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THE GLORY OF GOD IS INTELLIGENCE

Cover: East flank of San Rafael Swell, Emery County, Utah; looking north. Photo by W. K. Hamblin.

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Geology of Volcanic Rocks and Mineral Deposits in the Southern Thomas Range, Utah: A Brief Summary

DAVID A. LINDSEY
U.S. Geological Survey, Box 25046, Denver, Colorado 80225

ABSTRACT.— The Thomas Range contains three groups of volcanic rocks. The oldest group (38–41 m.y.) consists of rhyodacite flow rocks and rhyolitic ash-flow tuff. The middle group (30–32 m.y.) unconformably overlies the oldest group and consists of rhyolitic ash-flow tuff. Breccia on Spor Mountain probably formed after deposition of the ash-flow tuff, but additional study is needed to determine its origin. The youngest group consists of water-laid tuff and topaz rhyolite of Spor Mountain (21 m.y.), which are unconformably overlain by young (6–7 m.y.) water-laid tuff and topaz rhyolite of the Thomas Range. Major faulting of the volcanic rocks occurred after eruption of the topaz rhyolite of Spor Mountain 21 m.y. ago, but before eruption of the topaz rhyolite of the Thomas Range 6–7 m.y. ago.

Important deposits of fluorspar, beryllium, and uranium have been discovered in the Thomas Range. Uraniferous fluorspar occurs mainly in pipes and veins in Paleozoic rocks on Spor Mountain. Beryllium occurs with fluorite and uranium in the water-laid tuff of Spor Mountain. These deposits are believed to have formed by hydrothermal fluids that rose through faults in and near Spor Mountain and spread laterally through the porous water-laid tuff. Uranium also occurs without significant fluorite and beryllium in tuffaceous sedimentary rocks at the Yellow Chief mine and in veinlets of opaline silica in tuff at many localities. The genesis of these deposits requires additional study.

INTRODUCTION

The Thomas Range (fig. 1) contains important deposits of fluorspar, beryllium, and uranium. These mineral deposits are associated with an extraordinary sequence of volcanic rocks that includes large volumes of rhyolite containing topaz, beryl, garnet, bixbyite, and pseudobrookite. The geology and mineral deposits of the Thomas Range have been studied intensively by numerous investigators; a partial list includes Staatz and Osterwald (1959), Staatz and Griffitts (1961), Bowyer (1963), Williams (1963), Staatz and Carr (1964), Park (1968), Shawe (1968, 1972), Bullock (1976), and Lindsey (1977). New data and theory have brought continued modification of the concepts about the volcanic history and genesis of the ore deposits of the area. This report summarizes my current understanding of the volcanic rocks and ore deposits of the southern part of the Thomas Range and identifies some problems that remain to be solved.

GEOLOGY

General

The Thomas Range may be divided into two parts: an upthrown western fault block of Paleozoic rocks on Spor Mountain and a downfaulted basin filled with volcanic rocks that underlie most of the range (fig. 2). The Paleozoic rocks on Spor Mountain range from the Lower and Middle Ordovician Garden City (limestone) and Middle Ordovician Swan Peak (quartzite) formations to the Lower and Middle Devonian Sevy Dolomite and Middle and Upper Devonian Engelmann Formation (dolomite) (Staatz and Carr 1964, pl. 1). Volcanic rocks of Tertiary age fill the basin east of Spor Mountain, in The Dell and in the Thomas Range, and they also cover the southern and western edges of Spor Mountain. A major fault system (margin fault on fig. 2) separates Spor Mountain from the rest of the Thomas Range; this fault has been interpreted as a basin-and-range fault by Staatz and Carr (1964, p. 126) and as a caldera ring fracture by Shawe (1972). Numerous faults cut the Paleozoic rocks on Spor Mountain, and some of these extend into the volcanic rocks south and west of the mountain, where they form a series of small westerly dipping fault blocks (Shawe 1968).

Volcanic Rocks

Three groups of Tertiary volcanic rocks overlie Paleozoic sedimentary rocks in the Thomas, Keg, and Drum mountains (Shawe 1972, Lindsey et al. 1975). The oldest group consists of flows, agglomerates, and ash-flow tuffs that were deposited 38–41 m.y. ago. The middle group contains widespread ash-flow tuffs that probably originated from local volcanic centers 30–32 m.y. ago. The youngest group consists of water-laid tuff and breccia and topaz-bearing rhyolite. Topaz rhyolite volcanism began 21 m.y. ago at Spor Mountain, but most of the youngest group was desposited 6–7 m.y. ago in the Thomas Range (Lindsey 1977).

The accumulation of volcanic rocks was interrupted by diastrophism and erosion many times. Significant unconformities occur beneath each group and also within the oldest and youngest groups. Early topaz rhyolite volcanism at Spor Mountain 21 m.y. ago was followed by extensive faulting and tilting of the volcanic rocks prior to the onset of major topaz rhyolite volcanism 6–7 m.y. ago in the Thomas Range.

The oldest group is represented by two formations in the Thomas Range: the rhyodacite of Staatz and Carr (1964, p. 75–77), and rhyolitic ash-flow tuff (fig. 2). The rhyodacite, dated as nearly 41 m.y. old, is a dark flow rock with abundant phenocrysts of intermediate-composition plagioclase, hypersthene, and lesser augite in a fine-grained glassy to hyalopilitic matrix. The rhyodacite occurs in scattered outcrops around Spor Mountain, in The Dell, and south of Topaz Mountain. Pink rhyolitic ash-flow tuff unconformably overlies the rhyodacite south of Topaz Mountain and extends discontinuously along the east side of the Thomas Range. The tuff closely resembles ash-flow tuff of the middle group, inasmuch as it contains abundant quartz, sanidine, and biotite crystals in a partially welded matrix of devitrified pumice and shards. Orginally the tuff was assigned to the middle group (Shawe 1972), but numerous fission-track dates clearly establish its age as 38–39 m.y. It is overlain by black-glass welded tuff (Staatz and Carr 1964, p. 84) that crops out locally along the east side of Topaz Mountain. The age of the black-glass tuff is uncertain, but it is mapped with the rhyolitic tuff in figure 2 because of its small area of exposure.

The middle volcanic group consists of pink rhyolitic ash-flow tuff dated as 30–32 m.y. old (Shawe 1972, Lindsey et al.

1975) (fig. 2). This tuff is well exposed in The Dell, where it was mapped as quartz-sanidine crystal tuff by Staatz and Carr (1964, p. 79–80). The rhyolitic ash-flow tuff of the middle group is well exposed in the Keg Mountains, where it has been dated at Keg Pass. The crystal tuffs of Red Mountain (Staub 1975), in the southwestern part of the Keg Mountains, probably belong to the middle group also. In The Dell the tuff is characterized by abundant large euhedral crystals of quartz and sanidine with lesser amounts of plagioclase and biotite in a slightly to moderately welded matrix of pumice and shards. Much of the matrix glass has devitrified to potassium feldspar and cristobalite.

The intrusive breccia described by Staatz and Carr (1964, p. 85–86) has generally been placed in the upper part of the middle group (Shawe 1972). The most abundant type of breccia, exposed along the east side of Spor Mountain, consists of angular clasts of carbonate rocks and quartzite cemented in a matrix of finely comminuted particles of the same composition as the clasts. On the northeast side of Spor Mountain the breccia contains clasts of rhyodacite and carbonate rock cemented by red matrix of pulverized rhyodacite. North of Spor Mountain, the breccia consists of shattered dark dolomite in which the continuity of bedding is commonly preserved. The breccia is generally not altered or mineralized, and nowhere has it been found to contain fragments of rocks older than those exposed on Spor Mountain. Evidence for the intrusive nature of the breccia seems weak, resting only on the general crosscutting nature of its contacts with other formations. Further study of the breccia is needed before its intrusive origin can be confirmed or an alternative proposed.

The youngest volcanic group consists of light-tan water-laid tuff and breccia and gray topaz rhyolite. The two oldest formations of the youngest group are water-laid tuff and topaz rhyolite of Spor Mountain (fig. 2), dated as nearly 21 m.y. old (Lindsey 1977). These units lie unconformably on rocks of the two older volcanic groups and, southwest of Spor Mountain, on Paleozoic dolomite. The tuff and rhyolite extend into The Dell and are found north of Spor Mountain also. They are cut and tilted by as much as 30 degrees by numerous northeast-trending faults at the beryllium mines southwest of Spor Mountain and are downfaulted against Paleozoic rocks along the margin fault system that separates Spor Mountain from The Dell. A small plug of the rhyolite has intruded Paleozoic rocks on the south side of Spor Mountain. Abundant clasts of dolomite that commonly have

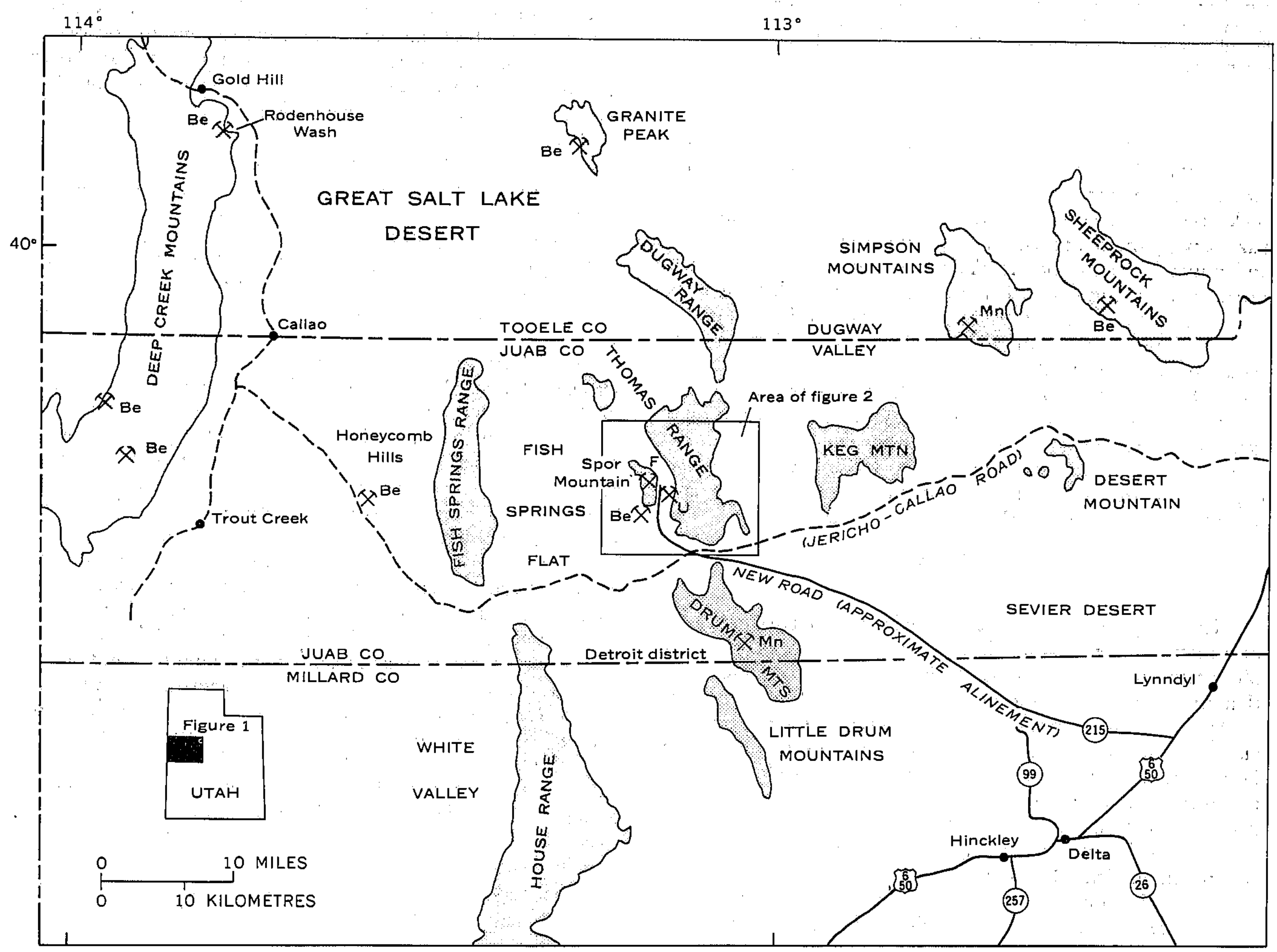


FIGURE 1.– Map showing location of Thomas Range, Spor Mountain, other geographic features, and mineral occurrences of beryllium (Be), fluorite (F), manganese (Mn), and uranium (U).

been altered to calcite, silica minerals, fluorite, and clay distinguish most of the tuff from younger water-laid tuff in the Thomas Range. The topaz rhyolite of Spor Mountain can be distinguished from most of the younger topaz rhyolite of the Thomas Range by the greater abundance of quartz, sanidine, and biotite phenocrysts in the former.

Tuffaceous conglomerate and sandstone are overlain by bentonite in a small downfaulted block at the Yellow Chief mine in The Dell. The sandstone contains abundant quartz and sanidine crystals derived from the underlying quartz-sanidine crystal tuff of the middle group. The tuffaceous sediments are believed to belong to the same period of erosion and volcanism as the water-laid tuff of Spor Mountain because they overlie the middle group and are tilted by faulting in the same manner as the water-laid tuff and topaz rhyolite of Spor Mountain.

Topaz rhyolite and associated volcaniclastic rocks of the Thomas Range unconformably overlie the topaz rhyolite of Spor Mountain. The general stratigraphic sequence of water-laid tuff, flow breccia, obsidian, and rhyolite flow rock is repeated five times in the Thomas Range (Staatz and Carr 1964, p. 87–88). The topaz rhyolite flows of the Thomas Range and the rocks interbedded with them are considered to be 6–7 m.y. old, although only the top three flows have been dated (Lindsey et al. 1975). Topaz, garnet, pink beryl, bixbyite, and pseudobrookite are found in lithophysae in the rhyolite.

Evolution of Volcanic Stratigraphy

Staatz and Carr (1964) first mapped and divided the volcanic rocks of the Thomas Range into two groups. An older, much faulted group consisted of rhyodacite, black-glass welded tuff, all the rhyolitic ash-flow tuffs, intrusive breccia, and part of the topaz rhyolite of Spor Mountain (part of which they called porphyritic rhyolite). The older group of Staatz and Carr (1964) also contained other units mapped by them in the northern Thomas Range and the Dugway Range. As such, their older group is approximately equivalent to the oldest and middle groups of Shawe (1972). Their younger group consisted of part of the water-laid tuff and topaz rhyolite of Spor Mountain and all the water-laid tuff and topaz rhyolite of the Thomas Range.

The interpretation of the volcanic stratigraphy of the Thomas Range has undergone considerable change since the work of Staatz and Carr (1964). Shawe (1972) reclassified the volcanic rocks of the Thomas Range into three groups, which he was able to map throughout much of the Keg, Desert, and Drum mountains. Recent geochronologic studies (Lindsey et al. 1975) confirmed much of Shawe's (1972) threefold division of the volcanic rocks of the region, and his classification, with some modification, is the one used in this report. Shawe (1972) also concluded that eruption of voluminous ash-flow tuffs of the middle group was followed by caldera collapse in the Thomas, Keg, and Desert Mountain areas. Caldera ring fractures like the one believed to separate Spor Mountain from the rest of the Thomas Range provided conduits for ore-forming fluids. Recent mapping by Staub (1975) did not confirm the caldera ring fracture in the southwestern part of the Keg Mountains that was projected by Shawe (1972).

Reexamination of the volcanic rocks of the southern Thomas Range (Lindsey 1977 and this report) indicates that the history of Tertiary volcanism and tectonism is more complex than the regional stratigraphic framework of Shawe (1972) would permit. The most important findings to date are these:

1. Much more rhyolitic ash-flow tuff than previously realized belongs to the oldest group (38–39 m.y.) instead of the middle group (30–32 m.y.).
2. The onset of topaz rhyolite volcanism at Spor Mountain began much earlier (21 m.y. ago) than eruption of the voluminous topaz rhyolite of the Thomas Range (6–7 m.y. ago).
3. A major period of faulting occurred at Spor Mountain after 21 m.y. ago.

As a result of the recognition and mapping of the topaz rhyolite of Spor Mountain, it can be established that faulting and tilting of the rhyolite southwest of Spor Mountain and major displacement of the rhyolite against Paleozoic rocks along the margin fault system occurred after 21 m.y. ago. If the margin fault formed as a result of caldera collapse 30–32 m.y. ago (Shawe 1972, Lindsey et al. 1975), then significant movement would be expected to have preceded eruption of the earliest topaz rhyolite also. Movement of the fault system during basin-and-range faulting, as originally suggested by Staatz and Carr (1964), is compatible with the new evidence, but movement of the fault before 21 m.y. ago, in response to caldera collapse, cannot be ruled out.

MINERAL DEPOSITS

Fluorspar

Fluorspar has been produced intermittently from Spor Mountain since 1943 (Thurston et al. 1954), with a total production through 1975 of 202,500 metric tons of ore that ranges in grade from 60 to 95 percent CaF_2 (Bullock 1976, p. 31). Fluorspar occurs in pipelike bodies and veins in the Paleozoic rocks on Spor Mountain and less commonly in intrusive breccia and rhyolite (Staatz and Carr 1964, p. 132) (fig. 2). Fluorite is also disseminated in beryllium deposits in the water-laid tuff of Spor Mountain, but the grade rarely exceeds 8 percent. Most of the production has been from pipes; 81,000 metric tons have been produced from the Lost Sheep mine alone (Bullock 1976, p. 30–31).

Fluorspar pipes range as large as 47 by 32 m, are irregularly shaped, and commonly diminish in size at depth (Staatz and Carr 1964, p. 130). The ore may be fine grained and earthy or coarsely crystalline, or it may form a boxwork (Bullock 1976, p. 30–31). The major gangue minerals are quartz, chalcedony, montmorillonite, calcite, and dolomite. Boxwork ore is abundant in most pipes, the boxwork being formed by fluorite, silica minerals, and clay surrounding breccia fragments of incompletely altered dolomite. Most of the fluorspar is uraniferous; Staatz and Carr (1964, p. 135) reported a range of 0.003–0.33 percent uranium. Although fluorspar and beryllium are closely associated in beryllium deposits in tuff, fluorspar from the pipes contains only 20 ppm beryllium or less (Staatz 1963, p. M25).

Beryllium

Beryllium in water-laid tuff of Spor Mountain was discovered in 1959, and production by Brush-Wellman began in 1969. Most of the larger deposits, including the Roadside, Rainbow, Blue Chalk, and Monitor, occur southwest of Spor Mountain; small deposits occur in tuff along the margin fault east of Spor Mountain at the Hogsback and Claybank prospects (fig. 2). Although production statistics are not available, it is possible to infer that the Spor Mountain ores provided a significant part of the 198 metric tons of beryllium metal consumed by the United States in 1975 (see U.S.

Bureau of Mines 1976, p. 18–19). Resources of beryllium at Spor Mountain are believed to be sufficient to supply the nation for many years at the current rate of consumption (Griffitts 1964). The grade of the ore averages less than 1 percent BeO, but the beryllium is competitive with imported beryl because it can be mined by open-pit methods and extracted by acid leaching.

The beryllium occurs as submicroscopic bertrandite ($Be_4Si_2O_7(OH)_2$) disseminated in hydrothermally altered tuff and fluorite nodules (Staatz and Griffitts 1961, Montoya et al. 1962). Most of the ore bodies are near the top of the water-laid tuff of Spor Mountain (Park 1968), where they coincide with the zone of highest fluorite content (1–8 percent) and most intense hydrothermal alteration (Griffitts and Rader 1963, Lindsey et al. 1973). Significant amounts of manganese, lithium (as much as 3,000 ppm), zinc (1.5 percent), and uranium (as much as 2,000 ppm) occur locally in the beryllium ore (Park 1968, Shawe 1968, Lindsey 1977), but the average content of these metals is much less than the maximum concentrations quoted. Lithium and zinc are in trioctahedral smectite, zinc is in manganese oxide minerals such as chalcophanite, and uranium occurs in the crystal structure of fluorite and opaline silica.

The water-laid tuff of Spor Mountain is the host for all the important deposits of beryllium discovered so far. The tuff consists of volcanic detritus—glass, zeolite, pyroclastic crystals, and fragments of older volcanic rocks—mixed with as much as 50 percent or more dolomite clasts (Lindsey et al. 1973). Volcanic detritus in the tuff has been incompletely altered to calcite, silica minerals, fluorite, and smectite. The most intensely altered tuff consists of abundant smectite, sericite, potassium feldspar, cristobalite, and fluorite, and contains almost no glass, zeolite, dolomite, or calcite. The alteration sequence dolomite-calcite-quartz-opal-fluorite was inferred from study of the nodules that formed by alteration of dolomite clasts. Alteration of volcanic glass probably followed the sequence glass-smectite-sericite-potassium feldspar in response to increasing pH of the mineralizing solutions as carbonate ions were released during alteration of the dolomite clasts.

At the Roadside beryllium pit, mineralization and hydro-

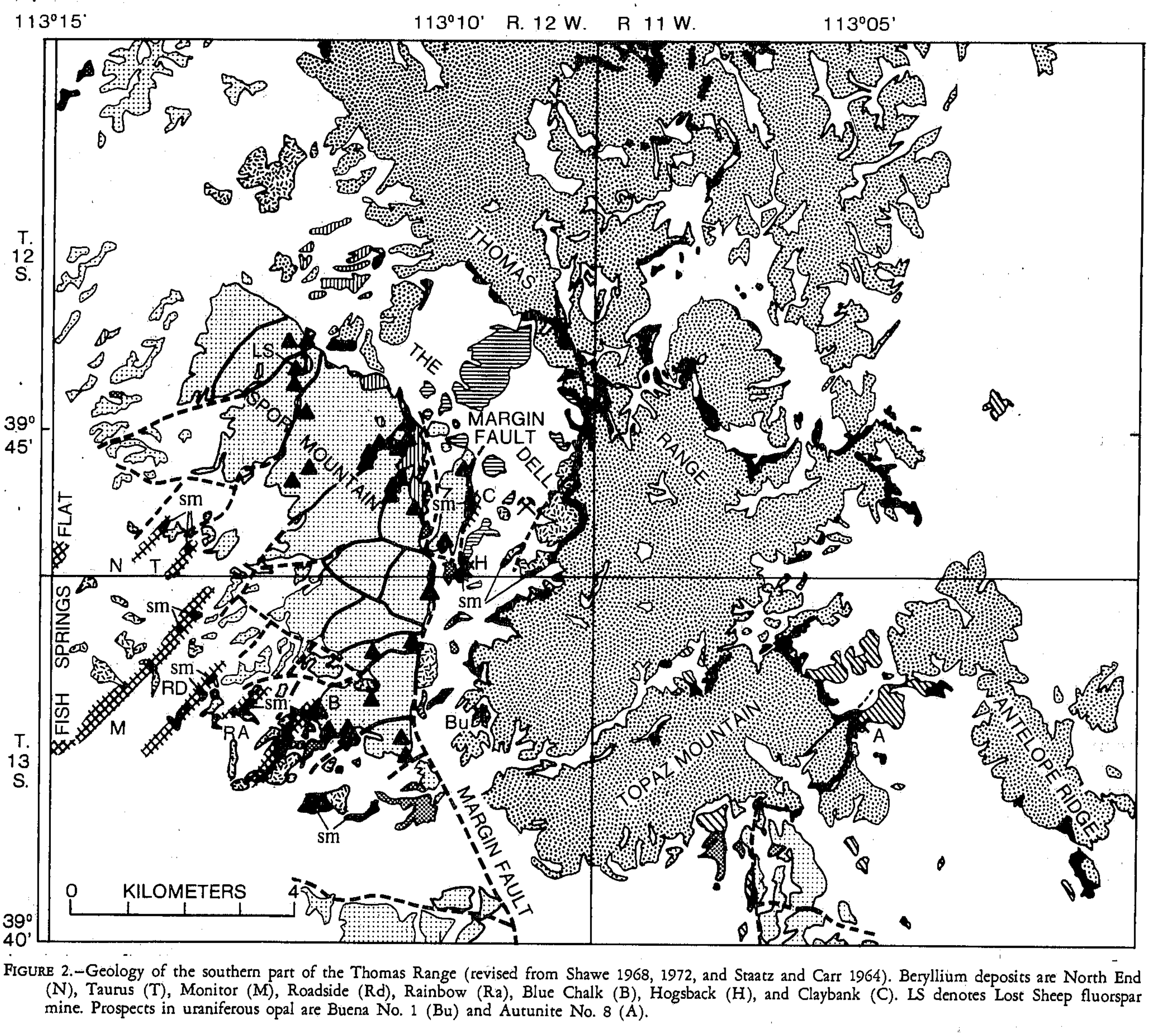


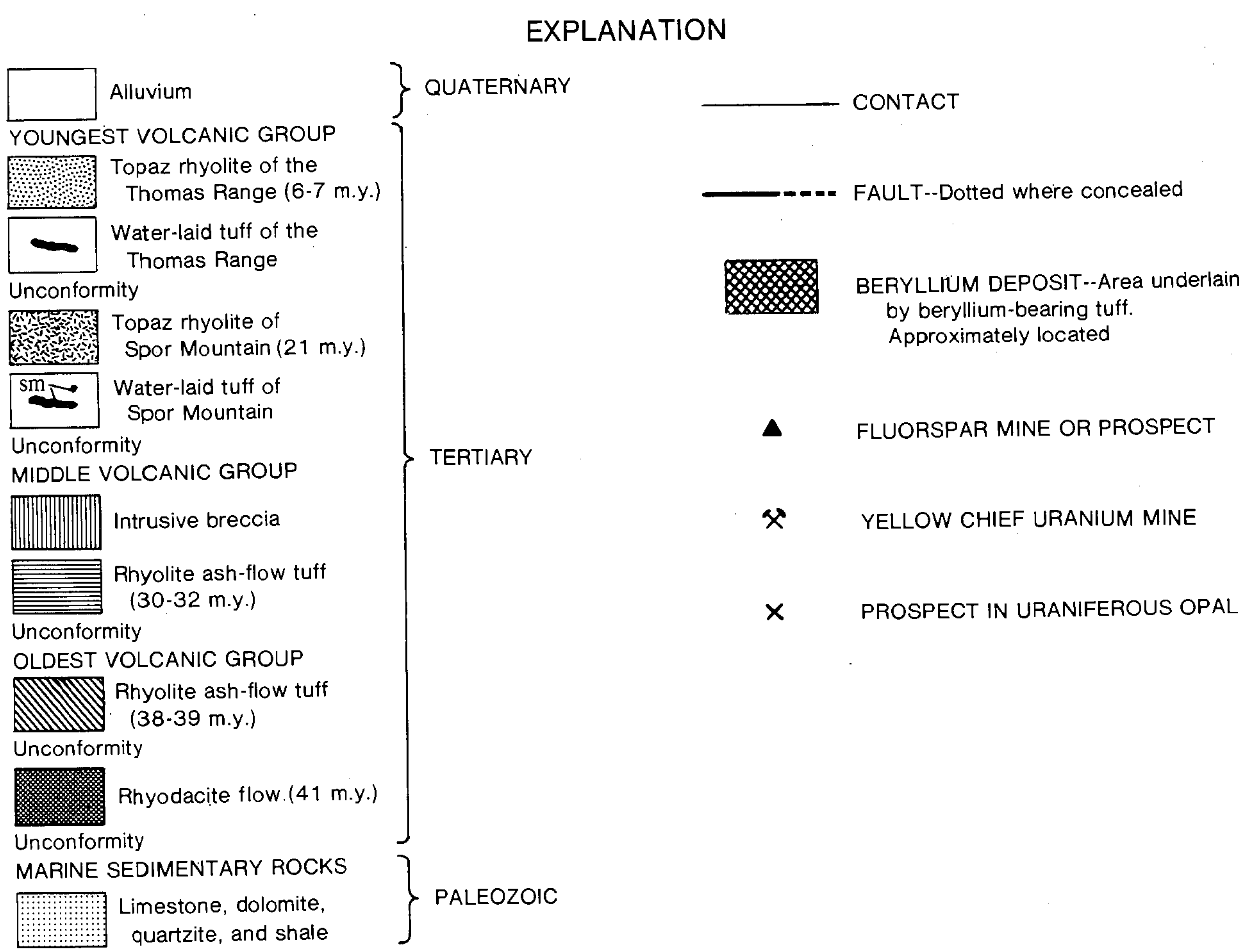
FIGURE 2.—Geology of the southern part of the Thomas Range (revised from Shawe 1968, 1972, and Staatz and Carr 1964). Beryllium deposits are North End (N), Taurus (T), Monitor (M), Roadside (Rd), Rainbow (Ra), Blue Chalk (B), Hogsback (H), and Claybank (C). LS denotes Lost Sheep fluorspar mine. Prospects in uraniferous opal are Buena No. 1 (Bu) and Autunite No. 8 (A).

thermal alteration were generally concordant to the bedding and were most intense in the upper part of the tuff (Shawe 1968, Lindsey et al. 1973). A zone of feldspathic tuff (≥ 20 percent potassium feldspar) occupies the uppermost 18 m and lowermost 9 m of a drilled section; incompletely altered argillic tuff is present between the feldspathic zones. The upper 6 m of tuff contains 1–8 percent fluorite, the underlying 18 m contains abundant calcite, and the remaining tuff contains abundant dolomite; this zonation reflects the decreasing intensity of alteration of the dolomite clasts from top to bottom. The fluorite zone approximately coincides with the beryllium ore, and the calcite zone corresponds to the zone of abundant lithium (500–1000 ppm) in trioctahedral smectite. Uranium is most abundant in a 9-m interval within the calcite zone, where it ranges from 120 to 162 ppm as determined by delayed neutron analyses. Uranium in the fluorite zone ranges from 45 to 82 ppm. The lower potassium feldspar zone is anomalous and may have resulted from diagenesis. Only the distribution of minor kaolinite is discordant to the bedding, and this mineral is believed to be supergene.

Uranium

Uranium occurs (1) in fluorspar pipes, (2) in beryllium deposits in tuff, (3) in tuffaceous conglomerate and sandstone at the Yellow Chief mine, and (4) in veinlets of opaline silica at many localities. Deposits of the first two types have already been discussed, so only the last two will be considered here. The only production of uranium has been from the Yellow Chief deposit (fig. 2), which was estimated to contain more than 90,000 metric tons of ore having a grade of 0.20–0.23 percent U_3O_8 (Bowyer 1963). Most of the ore was mined between 1959 and 1962.

The ore at the Yellow Chief is beta-uranophane ($Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$), a pale orange-yellow mineral (Bowyer 1963). It occurs in lenses as much as 6 m thick and 90 m long that are approximately concordant to the bedding in tuffaceous conglomerate and sandstone. The yellow mineral weeksite ($K(UO_2)_2(Si_2O_5)_3 \cdot 4H_2O$) occurs in lenticular zones less than 1 m thick and 10 m long in the limestone conglomerate that overlies the tuffaceous sandstone (Staatz and Carr 1964, p. 156). Both these minerals occupy interstices and fractures and coat sand grains and clasts in the conglomerate. Schroekingerite ($NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$) has been reported in veinlets in the tuffaceous sandstone (Staatz and Carr 1964, p. 157) but has not been found in most of the ore. Fluorine (except in schroekingerite), beryllium, lithium, vanadium, molybdenum, and other metals are not present except as trace constituents and are not enriched in the uranium ore bodies. The host rock is partially altered to smectite, and some limestone clasts in the conglomerates have altered shells, but evidence for intense hydrothermal alteration is lacking. Coarsely crystalline calcite cement and veinlets are widespread in the tuffaceous sandstone and conglomerate.



Uranium occurs in the structure of opaline silica veinlets in tuff at many places in the Thomas Range. The best-known and most uraniferous opal veinlets are in rhyolitic ash-flow tuff of the oldest volcanic group at the Autunite No. 8 prospect on the east side of Topaz Mountain (fig. 2), but uraniferous opal veinlets occur (1) in rhyolite of the youngest group at the Buena No. 1 prospect (Staatz and Carr 1964, p. 152–54) and in tuff west of Topaz Valley; (2) in rhyolitic ash-flow tuff of the middle group in The Dell, and (3) in the water-laid tuff of Spor Mountain in The Dell and at the Roadside beryllium pit. Reconnaissance suggests that at least minute quantities of uraniferous opal can be found in any tuff in the Thomas Range that is not densely welded. The veinlets are generally less than 1–2 cm wide and occur both singly and in zones less than 10 m wide and 30 m long. None has produced ore. Analyses at several prospects indicate a maximum grade of about 0.2 percent uranium (Staatz and Carr 1964, p. 152–54).

The opal veinlets are generally zoned, the zoning being defined by varying size of fibrous crystallites oriented perpendicular to the walls of the vein. (Opal is semicrystalline and gives broad X-ray diffraction peaks for α cristobalite and tridymite.) The opal fluoresces bright yellow-green under ultraviolet light, so that it can be distinguished readily from ordinary opal in the same area, which does not fluoresce. Calcite is common in the veinlets, and weeksite and fluorite have been reported (Staatz and Carr 1964, p. 152–54). Fission-track maps show that, at the Autunite No. 8 prospect, uranium is concentrated in the opal parallel to the zoning, so that there are large variations in uranium content between zones only a fraction of a mm thick (Zielinski et al. 1977). Uranium-lead apparent ages of pure opal from the Autunite No. 8 are nearly concordant at 3.5 m.y.

Origin of the mineral deposits

The fluorspar and beryllium deposits are believed to have a common origin, with the beryllium deposits in tuff representing the more distant effects of mineralizing fluids that formed the fluorspar pipes (Staatz and Griffitts 1961, Lindsey et al. 1973). Mineralizing fluids that carried beryllium and perhaps uranium and other metals in the form of fluoride complex ions emanated from the magma that was the source of the topaz rhyolite. Alternatively, the fluids may have derived their metal content by leaching a buried pluton that formed from the magma. The temperature of the fluids dropped as they invaded faulted and brecciated Paleozoic rocks on Spor Mountain, causing precipitation of fluorite and silica in pipes and veins. As the concentration of fluorine dropped, the fluoride complex ions became unstable, and beryllium and other metals were precipitated in tuff farther from the source. One unsolved problem of the mode of ore genesis is why at least some of the fluorspar pipes do not contain significant beryllium, manganese, and lithium.

Deep fractures and porous tuff beds provided a plumbing system for the mineralizing fluids and affected the location of ore deposits. The fluids rose along the margin fault system interpreted by Shawe (1972) as a caldera ring fracture and by Staatz and Carr (1964) as a basin-and-range fault. Other faults on Spor Mountain also served as conduits for the mineralizing fluids. The porous water-laid tuffs, situated between relatively impermeable sedimentary and volcanic rocks, provided a path for lateral migration of the mineralizing fluids.

The uranium deposits at the Yellow Chief mine are of uncertain origin. The paucity of fluorite and beryllium in the uranium ore suggests that the Yellow Chief deposits were not formed by the hydrothermal mineralization that produced the fluorspar and beryllium deposits. No uranous minerals or evidence of organic matter have been found to suggest that the uranium deposits resemble those of the Colorado Plateau. Metals that are locally abundant in the beryllium ores (such as manganese, lithium, and zinc) and in the Colorado Plateau ores (such as vanadium, copper, and molybdenum) are not concentrated in the Yellow Chief ore. Uranium at the Yellow Chief may have been introduced by ground waters bearing uranyl carbonate complex ions that dissociated when the calcite cement precipitated. Uranyl carbonate complex ions are stable in carbonate-rich solutions, but can be destroyed by decrease in the concentration of carbonate ions (Hostetler and Garrels 1962).

The origin of the uraniferous opal veinlets is speculative. The strong zoning of uranium concentration in the veins suggests wide fluctuations in the supply or rate of precipitation of uranium. If silica and calcite are the major phases in equilibrium with the fluids, the only likely mechanism for controlling the rate of precipitation is change in temperature. Fluctuating temperature would suggest a hydrothermal source. The late apparent age (3.5 m.y.) at the Autunite No. 8 prospect is in agreement with evidence that the water-laid tuff of the Thomas Range (6–7 m.y.) has been weakly mineralized by fluorine- and beryllium-bearing fluids (Zielinski et al. 1977). On the other hand, not enough study has been done to eliminate the possibility that the opal veinlets were deposited by ground water.

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