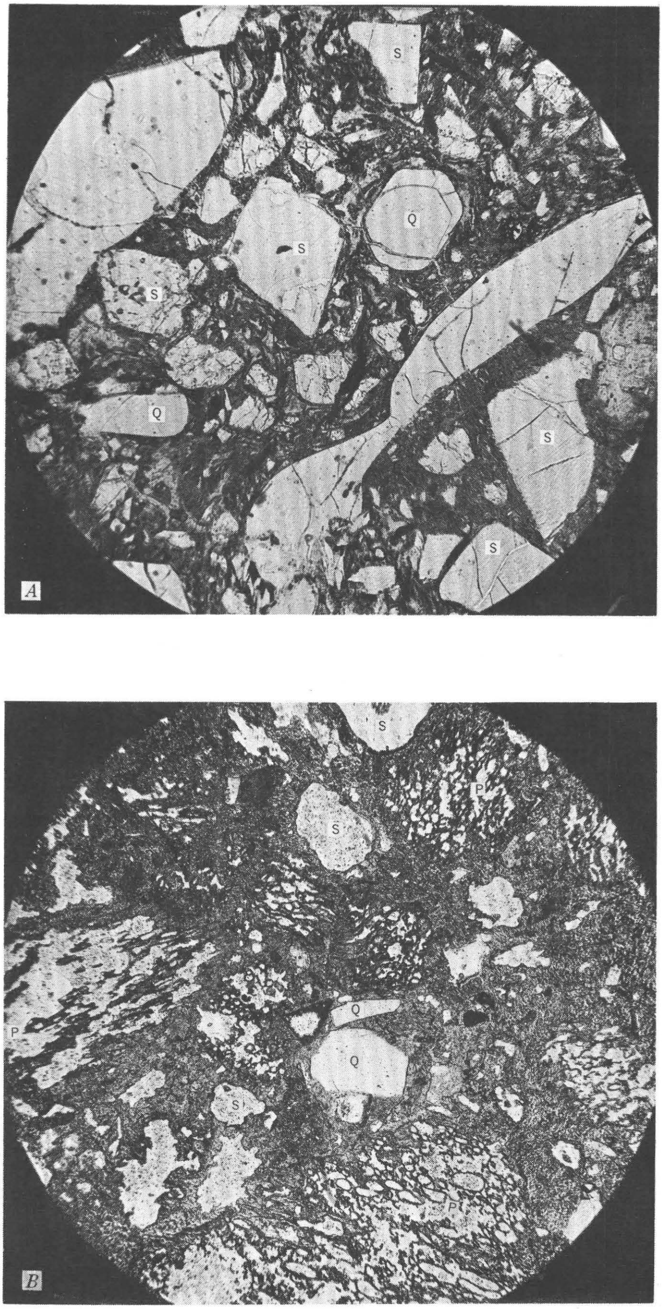

FIGURE 4.—Photomicrographs of two volcanic rocks. *A*, Quartz-sanidine crystal tuff, showing broken and embayed sanidine (S) and quartz (Q) crystals in a matrix of welded shards and brown glass. × 19; plain transmitted light; *B*, White vitric tuff, showing quartz (Q) and sanidine (S) crystals and abundant devitrified vesicular pumice (P) in an ashy matrix. × 19; plain transmitted light.

VITRIC TUFF

Vitric tuff of the older volcanic group is exposed near the Yellow Chief uranium mine and at a locality about 1 mile northeast of this mine. At the latter locality, the vitric tuff is found interbedded with quartz-sanidine crystal tuff. The vitric tuff generally forms thin layers. Vitric tuff of the older volcanic group, found throughout the Thomas Range, is not all the same age. Exposures in the vicinity of the Yellow Chief are generally poor, and relations to other units of the older group are not well known.

The vitric tuff is cream colored, brown, or pale green and contains abundant small angular to rounded pieces of glass. The glass fragments are commonly pumice and may make up as much as 50 percent of the rock. Small crystal fragments may make up as much as 5 percent of the rock, and most are quartz or sanidine, but minor amounts of plagioclase, biotite, and magnetite are present in some places.

The vitric tuff of the older volcanic group is identical in many of its physical characteristics with that vitric tuff of the younger volcanic group. The two are differentiated chiefly by their relations to other rocks of both groups.

PORPHYRITIC RHYOLITE

Porphyritic rhyolite is found in the northern and central parts of The Dell and in the southern part of Spor Mountain. In the latter area, the rhyolite intrudes dolomite of Paleozoic age. Whether this rock is mainly extrusive or intrusive in The Dell is not known, although in one small area near the north end of Spor Mountain thin dikes of this rock cut rhyodacite (fig. 3*A*). The rhyolite occurs as rounded ridges or hills with as much as 600 feet of relief. Tuff and rhyolite of the younger volcanic group unconformably overlie the porphyritic rhyolite to the east of the Yellow Chief uranium mine, along the east side of The Dell. Vitric tuff of the older group overlies the porphyritic rhyolite in the central part of The Dell, although it is found underlying the rhyolite to the north in the southern part of the Dugway Range. No contacts were found between porphyritic rhyolite and quartz-sanidine crystal tuff.

The porphyritic rhyolite is light gray to light brown and contains 15 to 70 percent phenocrysts in an aphanitic matrix. The most common phenocryst is generally sanidine, although in a few places quartz is more abundant. These phenocrysts show a large range in size—from 0.5 to 3.6 mm in length. Plagioclase (An_{20} to An_{43}) in amounts from 1 to 15 percent forms phenocrysts that are generally smaller than those of quartz or sanidine. Accessory biotite and magnetite are found in most specimens, and small amounts of zircon, sphene, and topaz are present in some. Groundmass is a clear, light- to dark-brown glass that generally is partly or completely devitrified.

INTRUSIVE BRECCIA

Intrusive breccia represents in most places various kinds of rock that were blown out by a volcanic explosion and then fell back in the vent or crater formed by the explosion. Pieces of the rock were later surrounded by rising lava, or by a red secondary dolomite, formed when fluids rising from the underlying lava dissolved dolomitic country rock. In some places, rock of similar appearance is produced by the fracturing of overlying dolomite by an underlying intrusive body, with the fractures being filled by red secondary dolomite.

Most of the bodies of intrusive breccia are found along the east side of the northern half of Spor Mountain, although the largest one, a body about 6,000 feet in diameter, is in the northern part of The Dell. The matrix of the intrusive breccia is generally easily weathered, and the breccia is commonly covered with a soil mantle. Characteristics of covered bodies are brick-red soil, smooth slopes, and randomly oriented blocks of dolomite as much as 50 feet across. The dolomite blocks come from several Paleozoic formations. Where the bodies are small, they are difficult to distinguish from rhyolite or rhyodacite in contact with dolomite, as all three rocks adjacent to carbonates form a red soil. Bodies of intrusive breccia are commonly in contact with shattered Paleozoic sedimentary rocks. In several places, the intrusive breccia is in contact with rocks of the younger volcanic group, but none of these contacts are well exposed.

The intrusive breccia is believed to belong to the older rather than the younger volcanic group, because it contains fragments of porphyritic rhyolite and rhyodacite but does not contain rock fragments recognizable as belonging to the younger group. This evidence does not prove that the intrusive breccia belongs to the older group, but it at least favors this correlation.

The intrusive breccia varies considerably in composition from place to place. Some bodies of intrusive breccia consist of blocks of dolomite, from various formations, in a red secondary dolomite matrix; some consist of a mixture of blocks of volcanic rock, mainly porphyritic rhyolite, with dolomite. Some bodies consist almost entirely of volcanic rock in a red dolomite matrix, and a few small bodies consist of volcanic blocks in a glassy volcanic matrix. Although most of the sedimentary blocks are dolomite, a few are limestone and quartzite.

Fluorspar ore bodies have been found in dolomite in the shattered zones adjacent to the intrusive breccia bodies. In a few places, veins of fluorspar cut the intrusive breccia.

TUFFACEOUS SANDSTONE AND CONGLOMERATE

Tuffaceous sandstone, locally overlain by conglomerate, has been exposed in one small area in pits and prospects at the Yellow Chief mine. These rocks are friable, easily weathered, and covered by talus. They are variable in thickness. The underlying sandstone is about 18 feet to at least 50 feet thick, and the conglomerate, though absent in some places, is at least 10 feet thick in other places. These sedimentary rocks are underlain by quartz-sanidine crystal tuff and overlain by a vitric tuff of the older volcanic group. The sandstone was apparently deposited in a small lake formed in a basin in the quartz-sanidine crystal tuff.

The sandstone is a white, light-gray, or yellowish-green, poorly sorted friable rock with an average grain size of 0.4 mm. Stratification varies from fair to poor. Sand grains are angular to subrounded and, like the underlying quartz-sanidine crystal tuff, consist chiefly of quartz and sanidine with minor amounts of plagioclase, biotite, and magnetite. A few pebbles of rhyodacite and porphyritic rhyolite are present. The matrix is chiefly clay, probably formed from altered ash, and some calcite. In mineral composition and size and sorting of grains, this rock closely resembles the quartz-sanidine tuff. It differs by being stratified and by having a much smaller amount of ash. The uranium ore bodies in the Yellow Chief mine are in the sandstone, which was probably preferentially mineralized because it has by far the highest porosity and permeability of any rock adjacent to the fault that served as a channelway for the uranium-bearing solutions.

The conglomerate rests on an irregular surface and in places fills channels in the underlying sandstone. It consists of subangular to well-rounded cobbles in a greenish-gray fine-grained tuffaceous matrix. Most of the pebbles are fine-grained pink, gray, or brown limestone; a few are rhyodacite, vein quartz, or chalcedony. Some of the limestone has been replaced by silica, and in places, parts of these pebbles have been replaced by the uranium mineral, weeksite.

YOUNGER VOLCANIC GROUP

The greater part of the exposed volcanic rocks belong to the younger volcanic group, which rests unconformably on the older volcanic group. In the Thomas and Dugway Ranges, the younger volcanic group consists of five main subgroups each of which is believed to have been an eruptive cycle that began with explosive eruptions of pyroclastic rocks, and ended with the extrusion of lavas. Each of the subgroups, where completely represented, consists in ascending order of vitric tuff, volcanic breccia, and rhyolite. All are rhyolitic in composition, and rhyolite is by far the most abundant rock type.

The five main subgroups overlap each other roughly en echelon. The lowest or first subgroup rests on the older volcanic group and Paleozoic sedimentary rocks in the Dugway Range, and the highest or fifth subgroup rests on the same rocks in the southern part of the Thomas Range. At no place do all five subgroups lie one on the other; in most places only two are superimposed. In addition to the five main subgroups, smaller subgroups or parts of subgroups were found in a few localities. The subgroups that crop out within The Dell are the third in the northern half and the fourth in the southern half. The fourth is also found on the southwest side of Spor Mountain.

The pyroclastic rocks are in general thin and erratic. In places they are absent. Tuff is more widespread and regular than volcanic breccia, because the large fragments of the breccias are found principally near their sources and decrease abruptly away from them.

VITRIC TUFF

Vitric tuff occurs along much of the mountainside east of The Dell, within The Dell at its southern end, and east of the Lost Sheep mine (3, fig. 2). It is absent, however, for a distance of about 1½ miles in the northern end of The Dell. Vitric tuff also crops out in the flats south and west of Spor Mountain. It is easily weathered, and where not capped by rhyolite, forms low, gently rounded knolls. It is best exposed along the east side of The Dell, where it underlies massive resistant rhyolite, although here it is commonly partly covered by rhyolite talus.

The vitric tuff is principally a white friable poorly bedded rock containing numerous small volcanic fragments, chiefly pumice, in a matrix of small crystal fragments and ash (fig. 5). Locally, it is gray, tan, pink, or greenish white. The tuff has a wide range in particle size. A few of the layers consist almost wholly of ash with no visible rock fragments; most of the layers, however, contain numerous fragments, 4 to 25 mm in diameter. This rock grades into volcanic breccia, and thin layers of breccia are found within the tuff. The thinner layers of breccia differ from thicker layers of breccia, described in the next section, by containing smaller and rounder fragments and more ash matrix. Rock fragments make

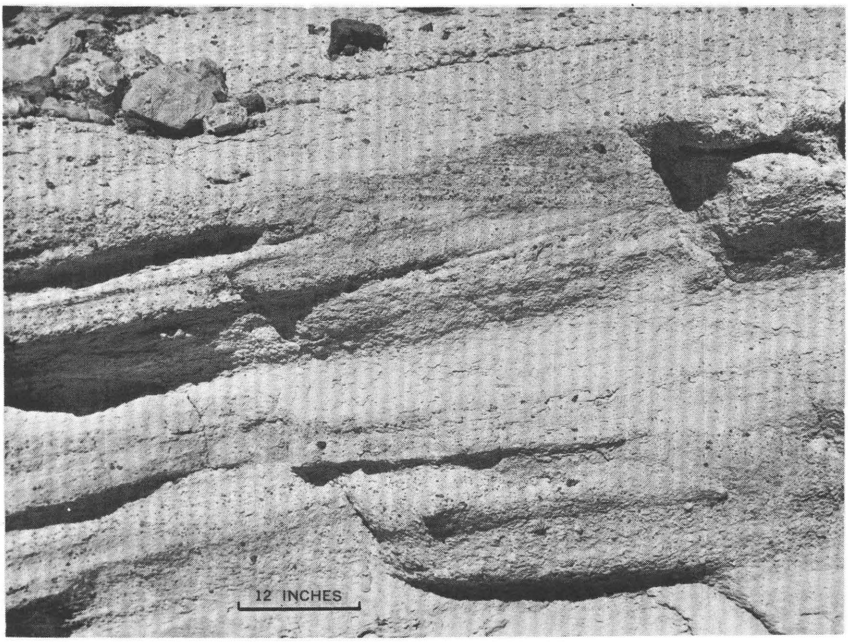

FIGURE 5.—White vitric tuff showing bedding, small rock fragments, and typical texture.

up from 10 to 50 percent of the tuff. Pumice fragments are by far the most common (fig. 4*B*), but red, black, or gray glass, porphyritic rhyolite, tuff, limestone, and dolomite are common in some places, and rhyodacite, and quartzite are rare. Obsidian fragments occur sparsely in most of the tuff but increase in abundance near the top along the east side of The Dell.

Pore spaces and small cavities are common and may make up as much as 30 percent by volume of this rock. In some places the cavities are a quarter of an inch across, but in most places they are much smaller. In addition to the pore space in the rock, the pumice itself contains many small pores. Small and inconspicuous crystal fragments make up 3 to 35 percent of the tuff. The principal crystal fragments are sanidine and quartz (fig. 4*B*). Plagioclase is found in lesser amounts, and biotite and magnetite are common accessories. The matrix of the tuff is an ash consisting of clear light- to medium-brown glass, in part devitrified. Glass shards are common in some specimens, absent in others, and tridymite and cristobalite line cavities in a few specimens.

Included in this vitric tuff in a few places are thin gray beds of welded crystal tuff that closely resemble welded crystal tuff in the older volcanic group. In some places the welded tuff is interlayered with the vitric tuff, and on the west side of Spor Mountain, a layer of welded tuff is found at the top of the vitric tuff unit (pl. 1).

VOLCANIC BRECCIA

The volcanic breccia generally overlies the vitric tuff and underlies rhyolite, but where the breccia is absent, as it is in many places, the rhyolite overlies the vitric tuff. The breccia is exposed along the east side of The Dell for 2 miles at its northern end, and for 1 mile at its southern end, east of the Bell Hill mine. It is also exposed in the flats and low hills on the west side of Spor Mountain in sec. 5, T. 13 S., R. 12 W. (pl. 1). The breccia is extremely irregular in thickness, and a considerable thickness of this rock may be preserved where it was deposited in irregular hollows, but little or none may remain where it was deposited at higher places. The breccia probably does not exceed 100 feet in thickness in The Dell and is considerably thinner on the west side of Spor Mountain. The best exposures and thickest sections of this rock are found to the east of the Bell Hill mine.

The volcanic breccia consists of poorly sorted angular fragments in a matrix of ash. From layer to layer and within an individual layer, the color of the breccia varies from black, gray, greenish white, brown, or tan. Fragments make up 25 to 85 percent of the rock and are all sizes up to 3 feet in diameter. They tend to be larger in the layers in which they are most abundant. The fragments are almost entirely volcanic material and most are glassy. Obsidian, gray glass, pumice, gray rhyolite, and porphyritic rhyolite are common. Pieces of sedimentary rock are rare. Fragments in the thick breccia east of the Bell Hill mine are mainly black obsidian; those in sec. 5, T. 13 S., R. 12 W., on the west side of Spor Mountain are mainly pumice and gray or brown glass.

The matrix of the breccia is a compact ash resembling that of the vitric tuff. As much as one-third of it is small mineral fragments among which sanidine and quartz are the most common, plagioclase appears in lesser amounts, and biotite and magnetite are accessories. Glass shards are abundant in some specimens of ash and absent in others.

RHYOLITE

Rhyolite makes up the greater part of the younger volcanic group. It is best exposed in the eastern part of the Thomas Range, but it is also found extending into The Dell in a few places, and in the flats on the south and west side of Spor Mountain. This rock is highly resistant to erosion and, along the northern part of the east side of The Dell, forms cliffs as much as 800 feet high.

Rhyolite in the same flow varies in color, texture, abundance of phenocrysts, and degree of layering. Rhyolites from the different subgroups also can vary in the same way so that some rocks from different subgroups have the same mineralogic and chemical composition. Thus, rarely can the subgroup of a rhyolite be determined by either hand or microscopic inspection of a specimen. The rhyolite has three distinct facies: obsidian, red spherulitic rhyolite, and gray rhyolite.

Obsidian occurs as a thin layer, formed by rapid cooling, at the base of most thick rhyolite flows. Such a layer is prominent in most places in the eastern part of the Thomas Range. It is lacking, however, at the base of the flow south and west of Spor Mountain. The obsidian is also found in a few places in the eastern part of the Thomas Range within bodies of rhyolite, where it presumably marks the chilled surface of flows. The obsidian consists mainly of black spherulitic glass with a conchoidal fracture. In some places it is dark gray and contains brown, reddish-brown, or light-gray layers or lenses.

In most places, red spherulitic rhyolite rests on the obsidian near the base of the flows. This rock is extremely variable in thickness, and may increase from a few inches to more than 200 feet in thickness along a lateral distance of 600 feet. The contact of the red spherulitic rhyolite with the obsidian is generally sharp, but with a few exceptions, its contact with the gray rhyolite is gradational. The red spherulitic rhyolite has many small spherulites set in an aphanitic or glassy groundmass. It is generally a hematitic red but varies to pale red, reddish brown, purplish gray, and gray. Flow structure is common. The spherulites range in diameter from less than ½ to 10 mm and consist mainly of radiating fibers of potassium feldspar and quartz. Small subhedral to euhedral phenocrysts make up about 10 percent of the rock. Sanidine and quartz are the principal minerals with lesser amounts of plagioclase. Biotite and magnetite phenocrysts make up less than 1 percent of the rock. The groundmass consists mainly of glass but also includes lens-shaped pockets of a very fine-grained mosaic of feldspar and quartz.

Gray rhyolite makes up about 75 percent of the rhyolite in the younger volcanic group. It generally is a dense, aphanitic rock containing small phenocrysts in a glassy groundmass. The rock is predominantly light gray, but locally, as on the west side of Spor Mountain, it is brown, purplish gray, pinkish gray, and purplish brown. In many areas the exposed surface of the rhyolite weathers with a characteristic honeycomblike appearance. Flow layers are common in some places, and they may form folds with an amplitude of several hundred feet. Toward the top of the flows the folds tend to become smaller and contorted. The strike and dip of individual flow layers rarely coincide with the attitude of the entire flow. Spherulites occur in about half the specimens of gray rhyolite, although in most specimens they are not as common as in the red facies. Most of the spherulites are too small to be seen in hand specimen. Lithophysae are locally abundant. A few small, inconspicuous phenocrysts are generally present in the gray facies and may make up as much as 35 percent of the rock, although some specimens lack phenocrysts. In some places, however, the phenocrysts are readily visible in hand specimen. In these places, as in some areas on the west side of Spor Mountain, the gray facies of the rhyolite may be extremely difficult to distinguish from the porphyritic rhyolite of the older volcanic group. Most of the phenocrysts are sanidine and quartz, with sanidine generally being more abundant. Plagioclase (An_{20} to An_{53}) is the next most common mineral, and, although absent in some specimens, may make up as much as 3 percent of the rock. Biotite and magnetite or hematite occur in small amounts. Fluorite and topaz are absent from most specimens, but they were found in about a third of the samples taken west of Spor Mountain. One specimen of rhyolite from an outcrop about 1 mile east of Horseshoe Well (pl. 1) contains about 4 percent topaz. The groundmass is either a glass or a mosaic of fine interlocking crystals. The glass is clear, light brown, and in places devitrified. The mosaic is made up principally of quartz and feldspar and minor amounts of biotite, magnetite, tridymite, and cristobalite.

BERYLLIUM DEPOSITS

Beryllium deposits are found on the flats on either side of Spor Mountain (fig. 2) associated with small amounts of fluorite. These deposits partly ring the high-grade fluorspar deposits on Spor Mountain. The beryllium deposits may extend into other areas around Spor Mountain, because volcanic rocks similar to those in which beryllium occurs are present throughout The Dell, at the northern end of Spor Mountain, and on the west side of Spor Mountain, to the west of the area of known beryllium deposits (fig. 2). Inasmuch as unconsolidated sediments cover the greater part of these areas, discovery of new deposits depends on deep trenching or drilling.

Although the beryllium deposits are associated with fluorite, beryllium is quantitatively unimportant in the fluorspar-rich pipes on

Spor Mountain. Analyses using a nuclear beryllium detector of 23 samples of fluorspar ore from 12 different pipes and veins disclosed no beryllium (see table below). Numerous other samples from the

Location of samples taken from fluorspar deposits on Spor Mountain and found by nuclear detector to contain no detectable beryllium

Property	Sample	Ore body	Location	Remarks
Bell Hill	SO-69-52	Pit no. 1	69-ft. level	Composite sample.
Do	SO-67-52	do	87-ft. level	Do.
Do	SO-68-52	do	108-ft. level	Do.
Do	SO-76-52	do	129-ft. level	Do.
Do	SO-75-52	do	150-ft. level	Do.
Do	SO-73-52	do	168-ft. level	Do.
Do	SO-74-52	do	In winze 14 ft. below 169-ft. level.	
Blowout	SO-81-52		Open cut	
Eagle Rock	SC-1-54	Vein	In trench 7 ft. below surface.	Siliceous material.
Floride	Fl-1	Veins	Adjacent and to north of main ore body.	Soft fluorspar ore.
Do	Fl-2	do	do	Breccia.
Do	SO-70-52	do	do	
Do	SO-71-52	Main ore body	End of upper sublevel.	
Do	SO-72-52	do	Lower workings	Composite sample.
Fluorine Queen No. 4.	SO-85-52			
Hilltop	SO-84-52	Larger pipe	Back of pit	
Lost Sheep	SO-77-52	Main pipe		
Do	SO-80-52	do		Composite sample.
Do	SO-79-52	South pipe	Adit level	
Do	SO-86-52	Vein	25 ft. east of main ore body.	
Lucky Louie	SO-78-52			Composite sample.
Oversight	SO-82-52			Do.
Do	SO-83-52	North end of pipe.		

fluorspar deposits have also been analyzed by various company personnel using nuclear beryllium detectors. Apparently, no beryllium was detected. Small amounts of beryllium can be detected in the fluorspar ores by more sensitive methods. Six specimens of fluorspar from three different deposits were analyzed spectrographically for beryllium. The results, given in the accompanying table, ranged

Beryllium spectrographic analyses of fluorspar ore from Spor Mountain, Utah

[Analyst, R. G. Havens]

Property	Sample	Ore body	Location	Beryllium content (percent)
Bell Hill	SB-51-50	Pit no. 1	Open cut	0.002
Do	BH-12-52	do	Between 330 and 334 ft. in drill hole 2.	.002
Fluorine Queen	SB-62-50	East pipe	Open cut	.0004
Do	SO-6-52	do	Adit	.001
Lucky Louie	CS-24-51		6 ft. below surface	.001
Do	SO-9-52		59 ft. below surface	.001

from 0.0004 to 0.002 percent beryllium and averaged 0.0012 percent beryllium. Two samples from the large ore body on the Yellow Chief uranium property showed no detectable beryllium when analyzed by a nuclear beryllium detector.

RELATION TO COUNTRY ROCK

The beryllium deposits are mostly in tuff, although in a few places they are in dolomite adjacent to volcanic rocks. On the west side of Spor Mountain, all the deposits exposed at the surface are in vitric tuff of the younger volcanic group; at the Claybank on the east side of Spor Mountain (25, fig. 2), they are in a quartz-sanidine crystal tuff of the older volcanic group; and at the Hogsback, they are in tuff, but which volcanic group the tuff belongs to is not clear. Small beryllium-bearing layers and veins have been found on the Sevy Dolomite, just below the younger vitric tuff at the Blue Chalk claim, and in the Lost Sheep Dolomite, adjacent to a rhyolite plug on the Prospector claim. All the deposits I observed in the carbonate rocks were too small to be of much economic value.

The beryllium deposits formed in fairly porous and permeable tuff by replacement of much of the glass, both in the ash and in pumice fragments. Beryllium deposits have not been found in the welded tuffs. Three specimens—one of fresh rock, and two of fairly altered tuff—were tested for effective porosity and permeability by R. F. Gantnier, of the U.S. Geological Survey, and the results are given in the following table. The porosity and permeability of the tuff after mineralization is quite different from that of unaltered rocks because later minerals fill the pore spaces. The completely altered tuff found within beryllium deposits is generally too soft and friable to test. The high permeability and porosity of the un-

Porosity and permeability of altered and unaltered vitric tuff of the younger volcanic group from the west side of Spor Mountain

	1	2	3
Effective porosity.......percent..	27.3	11.6	10.0
Permeability.......millidarcies..	571.3	1.5	2.2

1. Unaltered vitric tuff from central part sec. 14, T. 13 S., R. 12 W.
2. Partly altered vitric tuff from shallow trench near outer edge of mineralized area in the North End claims (27, fig. 2).
3. Partly altered tuff from main pit of Tarus claim (28, fig. 2).

altered vitric tuff is probably the principal reason why the tuff beds were favored as a site of beryllium mineralization.

SIZE AND SHAPE OF THE DEPOSITS

The size and shape of the various beryllium-rich parts of the tuff are difficult to determine because the beryllium-bearing parts cannot be visually identified. At least in part, the beryllium-bearing bodies favor certain layers within the tuff. Probably the best exposed one is on the Hogsback property (26, fig. 2), where a beryllium-rich bed is traceable completely around a small hill 900 feet long by 400 feet wide. This beryllium-rich unit lies in a bed about 5 feet below the contact between rhyolite and tuff. This layer or zone is about 6 feet thick on the east side of the ridge, and may be thicker on the south end. Another beryllium-rich layer, lying just below the rhyolite, can be traced for several hundred feet at the southwestern end of the Roadside claims. Just west of the road on the Roadside claims, several other beryllium-rich layers are found in lower horizons. Some of these layers are only a few inches thick; others may be at least 20 feet thick. They commonly end abruptly, and a beryllium-rich layer several feet thick exposed on one side of a bulldozer trench may not be found on the other. In general, the beryllium deposits consist of a number of erratic lens-shaped bodies which are in part controlled by the tuff layers.

STRUCTURAL CONTROL

Little structural control of the beryllium deposits is apparent. The tuff on the west side of Spor Mountain was laid down over a series of low dolomite ridges. The initial dip on the tuff over these ridges gives this rock an appearance of having been gently folded. Beryllium is found on the gently dipping northwest flanks of these apparent folds on the North End, Roadside, and Blue Chalk claims but is near the top of the apparent anticline at the Tarus and Rainbow claims. Some of the beryllium-rich tuff is also on the steeper southeast flank at the Rainbow; thus, the position of the beryllium minerals within the tuff does not appear to be controlled by the attitude of the tuff, although data are insufficient for this to be substantiated.

Many of the fluorspar pipes on Spor Mountain are controlled by faults. Most of the faults cut only the older Paleozoic rocks; some faults cut the volcanic rocks, but few of them are exposed near the beryllium-rich tuff. One prominent exception is a large north-trending Basin-and-Range-type fault that follows the eastern side of the ridge on which is found the Eagle Rock claim (19, fig. 2). This fault separates dolomite of Silurian age from quartz-sanidine crystal tuff on the Claybank property. Beryllium-bearing tuff on this property is found only on the hillside adjacent to the fault. Beryllium was not detected in lower beds away from the fault. The Hogsback deposit is 4,000 feet south of the Claybank property and adjacent to this same fault. In the flat covered by Lake Bonneville sediments, on the west side of Spor Mountain, faults have not been traced into the younger volcanic rocks, yet the underlying Paleozoic sedimentary rocks are cut by numerous faults. Some of the beryllium-rich areas lie along the extension of prominent northeast-trending faults (pl. 1; and Staatz and Osterwald, 1959, pl. 1). A small renewed movement on these faults could have formed passageways along which beryllium-rich fluids entered the tuff. The association of the large Basin-and-Range fault with the Claybank and Hogsback beryllium deposits, in addition to similar association of faults with many of the fluorspar deposits on Spor Mountain and with the Yellow Chief uranium ore body, suggests the conclusion that faults may have controlled much of the beryllium mineralization. The favoring of certain layers in the tuff by the beryllium minerals, and their probable relation to faults, suggest that the beryllium deposits may form in certain permeable and porous layers adjacent to faults in a manner similar to the manganese deposits in the Drum Mountains (fig. 1) just to the south of the Thomas Range (Crittenden, 1951, p. 28).

MINERAL AND CHEMICAL COMPOSITION

Most of the beryllium-rich rock appears to be a white soft, friable tuff containing numerous crystal fragments. Generally, all the glassy particles, such as ash or pumice fragments, have been replaced. New minerals replacing tuff include opal, chalcedony, montmorillonite, calcite, fluorite, at least one manganese oxide mineral, and bertrandite. Most of the replacing minerals are very fine grained and the bertrandite grains are about 1 micron in diameter. Opal, bertrandite, chalcedony, and some of the montmorillonite are white and because they are commonly intermixed, cannot be specifically identified in hand specimen.

Chalcedony and opal fill voids and replace selected fragments in the tuff. Ellipsoidal nodules, 1/16 inch to 1 foot in length, are common in some of these deposits (fig. 6*A* and *B*). Nodules range from white to gray through purple. They are commonly zoned; some have purple centers and white rinds; some have gray centers cut by blades of purple fluorite and white or gray rinds (fig. 6*A*); some are gray in the center and have brown or white rinds; some have concentric zones of purple and white material (fig. 6*B*), and in others the centers are speckled. The nodules are made chiefly of silica minerals and fluorite. Bertrandite, a manganese oxide mineral, clay, sanidine, and calcite have also been identified in the nodules. Opal is the principal silica mineral, but chalcedony is common. A little quartz and tridymite are also found in some nodules. Sanidine, quartz, and tridymite are probably residual from the tuff. Calcite-bearing nodules are quite rare, and none of them contained any beryllium. Opal and fluorite generally make up the central part of the nodule. The fluorite commonly occurs in blades (fig. 6*A*) which, in some nodules, are parallel with the cleavage in the fluorite and may be controlled by it. Bertrandite was not definitely identified by optical means in any of the thin sections of the nodules, but it was identified by X-ray in several beryllium-rich nodules.

Clay is common in many places. Five samples of clay from the Hogsback, Rainbow, and Roadside claims were X-rayed by Theodore Botinelly and F. A. Hildebrand, of the Geological Survey; all five were found to be montmorillonite. Montmorillonite, although white in some places, is commonly pink. The pink color is thought to be due to manganese. In order to verify its presence, a handpicked specimen of pink montmorillonite from the Roadside claim was quantitatively analyzed with a spectroscope by J. C. Hamilton, who found 0.19 percent manganese in this clay specimen. A semiquantitative spectrographic analysis of this same specimen by Hamilton indicated that it contains in addition, approximately 7 percent magnesium, 1.5 percent potassium, 0.7 percent calcium, and 0.7 percent sodium. White montmorillonite found in the fluorspar deposits is also high in magnesium.

Fluorite is generally purple although in a few places it is white. The white fluorite cannot be distinguished from other white minerals in hand specimen because its grain size is too small. Fluorite is commonly found in the tuff as replacements of small fragments, and in a few places, such as at the Rainbow property, as narrow rings around small rock fragments.

FIGURE 6.—Nodules from beryllium-bearing tuff. *A*, Specimens are from the north end of the Hogsback property. The greater part of both nodules consists of opal. The abundant thin dark blades are fluorite crystals. Nodules contain small amounts of finely disseminated bertrandite which are not visible in the photograph; *B*, The specimen at the left is from the north end of the Hogsback property, and consists of alternating fluorite-rich (dark) and opal-rich (light) zones. Small irregular fluorite veins can be seen cutting the zones. The specimen at the right is from a tuff outcrop in the central part of sec. 5, T. 13 S., R. 12 W., and consists mainly of banded opal with a little chalcedony. This nodule contains about 0.4 percent bertrandite, much of which is concentrated in the outer white rind.

A black manganese oxide mineral (or minerals) is found in some places. X-ray examination of one specimen indicated that it is psilomelane. Other specimens, however, may contain other manganese oxide minerals. Manganese oxide minerals occur in scattered blebs and bands. Some areas of altered tuff are black owing to the presence of large quantities of manganese oxide minerals; other areas are not colored by those minerals. On the Rainbow property most manganese oxide-rich layers are also rich in beryllium, although a few have none; the reverse, however, is true at the Roadside claims.

Bertrandite ($2Be_2SiO_4 \cdot H_2O$) is so extremely fine grained that discrete grains cannot be recognized in hand specimen. The extreme fineness of grain and similar birefringence make bertrandite easy to confuse with montmorillonite under the microscope. Bertrandite is commonly associated with fluorite, manganese oxide minerals, montmorillonite, opal, and chalcedony; it has not been found in unaltered tuff where the rock contains none of these minerals. The presence of any one of these minerals, on the other hand, does not mean that bertrandite is present. No exact correlation between the quantity of bertrandite and the quantity of any other mineral was noted. Bertrandite appears to be most closely associated with fluorite; as in almost all places that bertrandite was present, fluorite also was found. The reverse, however, is not true.

Bertrandite at Spor Mountain cannot be recognized in hand specimen, and its presence cannot be predicted with any assurance by the presence of its associated minerals. The beryllium content of a rock can be determined only by chemical analysis, spectrographic analysis, or activation analysis. The first two methods are slow and costly. Activation analysis measures neutrons released by beryllium when it is struck by gamma-rays. Several instruments for activation analysis have been described (Cantwell, Hawkes, and Rasmussen, 1958; Brownell, 1959; and Vaughn, Wilson, and Ohm, 1960).

I used the instrument described by Vaughn, Wilson, and Ohm (1960). More than 150 analyses were made on coarsely ground samples of unsorted tuff and nodules. They showed from 0.0 to 3.2 percent beryllium. Splits of the same sample provided fairly consistent results and none deviated more than 10 percent. The lack of a portable instrument in the field made it impossible in most places to outline ore bodies.

Beryllium is erratically distributed within the tuff as a whole, and also within specific beryllium-rich layers. Twelve samples were taken from the tuff exposed on either side of the wash at the original workings of the Rainbow property (fig. 7), six of these samples

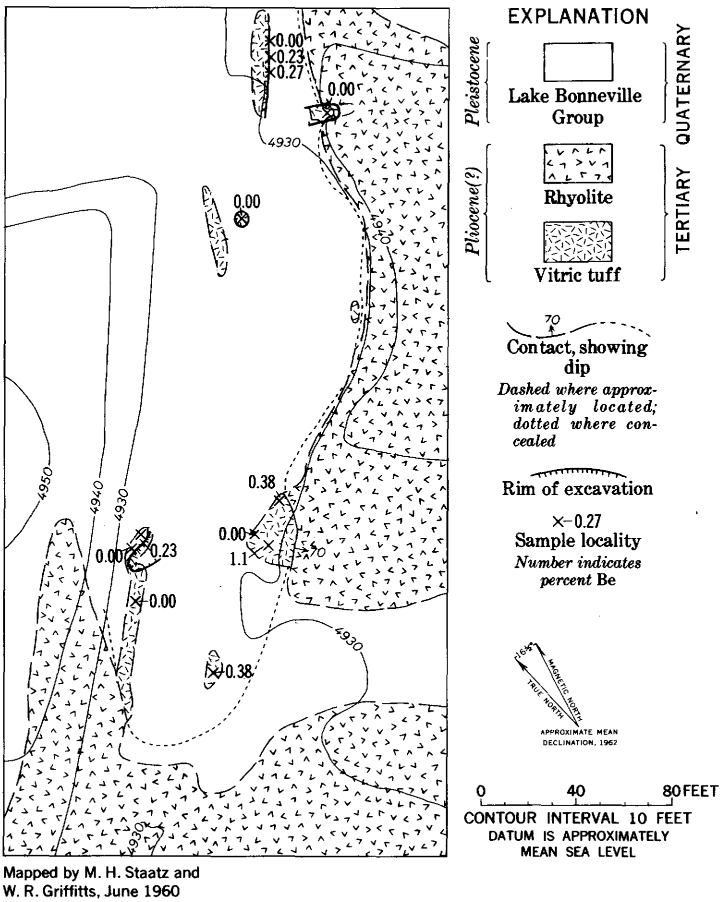

FIGURE 7.—Geologic map of the original workings on the Rainbow property (see loc. 30, fig. 2) showing sample locations.

contained no discernible beryllium, the other six contained 0.23, 0.27, 1.1, 0.38, 0.23, and 0.38 percent beryllium. Fifteen samples were taken on the southern end of the Roadside property; five of these contained no discernible beryllium; the other 10 contained 0.40, 0.35, 0.16, 0.03, 0.38, 0.17, 0.52, 0.20, 0.18, and 0.37 percent beryllium. On the Hogsback property, where a definite beryllium-rich layer can be traced around a small hill, only 1 out of 16 samples taken on this layer had no detectable beryllium. The other 15 samples contained 0.09, 0.09, 0.18, 0.07, 0.12, 0.23, 0.53, 0.73, 0.09, 0.10, 0.52, 0.07, 0.10, 0.27 and 0.07 percent beryllium. Of all the beryllium-bearing tuffs tested, the tuff lying in a zone about 170 feet long, adjacent and parallel to the big fault on the Claybank property, varied least in beryllium content. Only 1 sample out of 7 contained no discernible beryllium; the other 6 contained from 0.08 to 0.14 percent beryllium. The highest grade sample of unsorted tuff contained 1.1 percent beryllium; it was collected from the Rainbow property. At each of five properties, the Blue Chalk, Hogsback, Rainbow, Roadside, and Tarus, I have collected at least one sample of unsorted tuff containing as much as 0.25 percent beryllium.

Beryllium is commonly concentrated in nodules. In 4 nodules collected from the Hogsback, and in 1 from the Rainbow, the beryllium content was 7 to 19 times that of the enclosing tuff as shown below:

	Hogsback samples				Rainbow sample
	1	2	3	4	
Beryllium:					
In nodule percent	3. 8	0. 66	3. 2	1. 9	3. 3
In tuff do	. 52	. 09	. 18	. 10	. 38

Within some nodules the beryllium may be concentrated in certain layers. A nodule collected from a tuff in the central part of sec. 5, T. 13 S., R. 12 W., consisted of an inner part of very fine grained gray opal enclosed in a thin white rind of very fine grained material. The nodule as a whole contains 0.1 percent beryllium and the thin white rind contains 0.2 percent beryllium. At some properties, such as the Hogsback, ore can probably be upgraded by separating the nodules, but at other properties the nodules are either too small or too widely scattered for this method to be used.

Beryllium-rich rock is found in or on dolomite at a few places, notably the Blue Chalk (22) and Prospector (21) properties (fig. 2). At the Blue Chalk property, a hard white and brown cryptocrystalline layer is found on top of the Sevy Dolomite and below vitric tuff. This layer is erratically distributed, and, where present, ranges in thickness from a fraction of an inch to 5 inches. The lower three-quarters of the layer is a brown chalcedonylike rock; the upper one-quarter is a hard white rock. Both consist mainly of silica minerals, but in places contain a little purple fluorite. At one locality a sample of the lower brown material contained 0.62 percent beryllium and a sample of the overlying white material contained 1.47 percent beryllium. At a second locality a few feet from the first, the entire layer contained 4.1 percent beryllium. Similar material is also found in small irregular veins in the back of a southeastward-trending tunnel on the Blue Chalk property. These veins, which are as much as several inches thick, extend from the overlying tuff down into the Sevy Dolomite. A specimen of this vein material contained 0.25 percent beryllium.

Beryllium is associated with dolomite on the Prospector property, where a plug of porphyritic rhyolite has intruded dolomite of Silurian and Devonian age. In some places, the edge of the plug is marked by a chilled glass border. Surrounding the plug is a zone about 20 feet thick of calcareous clay formed by reaction of the hot plug with the dolomite. Small fluorspar veins have been found in this altered zone. A trench in this zone exposes a rib of unaltered dolomite which is plastered and cut by white and black cryptocrystalline siliceous veins with some purple fluorite. Veins are very irregular and range from a fraction of an inch to about 1 inch in thickness. Chip samples taken across the veined dolomite rib in two places contained 0.09 and 0.23 beryllium. A selected sample of the vein material contained 0.73 percent beryllium.

ORIGIN

The problem of origin involves the time the deposits were formed, the source of the mineralizing fluids, mechanics of emplacement of the fluids in the host rock, and method of deposition of the beryllium.

The question of timing is important and its answer throws light on the source of the mineralizing fluids. The beryllium deposits were formed after most of the volcanic rocks erupted. This can be shown at the Claybank property (25) in The Dell (fig. 2), where a beryllium deposit is in a quartz-sanidine crystal tuff of the older volcanic group, and in many places on the west side of Spor Mountain, where beryllium deposits are found in vitric tuff of the younger volcanic group. Fluorspar deposits on Spor Mountain and uranium deposits in The Dell and on the east side of the Thomas Range are also found cutting rocks of both the older and younger volcanic groups. All beryllium and uranium deposits and most of the fluorspar deposits appear to be younger than the volcanic rocks. In the lower workings of the Bell Hill mine (15, fig. 2), however, an intrusive rhyolite tuff cuts a fluorspar body (Staatz and Osterwald, 1959, pl. 7*B*). The fluorspar deposits, and probably the beryllium deposits also, thus were formed after the bulk of the volcanic activity, but before the last eruptions.

The source of the ore deposits appears to be related to the waning stages of the volcanism. A chemical relation exists between the rhyolite of the younger volcanic group and the ore deposits. This rhyolite is noted for the presence of the fluorine-bearing mineral, topaz, in its vugs. Some rhyolites in The Dell also commonly contain small topaz crystals in the groundmass, and in some places pink beryl and a manganese mineral, bixbyite, are also present. Five analyses for fluorine made on this rhyolite by L. M. Kehl, E. J. Tomas, and M. K. Balazs showed it contained from 0.14 to 0.32 percent fluorine; 10 analyses for beryllium by P. R. Barnett showed it contained 0.0011 to 0.0039 percent beryllium; and 11 analyses for uranium by R. P. Cox, M. T. Finch, Wayne Mountjoy, and Roosevelt Moore showed it contained from 0.001 to 0.006 percent uranium. These analyses indicate that the rhyolite of the younger volcanic group is rich in fluorine, beryllium, and uranium. Thus the magma from which the rhyolite was derived almost certainly contained abnormally large quantities of fluorine, beryllium, and uranium. These elements were probably progressively concentrated during the differentiation of the volcanic magma, and they went into hydrothermal fluids after consolidation of most of the rhyolite. These fluorine-rich, beryllium- and uranium-bearing fluids are believed to be the source of the fluorspar, uranium, and beryllium found in the deposits in the vicinity of Spor Mountain.

Available passageways were necessary for the fluorine-, beryllium-, and uranium-bearing fluids to move from their site of origin to their site of deposition. Many of the fluorspar deposits, as well as the Yellow Chief uranium mine and the Claybank and Hogsback beryllium deposits, are formed along or adjacent to faults. Faults probably also served as channelways for many of the deposits found on the covered flats on the west side of Spor Mountain. Lack of open connecting channelways is the principal reason that many tuffs, though chemically and physically similar to those containing the beryllium deposits, are barren. In some places, as in the eastern part of the Thomas Range, the tuffs are not cut by faults and, hence, lack channelways. In other places, as around Spor Mountain, faults are common, but the channelways are either blocked by gouge or do not connect with the chamber from which the mineralizing fluids came.

Beryllium and uranium form soluble complex ions with fluorine. In this form, they could be carried in solution in the late hydrothermal fluids to the site of their deposition. If they were transported in this fashion, the question arises as to why the fluorspar deposits on Spor Mountain contain only small amounts of beryllium and uranium. Apparently, the answer is that in the fluorspar deposits, the fluoride ion was not entirely precipitated. The concentration of the fluoride ion in these residual fluids was high enough so that little of the complex uranium or beryllium fluorides were broken down. These elements were deposited only when the fluoride concentration became small enough for the soluble complexes to break down. The distribution of the deposits in the Spor Mountain area (fig. 2), with the rich fluorspar deposits in the center and the beryllium and uranium deposits ringing them, supports this theory.

For beryllium deposits to form at any particular place there must be a channelway, such as a fault, along which the beryllium-bearing fluids can move, and there must also be a favorable host rock. As previously noted, the numerous faults in the area probably furnished the channelways. The favorable host rock is a porous tuff with a high permeability. Most of the other rocks in the vicinity of the deposits have a low porosity and permeability. The host rock in the area of the deposits also is high in calcite, which could react with the fluoride in the fluid to yield fluorite. In fluids with a low fluoride content, the precipitation of fluorite would simultaneously induce the breaking up of the soluble beryllium fluoride complex.

REFERENCES CITED

Allings, A. N., 1887, On the topaz from the Thomas Range, Utah: Am. Jour. Sci., 3d ser., v. 33, p. 146–147.

Brownell, G. M., 1959, A beryllium detector for field exploration: Econ. Geology, v. 54, p. 1103–1114.

Cantwell, Thomas, Hawkes, H. E., Jr., and Rasmussen, N. C., 1958, A nuclear detector for beryllium minerals: Mining Eng., v. 11, no. 9, p. 938–940.

Crittenden, M. D., Jr., 1951, Manganese deposits of western Utah: U.S. Geol. Survey Bull. 979–A, p. 1–62.

Eilertsen, D. E., 1960, Beryllium, *in* Minerals Yearbook, 1959: U.S. Bur. Mines, v. 1, p. 241–248.

Fitch, C. A., Jr., Quigley, J. E., and Barker, C. S., 1949, Utah's new mining district [Topaz Mountain]: Eng. Mining Jour., v. 150, p. 63–66.

Hillebrand, W. F., 1905, Red beryl from Utah: Am. Jour. Sci., 4th ser., v. 19, p. 330–331.

Jaffe, H. W., Gottfried, David, Waring, C. L., and Worthing, H. W., 1959, Lead-alpha age determinations of accessory minerals of igneous rocks (1953–1957): U.S. Geol. Survey Bull. 1097–B, p. 65–148.

Jones, A. J., 1895, Topaz crystals of Thomas Mountain, Utah: Iowa Acad. Sci. Proc., v. 2, p. 175–177.

Kunz, G. F., 1885, Precious stones, *in* Mineral resources of the United States, 1883–84: U.S. Geol. Survey, p. 723–782.

———1893, Precious stones, *in* Mineral resources of the United States, 1892: U.S. Geol. Survey, p. 756–781.

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, no. 10, p. 1045–1052.

Montgomery, Arthur, 1934, A recent find of bixbyite and associated minerals in the Thomas Range, Utah: Am. Mineralogist, v. 19, p. 82–87.

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.

Palache, Charles, 1934, Minerals from Topaz Mountain, Utah: Am. Mineralogist, v. 19, p. 14–15.

Patton, H. B., 1908, Topaz-bearing rhyolite of the Thomas Range, Utah: Geol. Soc. America Bull., v. 19, p. 177–192.

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.

Rittmann, Alfred, 1952, Nomenclature of rocks: Bull. Volcanol., ser. 2, v. 12, p. 75–102.

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: U.S. Army, Engineer Dept., Washington, 518 p.

Staatz, M. H., and Carr, W. J., 1963, Geology and mineral deposits of the Thomas and Dugway Ranges, Juab and Tooele Counties, Utah: U.S. Geol. Survey Prof. Paper 415, in press.

Staatz, M. H., and Griffitts, W. R., 1961, Beryllium-bearing tuff in the Thomas Range, Juab County, Utah: Econ. Geology, v. 56, no. 5, p. 941–958.

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.

Thurston, W. R., Staatz, M. H., Cox, D. C., and others, 1954, Fluorspar deposits of Utah: U.S. Geol. Survey Bull. 1005, 53 p.

Vaughn, W. H., Wilson, E. E., and Ohm, J. M., 1960, A field instrument for quantitative determination of beryllium by activation analysis: U.S. Geol. Survey Circ. 427, 9 p.

Wentworth, C. K., and Williams, Howel, 1932, The classification and terminology of the pyroclastic rocks: Natl. Research Council Bull. 89, p. 19–53.