MINERAL RESOURCE POTENTIAL OF PIUTE COUNTY, UTAH AND ADJOINING AREA

by

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FOREWORD

This study of the mineral resources of the Piute County area, prepared under a Utah Geological and Mineralogical Survey contract, was financed jointly by the Four Corners Regional Commission (Technical Assistance Grant–FCRC No. 421-500-043, Doc. No. 10250058) and the Utah Geological and Mineralogical Survey. The author, who holds advanced degrees in geology from the University of Oregon and Columbia University, has more than 40 years experience in evaluating mineral occurrences in North and South America, Europe, North Africa and the Middle East.

As an employee of the U. S. Geological Survey (USGS), he spent 1936, 1937 and 1938 in the Marysvale region studying the area's mineral deposits with special emphasis on the alunite occurrences, mapping the surface, and recording the geologic details in all accessible underground openings. In 1942 and 1943 Callaghan was commodity geologist for chemical minerals and participated with U. S. Geological Survey and U. S. Bureau of Mines in supervision of a physical exploration program for alunite. M. E. Willard and G. L. Bell were resident geologists. With R. L. Parker, he completed the regional mapping in 1952 and 1954.

In 1961 and 1962 the U. S. Geological Survey published four Geological Quadrangle maps and a Mineral Investigations map that embodied the results of the surface mapping. The studies of individual mineral deposits have not been published in full.

This study is organized around the geologic characteristics of the region with emphasis on the production history and evaluation of the production potential of the lead-zinc-silver, gold, uranium, manganese and iron, alunite and industrial mineral deposits of the region.

Unpublished data pertaining to metal content were obtained from mining interests. The area was revisited and detailed notes and sketches from the earlier studies, made available by the U. S. Geological Survey, were updated.

The report should provide a firm basis for those making decisions concerning economic development, industrial expansion and land use in the region.

W. P. Hewitt
Director, UGMS

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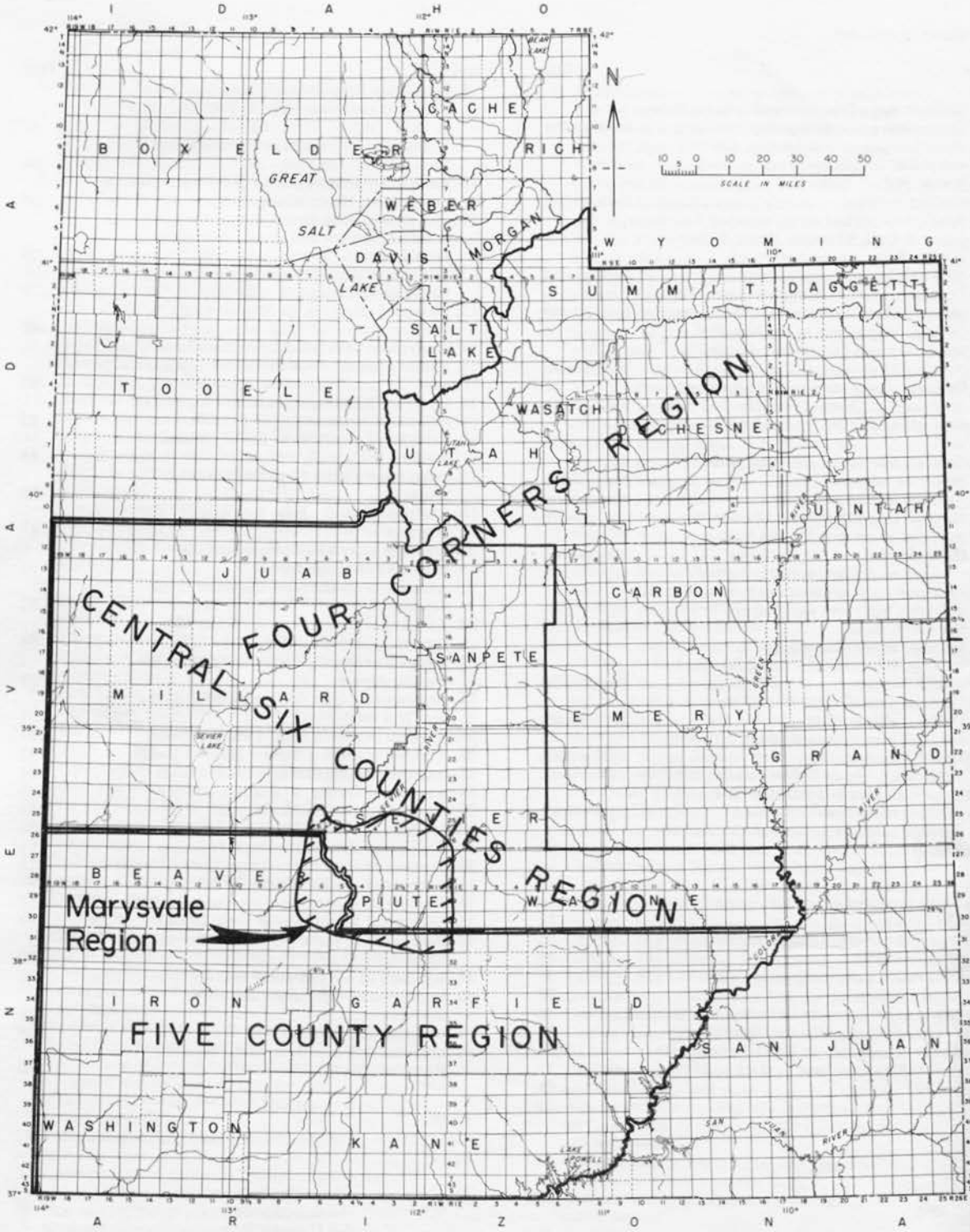

Figure 1. Outline map of Utah showing location of Marysvale region with respect to the Central Six County region and Five County region of the State Advisory Planning Committee and the part of the Four Corners region in Utah.

MINERAL RESOURCE POTENTIAL OF PIUTE COUNTY, UTAH AND ADJOINING AREA

by Eugene Callaghan[1]

ABSTRACT

The Marysvale region includes Piute County with adjoining parts of Beaver, Sevier and Garfield counties. In the past 100 years, gold, silver, quicksilver, copper, lead, zinc, uranium, manganese, iron, alunite for potash (World War I), alunite for aluminum (World War II), sulfur, and blending clay for brickmaking have been produced and fluorspar and corundum have been prospected. Gold and silver were produced mainly from the Annie Laurie and Deer Trail mines prior to World War I, uranium in the 1950's and clay currently. Lead and zinc ores were produced from the lower workings of the Deer Trail mine at the rate of 10,000 tons of ore per year until the closure of the Tooele smelter in November 1971. The spectacular advance in the price of gold in the free market has stimulated renewed interest in the long dormant gold mines and prospects.

Although lead and zinc occur sporadically in quartz veins, the significant source of the metals is a manto or stratiform type of ore body which was developed and mined from the Permian Toroweap Formation in the lower workings of the Deer Trail mine. The Toroweap is exposed only in the lower part of Deer Trail Mountain southwest of Marysvale and is deeply buried elsewhere in the region. That similar ore bodies may yet be found in the region is possible, but locating them under great thicknesses of cover defies present exploration methods. Exploration adjacent to the Deer Trail ore body has not yet revealed other ore bodies.

The known vein type uranium deposits are worked out, but a higher market price may stimulate further exploration, particularly deep drilling, for new discoveries.

Any copper recovered was incidental to gold mining. No disseminated copper minerals were noted in spite of widespread alteration and numerous quartz monzonite intrusions. Quicksilver, manganese and iron occurred in small deposits and any renewed production seems unlikely.

The high price of potash stimulated mining of some 250,000 tons of high-grade vein type alunite during World War I and some 12,000 tons of replacement type alunite were processed during World War II. Large reserves in many alunite deposits remain, but during 1972 to 1973 interest in alunite for aluminum with recovery of byproducts centers in the west part of Beaver County where large bodies of altered rock or replacement type alunite occur in favorable topographic situations.

INTRODUCTION

Closure of the Tooele lead smelter in 1971 and reduction of lead and zinc smelter capacity in the west United States led to the shutdown of such mills as the Midvale and of mines tributary to the mills. Because the lead-zinc mining industry is a vital segment of Utah's raw materials industry, Governor Calvin L. Rampton requested its study by the State Board of Higher Education; funds were requested from the Four Corners Commission to support an in-depth report by the Utah Geological and Mineralogical Survey covering potential lead and zinc resources, a production projection for Utah, and evaluation of the total mineral potential of Piute County and the adjoining mineralized area in Beaver, Sevier and Garfield counties. The Piute County report is based on published records and unpublished material loaned by the U. S. Geological Survey (USGS), which is on file at the Utah Geological and Mineralogical Survey (UGMS), with mine maps made by the writer and his assistants (1971 and 1972) and data derived from field checks. The location of the Piute County area in that part of the Four Corners region in Utah and in the county planning areas is shown in figure 1.

The area of study is bounded loosely on the west by Interstate 15 in Beaver County, on the north by State Highway 13 along Clear Creek in Sevier County and thence through Monroe across the north end of Sevier Plateau to Grass Valley near Burrville, on the east along Grass Valley to Coyote Gulch in Garfield County, and on the south, slightly south of the Garfield County boundary. The Tushar Mountains which rise to 12,173 feet or about 6,300 feet above the valleys on the east and west sides contain most of the mineral deposits mined in the past. The Sevier Plateau between the Sevier and Grass valleys rises to 11,227 feet in Monroe Peak or more than a mile above central Sevier Valley.

The Marysvale region encompasses the central and thickest part of a volcanic pile which dominates the High Plateaus of south central Utah and the

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adjoining part of the Great Basin. The volcanic cover thins outward, especially to the north where underlying sedimentary rocks are exposed. Recent isotopic age dating indicates that most of the volcanic pile accumulated in Oligocene time followed by a somewhat more restricted accumulation in the Miocene. In the Great Basin near the Marysvale region, volcanism continued into post-Lake Bonneville (Holocene) time. Many small intrusive bodies of quartz monzonite penetrate the lower part of the volcanic sequence. Exposures of pre-volcanic rocks (early Tertiary, Mesozoic and Paleozoic) are limited to the east front of the Tushar Mountains southwest of Marysvale and the vicinity of Antimony in Grass Valley.

Although most of the mineral deposits are in volcanic rocks, the most productive mine, the Deer Trail, is in the Permian Toroweap Formation. The precious and base metal deposits are in the older volcanics or in intrusive rocks or sedimentary rocks older than the volcanics. Deposits of uranium, sulfur, clay and some fluorspar occurrences are in or closely associated with the Miocene and later volcanics. Alunite occurs almost entirely in the older volcanics, quicksilver in Permian limestone and antimony as pods and disseminated grains in Paleocene conglomerate associated with volcanic breccias.

Little was written concerning the Marysvale region in the early days of mining and exploration activity. The geology was mapped in reconnaissance and described by Dutton (1880); Butler and Gale (1912b) of the U. S. Geological Survey made a reconnaissance study and recorded the discovery of vein alunite southwest of Marysvale. World War I delayed publication of the comprehensive report (Butler and others, 1920). Loughlin (1915) noted an increase in alunite discoveries. During World War I, alunite was prospected for and developed in three vein mines; the Mineral Products mine of Armour and Co. was the main producer.

The research of Arthur Fleischer, of Kalunite, Inc., designed to develop a process for separating the constituents of alunite, led to mapping of all the area containing alunite deposits by the U. S. Geological Survey. The writer was party chief. Field work began in 1936 and continued to 1938 when it was interrupted by assignment to the Strategic Minerals program. Preliminary reports on the geology and alunite deposits were published. During World War II when the bauxite imports were interrupted, the War Production Board authorized the construction of a processing plant in Salt Lake City employing the Kalunite process and a program directed by the U. S. Bureau of Mines (USBM) and the U. S. Geological Survey was undertaken to drill major alunite deposits. The USGS mapped four 15-minute quadrangles and part of the Beaver quadrangle as well as the individual deposits and the USBM issued a report on the drilling program. Alunitized altered rock from the White Horse open-pit mine was processed at the Kalunite plant at Salt Lake City and the aluminum oxide produced was sent to the metal plants for reduction. The resumption of bauxite imports, however, brought about closure of the mine and plant.

The discovery of uranium in the Antelope Range north of Marysvale in 1949 by P. Seegmiller, R. Smith and L. Anderson with the establishment of the Atomic Energy Commission's (AEC) buying station in 1950 stimulated prospecting and mine development. With the support of the AEC, P. F. Kerr, Columbia University, New York, and a group of graduate students undertook a thorough study of the uranium mineralization and mapped the central uranium area in detail. The results of the study were published in 1957. El-Mahdy (1966) reported on the alteration associated with uranium.

Pat Henry acquired control of the Deer Trail mine and in 1945 started a long adit some 600 feet below the workings of the old mine. In 1953 the property was leased to Arundel Mining Co. and the adit was extended. The continuation of the previously mined oxidized Deer Trail ore body proved to be primary lead and zinc sulfide ore containing silver and variable amounts of gold. It was mined until closure of the Tooele lead smelter and the Midvale mill forced shutdown of the mine in November 1971. Q. F. Treseder, geologist and manager of the Arundel Mining Co., is preparing a comprehensive report on the Deer Trail mine for publication by Utah Geological and Mineralogical Survey (publication in 1973) so only minimal information on the Deer Trail is presented here.

CONCLUSIONS, EVALUATIONS AND RECOMMENDATIONS

(1) The mineralized area of Piute County and adjoining areas is the eastward continuation and terminus of the mineral belt extending westward through Beaver County into the Pioche region of Nevada. The rock types and structures are favorable hosts for metallic mineral deposition and several igneous intrusive bodies indicate that the Marysvale area is a center of major igneous activity, generally considered a source or pathway of mineralizing solutions in or near the Great Basin.

(2) The alteration, which produced the replacement alunite deposits in the older or Bullion Canyon Volcanics, was active in many centers distributed over a

wide area. The rhyolitic ignimbrite of the Mt. Belknap Group was altered, but with the exception of uranium and clay minerals, no concentrations are associated.

(3) No large ore bodies have been found yet. The largest, the Deer Trail ore body, is a long ribbon which follows the plunging crest of an anticline in Permian rocks for some 3,500 feet and turns down the west flank. The upper part is thoroughly weathered and was valuable for gold and silver which was mined. The lower part is valuable for lead, zinc and minor gold and silver content. The weathered part of the Annie Laurie quartz-carbonate vein yielded considerable gold, but the low-grade ore in the unweathered part has discouraged mining in the past. The quartz veins of Bullion and Cottonwood canyons are impressive in size and extent, but the ore shoots have been small and disappointingly low grade.

(4) The Permian Toroweap Formation in which the Deer Trail ore body lies also has proved favorable to mineralization in the Milford area in Beaver County and may contain other ore bodies in the Marysvale region. The area of outcrop is only a few hundred feet long and the great thickness of overlying formations discourages drilling. The ore zone was prospected in the lower workings of the Deer Trail, but no new ore bodies were located.

(5) The replacement alunite deposits contain an estimated aggregate of 3,750,000 tons of material containing 19 percent alumina. Over 10 million tons averaging less than 35 percent alunite also have been estimated. Altered rock in west Beaver County, although averaging 15 percent alumina, is a continuous body in the upper part of a ridge and is more favorable for many millions of tons. Nevertheless, altered rock from several properties in the Marysvale area could be mined and blended to yield satisfactory feed for separation and recovery of potash, aluminum and sulfur.

(6) The quicksilver replacement deposits in limestone are worked out. Whether drilling on the same horizon would reveal other ore bodies is not known. As the formation dips into the mountain, the thickness of cover increases rapidly so that deep drilling would be necessary to locate more ore.

(7) The known uranium veins were worked to the economic limit and the mines were closed down. A firm commitment for the construction of nuclear power plants and a steady market for uranium are necessary before a vigorous campaign to find more uranium is justified.

(8) The iron deposits in the Antelope Range north of Marysvale are of two types: a contact deposit of magnetite and a body of ochre containing a bed of manganese oxide. The body of ochre was essentially mined out and the contact deposit is too small to be of commercial interest.

(9) The distribution of stibnite in Garfield County is spotty, but widespread. A mining and treatment procedure may be developed to permit its utilization.

(10) Mining of rock with a variable but adequate clay content has developed in the past 5 years. Altered rhyolitic tuff and ignimbrite on Mill Creek, south of Clear Creek on the north side of the Tushar Mountains, and altered latite on the east side of the Sevier Plateau above Grass Valley near Greenwich should provide blending material in the years to come.

(11) Sulfur has been mined intermittently for many years in the vicinity of Cove Fort. Estimates of material remaining which contains more than 20 percent sulfur range from 2 to 4 million tons. Price and demand will determine if mining is resumed.

(12) Small fluorspar occurrences have been prospected, particularly in the drainage of Beaver Creek near Marysvale. Further prospecting may reveal a minable deposit. Market conditions for fluorspar should be favorable.

(13) Corundum occurs in blocks of metamorphic rock included in a volcanic breccia in Pine Canyon on the east side of Sevier Plateau above Grass Valley. As such it remains a mineral curiosity rather than a commercial resource.

(14) It is recommended that the area of sedimentary rocks between Bullion Canyon and Gold Gulch on the Deer Trail Mountain front be mapped at a scale of 1 inch = 2,000 feet on a new topographic base and that the stratigraphy and structure be determined in detail. This may lead to drilling to locate other ore bodies having the metal content and geologic characteristics of the Deer Trail ore body.

(15) It is recommended that the area including the Annie Laurie and Sevier mines be mapped carefully as a basis for drilling and sampling of both the veins and associated altered rock for small but minable gold content at high gold prices.

(16) It is recommended that the search for fluorspar be intensified throughout the area.

(17) It is recommended that the clay deposits be mapped, sampled and tested for uses that have a higher value.

GEOLOGY

Regional Features

The Marysvale region is in the south central High Plateaus, a part of the Colorado Plateaus adjacent and transitional to the Great Basin (figure 2) on the west. The High Plateaus physiographic subprovince, 200 miles long and nearly 50 miles average width (maximum 80 miles wide), lies between the route of the Rio Grande Railroad at Soldier Summit on the north and the vicinity of Cedar City on the south. The average trend is N. 30° E., but changes to north in the Marysvale area. The High Plateaus terminate against the Wasatch Mountains on the north, a portion of the Middle Rocky Mountains physiographic province, and against the south margin of the Markagunt Plateau on the south. The east border facing the Canyonlands subprovince of the Colorado Plateaus is marked by a persistent erosional scarp. The west border with the Great Basin is drawn along the base of the slope descending from the high summit areas. At the north end along the Gunnison Plateau, the slope is abrupt and marked by recent fault scarps; at the south end also, near Cedar City and Parowan, the slope is abrupt. In the central portion the plateaus tend to slope into the Great Basin and to have projecting salients so local boundaries must be drawn arbitrarily.

The dominant feature of the High Plateaus is their height above adjacent surfaces; the summit levels of the Canyonlands to the east are generally 5,000 to 6,000 feet lower. The High Plateaus rise abruptly to 10,000 feet in the Wasatch Plateau and to 11,000 feet in the Aquarius Plateau (Boulder Mountain) and in the remnant preserved in Thousand Lake Mountain. The Paunsaugunt Plateau, which terminates in Bryce Canyon National Park, rises to altitudes near 9,000 feet. At the south end, the Markagunt rises to more than 9,000 feet and, in the Marysvale region, the Sevier and Fishlake plateaus attain altitudes of 11,000 feet and the Tushar peaks, 12,000 feet. The Pavant Range reaches 10,000 feet, but the smaller Valley Mountains and Gunnison Plateau or San Pitch Mountains reach 8,000 feet. The High Plateaus are broken by longitudinal, tectonically controlled valleys drained by Sevier River and its tributaries (figure 3). The valleys are usually 3 to 7 miles wide, but may be interrupted by cross structures or may contain parallel ridges of underlying rocks. The altitudes of the valleys range from 5,100 feet, where the Sevier River enters the Great Basin, to 7,000 feet in the upper reaches in the Markagunt Plateau. Sanpete Valley is mostly between 5,500 and 5,800 feet and Grass Valley between 6,300 and 7,000 feet.

The High Plateaus differ from the Canyonlands in having deep longitudinal tectonic valleys, and from the Great Basin, in which the mountain ranges commonly are separated by 12-mile expanses of desert, in having six times the width of upland as valley in a typical section. Hunt (1956) did not include the Tushar, Pavant, Valley and Gunnison plateau units in the High Plateaus. The writer feels that the original assignment of Dutton (1880), clarified and followed by Fenneman, Callaghan and Thornbury (1947, p. 27-49), is valid and should be continued.

Because of their greater altitude and broad expanse of upland, the High Plateaus receive more precipitation than the deserts to the west or the low Canyonlands to the east; large areas are forested, mountain meadows are widespread and permanent streams flow through deep canyons onto the floors of the longitudinal valleys (figures 4 to 10). Above 10,000 feet, uplands produced glaciers during the Pleistocene, especially on the northerly and easterly slopes or heads of valleys. In the Tushar Mountains glaciers moved down the valleys to a minimum altitude of 7,300 feet. Some lakes occupy basins abandoned by glaciers, but many lakes such as Puffer Lake in the Tushar Mountains were trapped by landslides.

Sedimentary rocks of Tertiary age dominate the north half of the High Plateaus (figure 11). Older rocks are exposed in valleys where erosion has cut deeply or where rocks normally under younger cover are elevated. In the Marysvale area and adjoining areas to the east and south, sedimentary rocks older than the volcanics are confined to Deer Trail Mountain near Marysvale and the Antimony area. Volcanic rocks, which extend across the Great Basin into Nevada, especially in a southwesterly direction, have their greatest thickness in this area, thinning north and south.

The High Plateaus structure is complex. Pre-Tertiary sedimentary rocks were thrust from the west, folded and faulted. In the west margin of the Pavant Range, early Paleozoic rocks are thrust over Jurassic rocks. A conglomerate (Price River Formation, late Upper Cretaceous age) is deposited on an erosion surface that cuts across the thrust. At Marysvale the great thickness of Cretaceous rocks and Tertiary sediments is absent and volcanics rest directly on Jurassic rocks or on a thin intervening conglomerate. Along the east and south sides, typical plateau structures of the Canyonlands project under the High Plateaus although the anticlinal structure of the Waterpocket Fold of Capitol Reef National Park curves westward under the High Plateaus. Thus beneath the Tertiary sedimentary and volcanic cover, the complex structure of the older processes in the Great Basin changes to the generally less complex structure of the Colorado Plateaus.

The configuration of ranges and valleys in the Great Basin is determined by basin and range faulting.

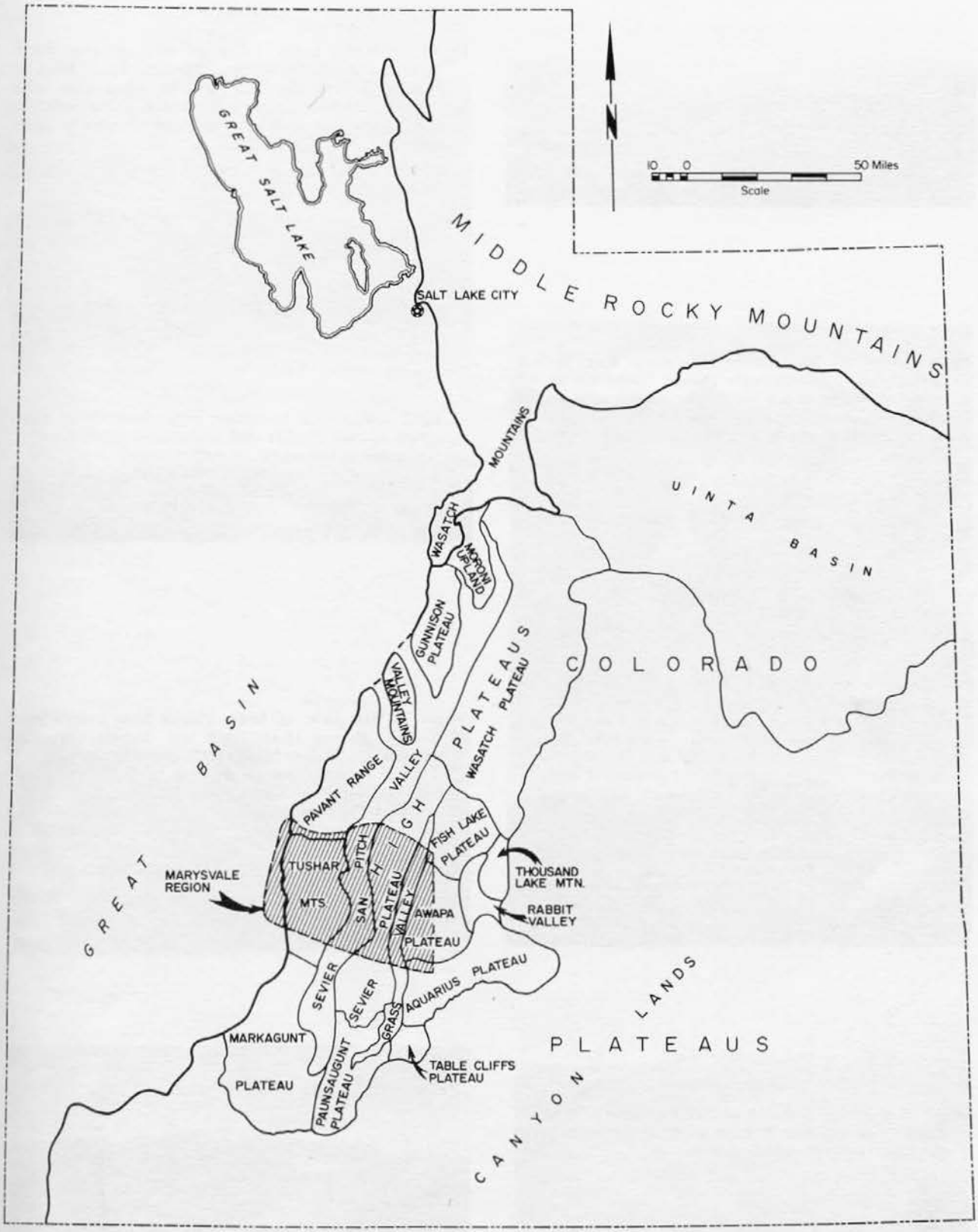

Figure 2. Outline map of Utah showing relation of Marysvale region, Piute County, and parts of adjacent counties to major physical divisions of Utah and minor units of the High Plateaus (modified from Callaghan, 1947, plate 4).

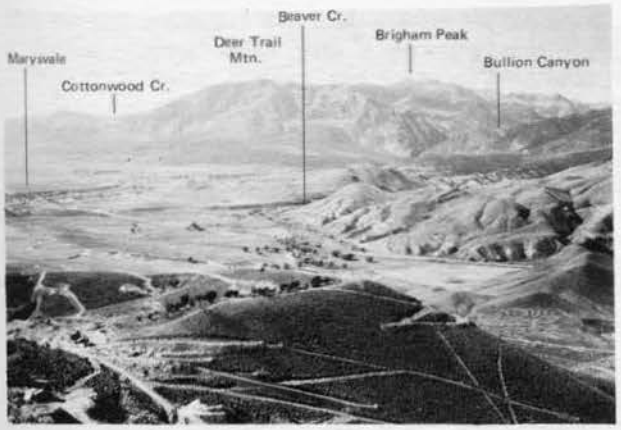

Figure 7. Deer Trail Mountain (10,950 feet) and high part of Tushar Mountains (12,273 feet) from uranium mine area in Antelope Range. Sevier River enters Marysvale Canyon (5,830 feet) at extreme right. Marysvale in middle distance at extreme left.

Figure 8. Glaciated upper reaches of Cottonwood Creek in Tushar Mountains. Delano Peak (12,173 feet) on skyline at left center. Quartzite (Navajo Sandstone) in valley bottom in center. Lateral moraine at lower right.

Figure 9. View northwest across upper part of Bullion Canyon from L&N mine. Lower 2,000 feet of Bullion Canyon Volcanics in middle ground; remnants of Delano Peak Latite Member at top of canyon wall. Mt. Baldy (left) and Mt. Belknap, both consisting of rhyolite, on skyline (see figure 13).

Figure 10. Upland of Sevier Plateau northwest of Greenwich.

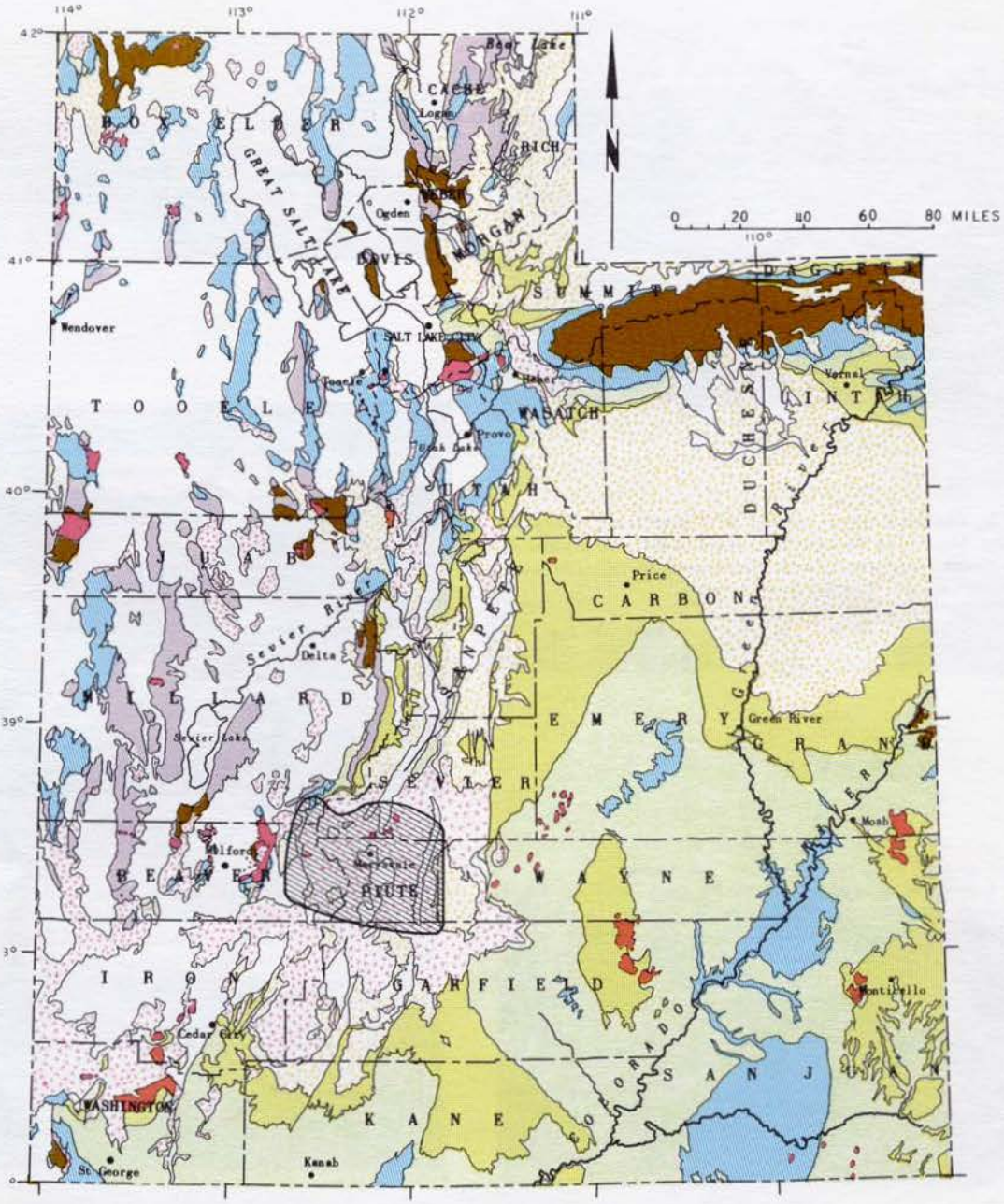

Figure 11. Outline map showing location of Marysvale region and distribution of major igneous and sedimentary units of Utah (modified Utah Geological and Mineralogical Survey Map 23).

The Tertiary sediments and volcanics are broken by a system of normal faults with a generally north to northeasterly trend; flexures and folds are associated with many of the faults. The major valleys are, for the most part, determined by opposing faults so that the valley block is depressed below the plateau blocks on either side. That the valley blocks are not depressed uniformly is shown in the Marysvale area where the cross structure of the Antelope Range stands high and the volcanic units dip northerly on the north side and southerly on the south side. The plateau blocks also differ; the Tushar block and the Pavant block are separated by the Clear Creek synclinal downwarp which plunges to the east and is cut off by the faults on the west side at the Central Sevier Valley. Basin and range type faulting is not confined to the valley margins, but occurs within the plateaus as exemplified by Joes Valley in the Wasatch Plateau. Recent movement on frontal faults is shown along the west side of the Gunnison Plateau and the east side of the Pavant adjacent to Round Valley. In the Wasatch Plateau, glacial moraines reportedly are displaced by recent fault movements. A strong earthquake occurred at Elsinore on the west side of Central Sevier Valley in 1921 and subsequent shocks have been reported.

Stratigraphic Sequence

Pre-volcanic Sedimentary Rocks

Volcanic rocks dominate the Marysvale region as shown by the geological map (plate 1) but the small exposure of upper Paleozoic and lower Mesozoic formations on the east face of the Tushar Mountains (figure 11) contains the area's most productive mine, the Deer Trail. The outcrop area occupies the steep front of the Tushar Mountains from California Gulch on the northwest to Tenmile Creek on the southeast, a distance of 7½ miles, and extends westward up Cottonwood and Bullion canyons for 3½ miles. An oil well test drilled in Kingston Canyon in sec. 30, T. 30 S., R. 2 W., 1.2 miles west of Otter Creek Reservoir, reached the top of the Paleozoic section at 1,550 feet and was continued into the Cambrian Tapeats Sandstone at a total depth of 7,925 feet. The upper part of the well penetrated 670 feet of volcanics, 590 feet of Tertiary sediments designated as Wasatch and 290 feet of Moenkopi. Tertiary sediments called Flagstaff, which contain the antimony deposits, are exposed in Antimony Canyon and in the next canyon to the north in T. 30 and 31 S., R. 1 W., southeast of Otter Creek Reservoir. The stratigraphic sequence used in this report and derived from many sources is given in figure 12.

Workers in the Marysvale area have interpreted and correlated the stratigraphic section with varying results. Dutton (1880, p. 184) found the fossil, *Pentacrinus asteriscus,* which occurs in limestone overlying thick quartzite, and called the entire section Jurassic. Butler and others (1920, p. 538) collected more fossils from the same limestone, but did not estimate ages. Eardley and Beutner (1934, figure 1, plate VI) represent the exposure as Jurassic sandstone. Callaghan (1938, p. 98) noted the pre-Tertiary rocks and (1939a, p. 440) presented a diagrammatic section showing Coconino (?) at the base, Kaibab, Triassic marine facies followed by continental Moenkopi-Ankarah, Chinle, Navajo Sandstone (quartzite) and Carmel Shale and Limestone. Callaghan and Parker (1962a) represented the lower part of the section as Kaibab, including the quartzite at the base which they suggested might be Coconino. They pointed out the lower marine and the upper nonmarine phases of the Moenkopi and noted the Shinarump Sandstone between Moenkopi and Chinle and the massive quartzite equivalent to the Navajo Sandstone. At Spieker's suggestion (personal communication), they brought the term Arapien southward to include the sedimentary rocks over the Navajo and divided them into the Twelvemile Canyon and Twist Gulch members. The Twelvemile Canyon consists of 1,000 feet of limestone and shale with a "Carmel" fauna at the base and 1,145 feet of sandstone and shale. The Twist Gulch, some 700 feet of which remain below Tertiary conglomerate, consists of siltstone, sandstone, shale and lenses of calcareous grit.

Kerr and others (1957, p. 9-14) designate limestone seen in the long adit at the new Deer Trail mine as Carboniferous and the upper section below a thick quartzite as Supai. They call the thick (534 feet) quartzite at the base of the mountain (figure 7) Coconino; it is overlain by a lower unit of interlayered quartzite and carbonate rock and an upper unit of massive fossiliferous limestone. Both are included in the Kaibab with a total thickness of 776 feet. The Moenkopi is made up of 104 feet of shale and silt, 339 feet of fossiliferous limestone designated as Virgin Limestone and 1,430 feet of red to green shale and siltstone. A unit consisting of sandstone grading to quartzite, shale and conglomerate is designated as the Shinarump (member in the text, formation in the geologic section) which has a thickness of 133 feet. The Chinle Formation is 393 feet thick and is overlain by 2,200 feet of massive cross-laminated quartzite assigned to the Navajo Formation (figure 4). The overlying limestone is called Carmel. Kerr (1963, p. 125 and 1968, p. 1026) presents the same section in tabular form.

Brill (1963, p. 320, 322, 323 and 325), in a discussion of Permo-Pennsylvanian stratigraphy, briefly mentions the Marysvale section. He equates the Talisman of Milford, Minersville and Cove Fort with the

Series	Isotopic age (million years)	Stratigraphic units	Thickness (feet)	Structural and erosional events	Alteration	Mineral deposits
Holocene Pleistocene Pliocene		Alluvium Basalt volcanoes Lake Bonneville sediments and glacial deposits Alluvium and terrace gravels		Volcanism Hot springs Erosion and deposition	Siliceous sinter, clay	Sulfur at Cove Fort
				Major dislocations, Basin Range faulting		
		Basalt flows Sevier River Formation and included basalt flows	0-1,000	Volcanism Erosion, deposition and volcanism		
Miocene	13.7-20			Warping, faulting, erosion		
					Kaolinite	Clay at Mill Creek and on Sevier Plateau
					Quartz, kaolinite, montmorillonite, illite, fluorite	Uranium
		Joe Lott Tuff	0-1,000	Central eruption of ashfall tuff and incandescent flow		
		Mt. Belknap Rhyolite	0-2,000	Central ignimbrite eruption, local rhyolite domes and dike intrusions. Probable caldera		
				Erosion		
		Osiris Tuff Dry Hollow Formation Basaltic andesite Latite Tuff	0- 200 0-4,000	Crystal tuffs variably welded, intertonguing latite and basaltic andesite flows, local centers		
				Erosion, probably some warping and faulting		
		Roger Park basaltic breccia	0-2,000	Lava and breccia flows		
					Major thermal interval Quartz, alunite, kaolinite, montmorillonite, illite	Alunite
				Major erosion, some warping and faulting		
Oligocene					Quartz carbonate, sericite, chlorite	Gold, silver, quicksilver, antimony and base metal Fluorspar, manganese
	26.0	Quartz monzonite and related intrusives		Major intrusive activity	Magnetite, orthoclase	Iron
				Faulting, warping		
	29.5-31.5	Bullion Canyon Volcanics	0-3,000	Breccia flows, tuffs, flows		
				Major erosion interval Widespread erosion and deposition		
Paleocene and Eocene		Flagstaff Formation and Tertiary conglomerate	0-1,300	Uplift, erosion		
Cretaceous		Price River Formation	0- 450			
				Major thrust faulting, folding, uplift, faulting and erosion		
Jurassic		Arapien Formation Navajo Sandstone (quartzite)	2,800 2,200			
Triassic		Chinle Formation Shinarump Formation Moenkopi Formation	400 200 1,800			
Permian		Kaibab Formation Toroweap Formation Queantoweap (Talisman) Formation Pakoon Formation	500 200 500 0- 200			
Pennsylvanian		Callville Limestone	1,000			

Summary of estimated stratigraphic thicknesses:

Sedimentary rocks, Callville through Arapien	9,800
Sedimentary rocks below Callville	4,000
Price River and Flagstaff	1,750
Volcanics through Joe Lott Tuff	12,200
Total	27,750

Figure 12. Stratigraphic sequence in the Marysvale region, isotopic ages, structural and erosional events, and rock alteration and mineralization events.

thick quartzite at the base of Deer Trail Mountain and notes that it probably is equivalent to the Cedar Mesa Sandstone of central Utah and the Queantoweap Sandstone of northwest Arizona. He notes that interbedded sandstone and dolomite between the Talisman and the Kaibab Limestone may be Toroweap, but mentions the thinning of the Toroweap to the northwest from its type area in north Arizona.

Kennedy (1963a, p. 21-40 and 1963b, p. 118-124) called the limestone in the new Deer Trail tunnel, Callville of Pennsylvanian age. Noting Brill's assignment to Talisman, he assigned the overlying quartzite to Oquirrh. He described the Toroweap, Kaibab, Moenkopi, Shinarump, Chinle and Navajo much as earlier authors, but differs from Callaghan and Parker (1962a) in assigning the Jurassic beds over the Navajo to the Winsor.

Lessentine (1965, p. 2012) shows the Coconino as pinching out northward at the Utah-Arizona border, not represented in the Marysvale area. He also shows an east limit at the Kaibab to the east of Piute County.

From Antimony Canyon well data (Ritzma, 1972, p. 75), the carbonate rocks underlying the thick quartzite at the base of Deer Trail Mountain are designated Callville, which in the well section is 1,000 feet thick. Because the thick sandstone at Marysvale is quartzite like the Talisman west of Marysvale, rather than sandstone as in the Cedar Mesa to the east, the writer believes that Brill's (1963) designation of Talisman should be used and the overlying interbedded dolomite and quartzite designated as Toroweap. The other terms seem reasonable, but the writer lists the uppermost Jurassic in the section as Arapien.

A thin selvage of conglomerate occurs discontinuously along the contact of the Jurassic rocks and the overlying volcanics. It is mostly less than 50 feet thick and in many places is absent. It consists of limestone and quartzite pebbles and sandy layers. In some places bedding was sufficiently continuous so that the unit is the locus of sills of intrusive latite. In many places, particularly mineralized areas, the conglomerate lies directly on the quartzite (Navajo), but where the Arapien is preserved the conglomerate rests on it. In Bullion Canyon the conglomerate is occasionally preserved, particularly in downfaulted segments of quartzite or in erosional depressions. In the Great Western mine both tuff and conglomerate were found lying on quartzite within a few feet of each other. Callaghan and Parker (1962a) classify the units as Tertiary (?) conglomerate in the Delano Peak quadrangle. Kennedy (1963a, p. 39-40) calls this unit the Tushar Conglomerate and suggests a Cretaceous (?) age. In view of the occurrence of 590 feet of sandstone, limestone and conglomerate designated as Wasatch in the Antimony Canyon well (Ritzma, 1972, p. 75) directly overlying Moenkopi and the designation of conglomeratic beds in Antimony Canyon as Flagstaff (Williams and Hackman, 1971) on the map of the Salina quadrangle, the writer believes that the thin conglomerate is of lower Tertiary age, that it represents a thin cover deposited over exposures of early Mesozoic formations and was itself eroded before deposition of the volcanic rocks.

Volcanic and Intrusive Rocks

Dutton (1880, p. 187) recognized three eruptive epochs separated by periods of cessation of volcanic activity and accompanying erosion; subsequent workers more clearly defined the units. Callaghan (1938, p. 98) found that gold, silver and base metal veins–most of the alunite deposits and intrusive bodies of quartz monzonite–were restricted to pre-volcanic rocks and to a lower group of volcanic rocks which he (1939a, p. 441) designated the Bullion Canyon Volcanics (plate 1 and figure 12). No definite age could be assigned so the Bullion Canyon was then called Earlier Tertiary to distinguish it from subsequent units called Later Tertiary. The Bullion Canyon is composed of many variable interfingered and interlayered flow and fragmental units. Mapping of individual flows or fragmented masses was impractical at the scale required. One large and readily recognized latite unit that makes up much of the cliff faces along the summit area in the vicinity of Delano Peak was mapped separately as the Delano Peak Latite. Kerr and others (1957, plate 12) mapped at publication scale of slightly less than 1,000 feet to the inch and distinguished individual units and variations in the uranium area northeast of Marysvale.

The group designated Later Tertiary Volcanics (Callaghan, 1939a, p. 446-450) was divided more readily into mappable units (plate 1 and figure 12). A dominantly fragmental unit called Rogers Park Basaltic Breccia is prominent in the vicinity of Junction and Circleville. The widespread Dry Hollow Latite overlies the Bullion Canyon Volcanics and the Rogers Park (figure 5). It is characterized by latite flows and tuff beds, and in the north, especially in the Sevier Plateau near Monroe, is dominated by basalt or basaltic andesite. It is followed by a dominantly rhyolitic unit, the Mt. Belknap, which forms the high peaks in the summit area (figures 9 and 13) where eruptive units are not readily differentiated; outward from the center, a reddish ignimbrite-welded fragmental unit, the Red Rhyolite, is distinguished as well as Gray Rhyolite flows. The great pile of fragmental material at Mt. Belknap (figure 13) and the Red Rhyolite probably were erupted from a large vent or caldera in the area of Mt. Belknap, but the Gray Rhyolite may have erupted from other centers as well, notably in the Antelope Range. The Mt. Belknap is succeeded by the Joe Lott

Figure 13. Mt. Belknap Rhyolite in Mt. Belknap (right).

Figure 14. Columnar structure in Joe Lott Tuff at north side of Clear Creek Canyon.

Tuff (figures 14 and 15), a variably welded rhyolite tuff with gray rhyolite fragments which probably was erupted from the Mt. Belknap center as a final phase. It is more widespread to the north, east and south than the Red Rhyolite, but is mostly restricted to the Tushar Mountains and the Sevier Valley. Not until uranium veins were discovered in Red Rhyolite and in underlying quartz monzonite and clay deposits were explored in rhyolite tuff and in Dry Hollow Latite were mineral deposits found in the Later Tertiary rocks. Altered rhyolite containing alunite northeast of Beaver is assumed to belong to the Later Tertiary volcanics.

At the cessation of the Later Tertiary volcanism the surface undoubtedly was irregular and marked by many basins which were filled by debris eroded from higher elevations. The resulting formation was named the Sevier River (figure 15; Callaghan, 1938, p. 101). The sedimentary materials commonly are poorly sorted and contain abundant rock fragments. Near Marysvale exposures contain abundant quartzite fragments. As the Joe Lott Tuff is commonly the underlying formation, the adjacent Sevier River Formation is composed for the most part of this material. Basaltic lava flows occur on and within the formation. Near the confluence of Clear Creek and Sevier River in Sevier County, the pinkish clastic beds of the Sevier River Formation change to nearly white lacustrine beds containing fossil diatoms, indicating that lake basins existed at the time. As the Sevier River Formation was the last deposited in the Tertiary succession, it is preserved only in protected basins such as Beaver River and Clear Creek, along the valley of Sevier River (Carpenter and others, 1967, p. 21-22; Young and Carpenter, 1965, p. 20), in the valley of the East Fork, and Grass Valley (Williams and Hackman, 1971). No hypogene mineralization is recognized in the Sevier River Formation. It is not known to overlie directly uranium veins, but no primary uranium occurrences are noted in it. The Sevier River Formation is younger than the uranium mineralization which Kerr (1963, p. 1041) dates as 10 to 13 million years. On the basis of contained diatoms, the age is late Pliocene or early Pleistocene (Callaghan, 1938, p. 101).

A belt of igneous intrusive quartz monzonite rocks extends across the Tushar Mountains and Antelope Range into the Sevier Plateau, southeast of Monroe and westward through much of Beaver County and into Nevada. The intrusives are confined to the Bullion Canyon Volcanics except for a small dike in the Permian Toroweap in the Deer Trail mine and a pipe or small stock in Moenkopi just south of the mouth of Bullion Canyon. The largest outcrop in the Antelope Range, 3 miles north of Marysvale, is 1.5 miles wide north-south and 3.7 miles long east-west, if the exposed areas are connected beneath a covered interval. As mapped and described in detail by Kerr and others (1957, p. 37-45), this intrusive, although consisting mainly of quartz monzonite, contains quartz monzonite porphyry and granite-like material. Rafted blocks of quartzite ranging from a few feet to as much as 300 feet long occur near the borders of the intrusive; shapes range from nearly circular cross sections to long, thin tabular bodies. Small bodies tend to be porphyritic with fine-grained groundmass. The body south of the mouth of Bullion Canyon contains inclusions of earlier formed igneous types as well as fragments of sedimentary rock. Adjacent shale and siltstone are hardened.

The large intrusive masses, particularly the large body in the Antelope Range, modified the adjacent latite flows and breccias by introducing potash, silica and iron; the original plagioclase of the volcanic rock is altered to orthoclase, ferromagnesian phenocrysts to aggregates of magnetite and biotite, and the groundmass is largely silicified. The rocks change to a pinkish color where orthoclase is dominant, to black where

Figure 15. Steeply inclined Joe Lott Tuff at left and intricately eroded Sevier River Formation at right in south part of Clear Creek downwarp.

magnetite is dominant and to green where epidote or chlorite is abundant. A body of magnetite occurs at the south side of the Antelope Range intrusive and altered rock grades into unaltered phases. Aside from magnetite, no mineral deposits formed as a result of the igneous intrusion. Quartz veins with sulfide minerals cut some of the intrusive bodies, but ore-bearing materials are not noticeably clustered about exposed intrusions. The Sevier quartz vein at Kimberly is associated with a group of intrusions, but no intrusive outcrops are known to occur with the clusters of veins in Bullion and Cottonwood canyons. The Antelope Range intrusive was eroded and capped with the Red Rhyolite or ignimbrite prior to formation of the uranium veins which penetrate the intrusive and rhyolite.

The ages of the igneous rock groups are indicated by isotopic analysis (figure 12). According to Bassett and others (1963, p. 217) the isotopic age of the Bullion Canyon is approximately 29.5 my, the quartz monzonite intrusives range from 23.6 to 26.0 my, the Mt. Belknap rocks from 13.7 to 20.0 my, and the uranium ore, 13 my. Kerr (1963, p. 1041) lists age determinations of the pitchblende as 10 to 13 my indicating an early Pliocene or latest Miocene age. According to the Holmes (1960) chart, the Bullion Canyon would be Oligocene, the intrusives, latest Oligocene or earliest Miocene, and the Mt. Belknap rocks, Miocene. Accordingly, the Dry Hollow units, latite, tuff and basalt, which intervene between the unconformity over the Bullion Canyon and the Mt. Belknap rocks, would be Miocene. The Sevier River Formation would be younger than the primary uranium mineralization. Although radioactive opal was noted in a fault, Malloy and Kerr (1962, p. 233) give no evidence of primary uranium mineralization in the Sevier River Formation which would place it in the Pliocene. Lohman's examination of diatomaceous samples gave an age of late Pliocene or earliest Pleistocene (Callaghan, 1938, p. 101). Without fossils or isotopic age determinations, Callaghan and Parker (1962a) assigned a Miocene (?) age to the Bullion Canyon Volcanics and a Pliocene (?) age to the Later Tertiary volcanic rocks.

From the mineral groups present, the iron deposits (magnetite) would have been emplaced at the time of the quartz monzonite intrusion or near the end of the Oligocene. The gold and silver veins, lead-zinc-copper veins, lead-zinc replacement deposits, and probably the quicksilver (mercury selenide) deposits were emplaced closely following the intrusion of quartz monzonite and prior to the erosion period that preceded the extravasation of the Later Tertiary volcanics or latest Oligocene or early Miocene. The vein and replacement alunite mineralization is believed slightly later than the metallic deposition or earliest Miocene. The primary uranium mineralization is later than the Mt. Belknap rocks and latest Miocene or Pliocene. Clay deposits are in Mt. Belknap and Dry Hollow rocks and, therefore, are probably Pliocene; sulfur is probably Pleistocene. The stibnite deposits are in Paleocene sedimentary rocks, but no upward limit has been determined. No definite age can be assigned to the manganese oxide deposits with associated calcite. They could be of late Pliocene age.

Structure

Almost all of the economic minerals in the Marysvale region were introduced subsequent to the formation of the rocks enclosing them. Displacements in the primary layering sequence provide passageways for the ore-bearing solutions or gasses, and folds may trap the solutions, thereby inducing precipitation and concentration. Faults provide lines of weakness or actual openings in the rock for precipitation of ore elements. Structural events critically affect mineralization–a structure favorable to transmission or precipitation of ore elements must be available when the ore elements are.

In the Marysvale area the structural development in the rocks older than the volcanics differs markedly from that in the volcanics. Much of the concealed structure is conjectural because older rocks outcrop only twice in the area and only two oil well tests penetrate the volcanic cover. The older rocks are affected by folding, faulting and thrusting subsequent to their deposition, but they also are affected by folding, tilting, faulting, igneous intrusion and related events evident in the overlying volcanic cover.

The striking feature of the pre-volcanic rocks in the Marysvale region is the absence of the uppermost part of the Jurassic and all of the Cretaceous. In the

Antimony Canyon (Kingston Canyon) well, most of the Triassic and all of the Jurassic also are missing (Ritzma, 1972, p. 80); the thick accumulation of Tertiary sedimentary formations north of the Marysvale area is represented by a conglomerate, mainly less than 100 feet thick, and by 590 feet of conglomerate, sandstone and limestone in the Antimony Canyon well. The area was apparently a structural high prior to the erosion that occurred before the volcanics were accumulated. Butler and others (1920, p. 100, plate XI) called the structural highs "domical uplifts" and their plate XI shows the Beaver Uplift, elongate in an east-west direction projecting into the Marysvale area. Had information from the Antimony Canyon well been available, he doubtless would have extended the Beaver Uplift southeastward toward Antimony. Callaghan and Parker (1962b) noted a marked thinning of the Tertiary and Cretaceous units southwestward in the Pavant Range, and the Cretaceous apparently also thins at the east side of the High Plateaus. It may be assumed that the Beaver Uplift was moving upward for the most part in Cretaceous, Paleocene and Eocene time. The structure and the accompanying disturbance and dislocation of the underlying rocks made it favorable for subsequent igneous extrusion, intrusion and mineralization. The Beaver Uplift is coextensive with the Pioche-Beaver-Tushar mineral belt shown in figure 16.

Because of the westward tilt of formations in the Tushar Mountains into the Beaver Valley, the volcanics cover the pre-volcanic rocks along the west side. North of the Marysvale region in the west side of the Pavant, the pre-volcanic rocks are exposed and exhibit a complex pattern of overfolding and thrusting from the west (Crosby, 1959, p. 1-59; Callaghan and Parker, 1962b; Burchfiel and Hickcox, 1972, p. 60). Thrusting of Paleozoic rocks over the top of the Navajo Sandstone indicates that the incompetent Arapien, an obvious choice for the resolution of forces, was moved eastward to what is now the Sevier Valley where the exposed Arapien exhibits great thickness and a wildly complex compressed structure. This belt of overthrust structures may project beneath the west side of the Tushar, but may curve outward or southwestward into the Great Basin. No comparable thrusting is shown on the Geologic Map of Utah, SW quarter (Hintze, 1963), south of Cove Fort.

Geologic events are tabulated in figure 12. Accumulation of the great pile of the Bullion Canyon Volcanics began in the Oligocene and was followed by the quartz monzonite intrusions. The volcanics were broken by normal faults having for the most part a northerly trend. The faults extended into the underlying sedimentary rocks and many became pathways for the upward movement of solutions or gasses carrying ore elements and loci of mineral deposition. These lines of weakness provided favorable situations for precipitation of ore elements. The anticline in Permian rocks at the Deer Trail mine served as a pathway and a trap for ore solutions and led to the formation of a remarkably long and narrow ribbon-like manto deposit. Subsequent hot spring or solfatara activity brought potash with hot water and formed the alunite deposits in the volcanics. Erosion in places cut down to the upper parts of intrusions, notably in the Antelope Range and in the Gold Mountain district.

With the Miocene began the outpouring of the basaltic volcanics of the Roger Park Basaltic Breccia (Callaghan and Parker, 1962a), which occurs in the southwest part of the region, and of the Dry Hollow latite, tuff and basalt, which thicken to the northeast as basalt increases. The formation of the Mt. Belknap caldera followed, from which rhyolite ignimbrites, flows and ashfall tuffs issued. The Miocene eruptive epoch was followed by faulting and fracturing which provided situations for emplacement of uranium minerals; additional hot spring activity led to formation of clay deposits and minor occurrences of alunite.

Subsequent to the Miocene, the faults responsible for the present configuration of the High Plateaus in the Marysvale region began to form. Basins formed from irregularities of volcanic accumulation, or warping and faulting served as loci for the deposition of the Sevier River Formation. The Sevier River Formation was formed from older rocks eroded from higher areas and deposited in basins that probably were not served by through-flowing streams. Basaltic volcanic eruptions took place along with the filling of the basins.

With uplift and concurrent development of basin and range type faults, relatively narrow grabens permitted the lowering of the graben blocks now drained by the Sevier River and its tributaries. The Tushar Mountains block was tilted westerly while the Sevier Plateau was tilted eastward. The Awapa Plateau (Parker Mountain) and the Pavant Range north of Clear Creek also were tilted eastward. Adjustment between the eastward tilt of the Pavant and the westward tilt of the Tushar was accomplished by the Clear Creek downwarp, an eastward plunging syncline in which Dry Hollow Latite, Joe Lott Tuff and Sevier River Formation are deposited. On the south side, the Joe Lott Tuff and the superincumbent Sevier River Formation were buckled in a sharp anticlinal fold which further dislocated as a thrust fault (figure 15). In the Central Sevier Valley in the vicinity of Richfield, the formations on either side are tilted toward the valley, but nevertheless are broken by bounding faults. At the south end of the valley on the north side of the Antelope Range, the Later Tertiary rocks under the valley fill emerge in a synclinal form and lap up on the older volcanics of the Antelope Range. Elsinore fault on the northwest side of the Central Sevier Valley continues

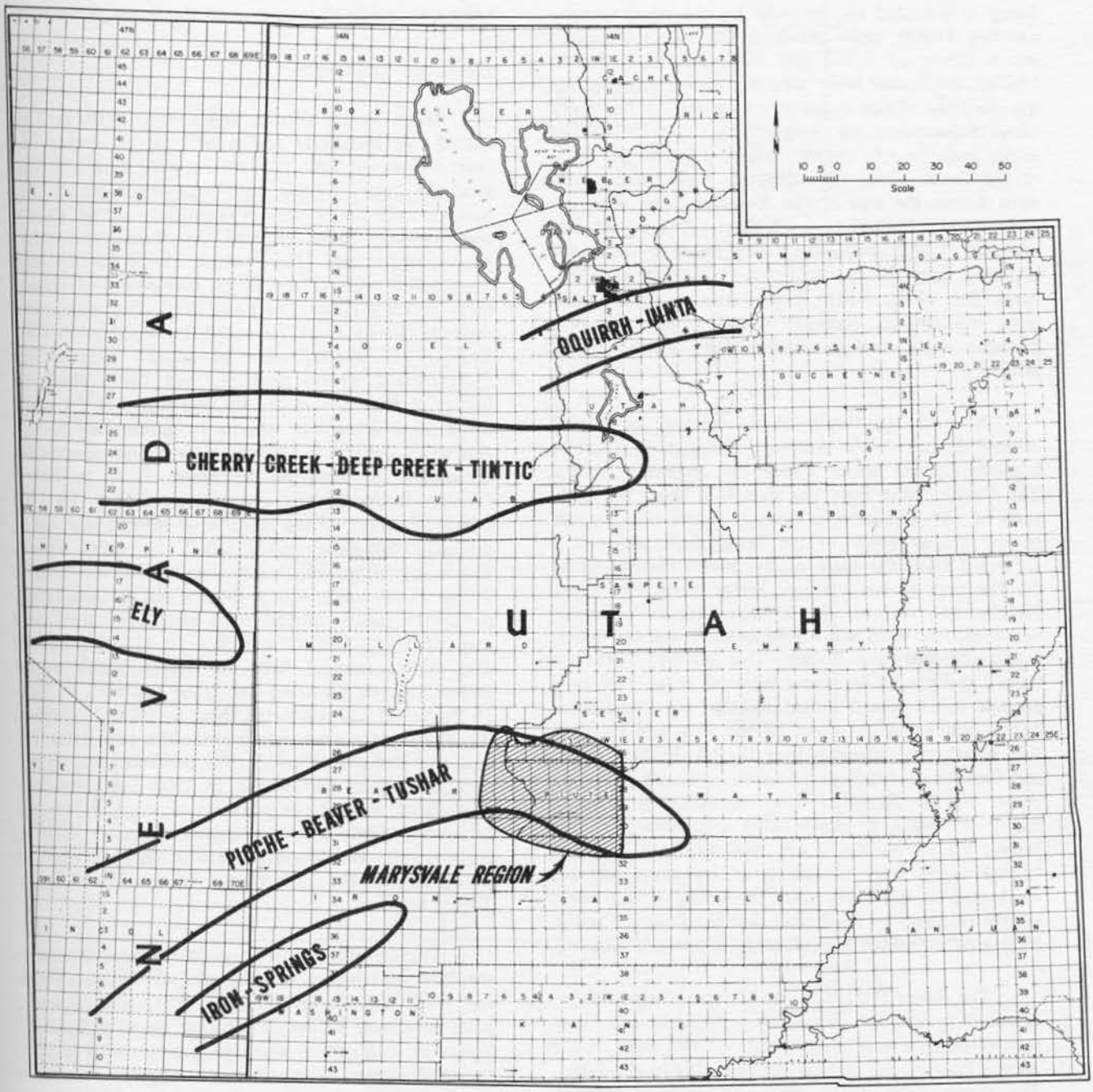

Figure 16. Index map of Utah and eastern Nevada showing mineral belts.

across Clear Creek and fades out in the north face of the Tushar Mountains.

Marysvale Valley on the south side of Antelope Range is bounded on the west by the northwesterly trending Tushar fault, which at Deer Trail Mountain has a throw of 3,500 feet (Callaghan and Parker, 1962a); the Tushar fault fades out to the north against the Antelope Range cross structure and to the south where adjustments are absorbed by other faults. The Sevier fault bounds the east where it marks the front of the Sevier along the Marysvale Valley and northward across the end of the Antelope cross structure and into the Central Sevier Valley. On the west side near the Tushar fault, the valley block is depressed, exposing only the Sevier River Formation and alluvium. East of the Sevier River a succession, beginning with the Bullion Canyon Volcanics and including younger units through Sevier River Formation, is noted.

A most significant small structure containing mineral deposits is the Antelope Range cross structure between Central Sevier Valley and Marysvale Valley. The Tushar fault does not detach it from the main mass of the Tushar, so it extends eastward as an arm of the Tushar block to the Sevier fault where it is separated from the mass of the Sevier Plateau (plate 1). The core of the Antelope Range consists of flows, breccias and tuffs of the Bullion Canyon Volcanics, which dip eastward and northeastward, and the quartz monzonite intrusive bodies. This positive core was eroded sufficiently to expose intrusive rocks. This deep erosion was followed by eruption of the Dry Hollow Latite, which did not cover all the area, and by eruption of rhyolitic materials from the Mt. Belknap center and from local vents, one of which produced a rhyolite dome. As the Antelope Range remained attached to the Tushar mass, it was uplifted with respect to the graben blocks to the north and south so that the younger rocks slope northward on the north side and southward on the south side. The younger rocks were mostly removed by erosion so that the Bullion Canyon Volcanics, intrusives and uranium veins were exposed.

The Sevier Plateau in the Marysvale region slopes eastward toward the Grass Valley. Williams and Hackman (1971) show a fault system on the front of the Awapa Plateau, but not on the west side of the valley. The abrupt face of the valley on the west strongly suggests the presence of concealed faults on the west side also.

The basin and range type faults, which determined the present configuration of the High Plateaus in the Marysvale region, are later than mineralization epochs. With the exception of the sulfur deposits near Cove Fort, no alteration or mineralization, except that associated with hot springs, such as those at Monroe and Joseph, is related to the basin and range type faults. Uplifts have exposed mineralized ground to erosional forces and made it available for prospecting.

MINERAL DEPOSITS

When Butler (Butler and others, 1920, p. 536) visited the Marysvale region in 1911, it already had been prospected and much mining done during the previous 43 years. Alunite had been discovered in 1910 and the only major mineral occurrence not yet located was uranium. Butler grouped the mineral occurrences as gold-silver veins (for example, Annie Laurie), lead-copper-zinc veins (Bully Boy), lead-silver-gold replacement deposits (Deer Trail) and quicksilver replacement deposits (Lucky Boy). He noted the iron deposits (Max Krotki), the alunite veins of Alunite Ridge in the Cottonwood Creek drainage, and the replacement bodies of alunitized rock. He also described the occurrence of antimony as stibnite in sedimentary rock in Antimony Canyon in Garfield County and reported the occurrence of tungsten on North Creek in Beaver County. Butler (Butler and others, 1920, p. 100-105) called attention to the relation of mineral deposits to generally east-west trends which he called uplifts. Exposures of granitoid intrusive bodies also tend to follow these zones which Hilpert and Roberts (1964, p. 29-31) called mineral belts and represented on a map of Utah. Hilpert and Roberts (1964, p. 39-45) also depict mineral belts in Nevada which in the eastern part of the state also trend east-west. In figure 16 the writer has connected these trends and combined the appropriate nomenclature for the two states. Hilpert and Roberts (1964, p. 31) point out that 95 percent of mineral production in Utah has come from these belts. Recent compilations of magnetic intensity in western Utah show anomalous intensities following these trends. The Marysvale area is shown in figure 16 as occupying the eastern end of the Pioche-Beaver-Tushar belt.

The distribution of epigenetic mineral deposits in the Marysvale region and the arbitrary districts enclosing them are shown in plate 2. Concentrations of patented claims in the districts are shown in figure 17. Taken in conjunction with the geologic map (plate 1) the relationships of mineral occurrences to outcrops of the Bullion Canyon Volcanics and to intrusive bodies may be noted. Mineral localities are most concentrated on the west side in Beaver County (Newton mining district), in or near the Bullion (Ohio district) and Cottonwood canyons (Mt. Baldy district) southwest of Marysvale, northwest of Marysvale on the slope into Clear Creek (Gold Mountain district), and in the Antelope Range (Henry district). Scattered deposits occur

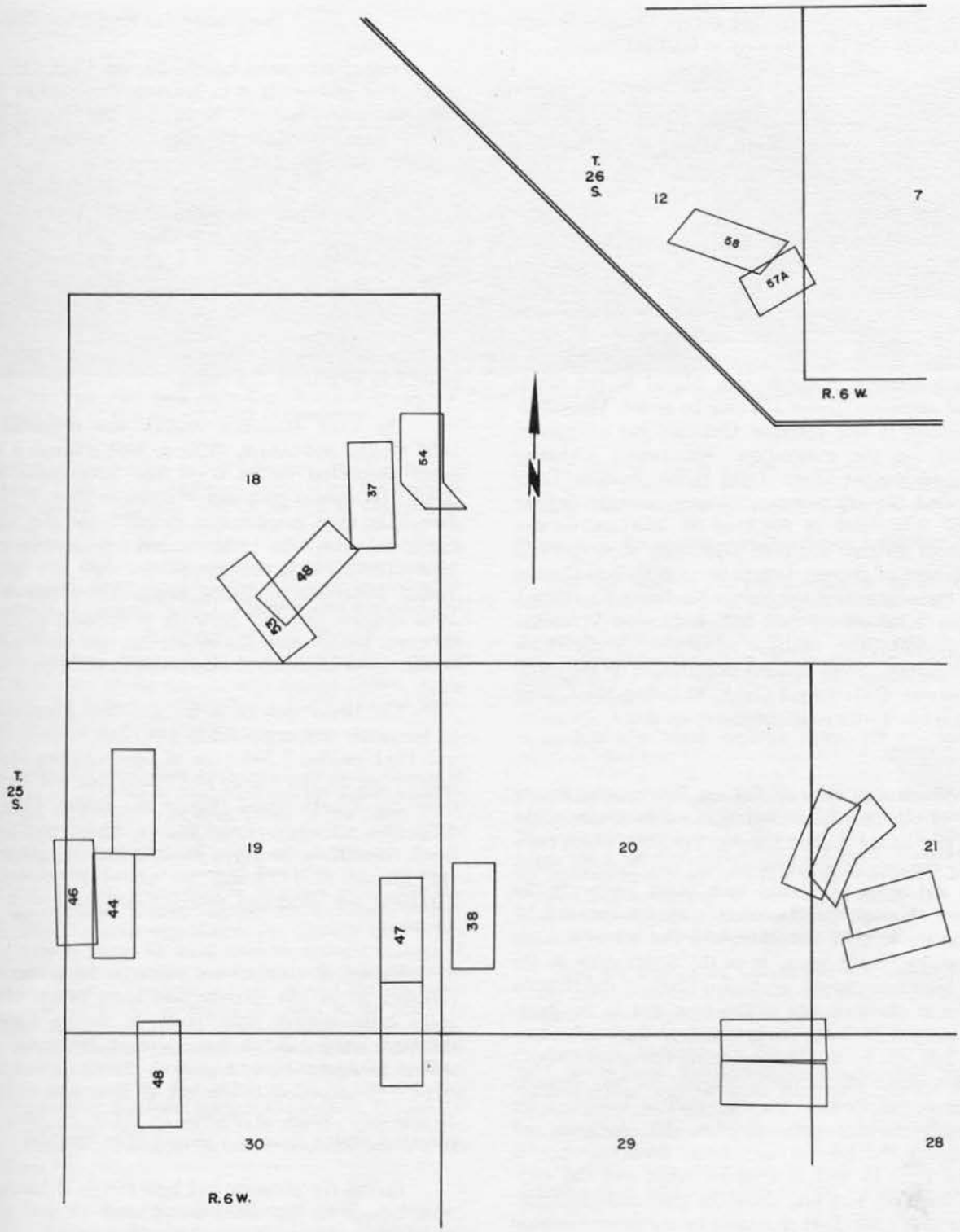

Figure 17. Patented claims and claims surveyed for patent (NP) in the Gordon mining district, Marysvale region (see plate 3 for Gold Mountain, Henry, Ohio and Mt. Baldy mining districts).

near the greater concentrations except the clay in east Piute County and the antimony in Garfield County.

The base and precious metal deposits and almost all the alunite occurrences are limited to the outcrop areas of the Bullion Canyon Volcanics and older rocks (plates 1 and 2). For example, the Gold Mountain district in T. 27 S., R. 5 W. occupies a window in the post-mineral volcanic cover which has been completely eroded in that area; uplift and erosion, therefore, exposed the mineral deposits. The uranium deposits occur in the younger rhyolite and in the older rocks. The clay deposits also occur in the younger rhyolitic and latitic rocks. In addition to horizontal distribution of mineralization, a distribution related to the stratigraphic sequence (figure 12) may be noted. Mineralization occurs in the Talisman Quartzite but of especial interest are the manto-type replacement lead-zinc-silver-gold deposit (Deer Trail) in the Permian Toroweap and the replacement mercury selenide deposit (Lucky Boy), also in the Permian. Workings in the Moenkopi siltstone and shale supposedly show sporadic occurrences of copper. Quartz veins in Bullion Canyon cross the contacts of the Navajo Sandstone (quartzite), Tertiary conglomerate and Bullion Canyon Volcanics. The quartzite also contains veins without significant mineralization. Some mineral occurrences on the south side of the Cottonwood Creek, including the Crystal mine, are in Tertiary conglomerate.

The quartz veins of Bullion Canyon, the alunite veins of Alunite Ridge and many others are in the basal part of the Bullion Canyon Volcanics which commonly consists of well-bedded tuff and breccia. Other veins and areas of altered rock reach higher in the section, although the uppermost part not removed by erosion shows little mineralization. The intrusive rocks are cut by quartz veins, as at the Sevier mine in the Gold Mountain district, on Indian Creek in the Newton district at the west side of the area, and in the Antelope Range. The intrusive in Antelope Range also contains uranium veins which penetrate the much younger rhyolite above the intrusive. Except for clay deposits in the Sevier Plateau, the Dry Hollow Volcanics are singularly free of mineralization. Mt. Belknap red tuffaceous rhyolite or ignimbrite contains clay in altered areas as well as uranium veins, and the overlying Joe Lott Tuff may show the same mineralization. Sulfur near Cove Fort is related to the present erosion surface where hot springs have been active. Sulfur is found in siliceous sinter formed from Price River Conglomerate and in tuff as well as in alluvium. Except where it may be modified by hot spring activity, the Sevier River Formation is not affected by primary mineralization, although some opal has been noted.

Prospecting and Production History

Prospecting spread rapidly through Utah after the state's first mining claim in Bingham Canyon near Salt Lake City was recorded in September 1863 (Butler and others, 1920, p. 118). The Ohio mining district was organized in 1868 (p. 540) after gold was recovered from sand in Pine Creek near the outlet of Bullion Canyon. Camps called Bullion and Webster cities with population of 200 were established sometime in the 1870's. The Mt. Baldy district was organized in 1878 after the discovery of the Deer Trail mine. A brief record of production for 1878 through 1882 shows recovery of 334.9 ounces gold and 32,149 ounces silver. Mercury was noted early and the Lucky Boy claim yielded an estimated 213 flasks.

The Gold Mountain district was organized in 1889 (Butler and others, 1920, p. 540) although it had been prospected before then. The Sevier mine produced 100 ounces gold and 398 ounces silver in 1892. Two mills were in operation in 1895 and the Annie Laurie mill, built in 1899, worked continuously until 1908. The Newton district on the west side of the Tushar Mountains north of Beaver was organized in 1892 and the Rob Roy property produced gold valued between $7,000 and $9,000 in the year ending September 1893 (Butler and others, 1920, p. 543).

The Henry district in the Antelope Range north of Marysvale was organized in 1883 and between 1902 and 1911 yielded 1,598 tons of ore containing $8,583 in gold and 28,316 ounces silver. Iron flux was shipped from the Krotki claims (Butler and others, 1920, p. 543). The antimony of the Coyote district on Coyote Creek (Antimony Creek) in Garfield County reportedly was located in 1879 and ore valued at more than $100,000 was produced within a few years after the discovery.

Numerous claims were surveyed for patent and patented in all the districts and some of the historically early surveys were made in Bullion Canyon. Patented claims and a few surveyed for patent are shown in figure 17 and plate 3. The status of land ownership according to current U. S. Bureau of Land Management maps is shown by plate 4. Areas of patented mining claims are shown as private land.

Claims for precious and base metals undoubtedly were located on the well-exposed veins of "pink spar" on Alunite Ridge (figure 18) by early prospectors. Callaghan (1938, p. 104-109) comments on the history, development and production of alunite:

> In November 1910 Tom Gillen, one of the prospectors in the area, was sufficiently interested in the "pink spar" to send a sample to A. E. Custer, who was then connected with the

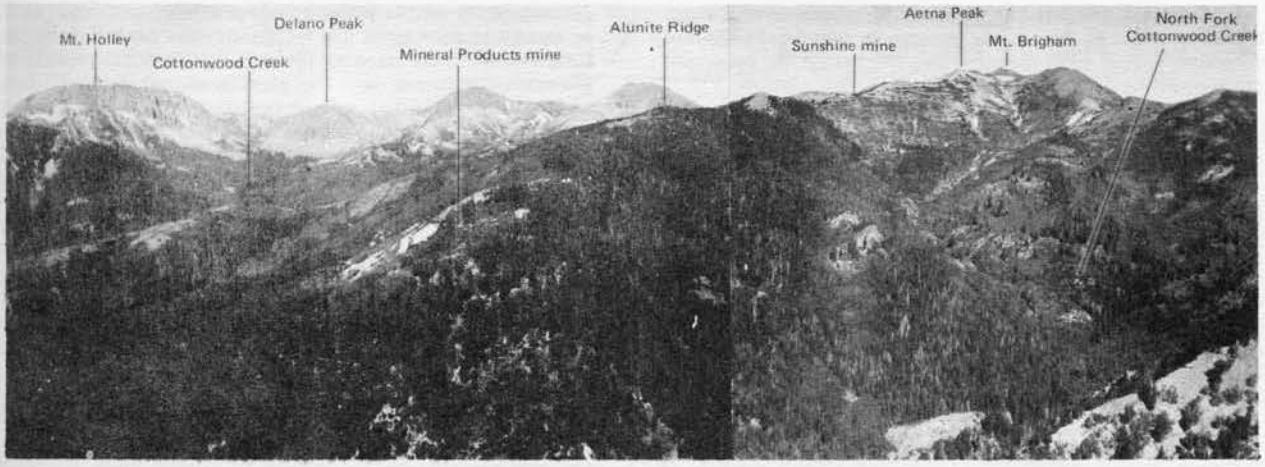

Figure 18. View west from Deer Trail Mountain to Alunite Ridge (center) and crest of Tushar Mountains on skyline. Valley of North Fork of Cottonwood Creek in foreground.

United States assay office in Salt Lake City. This material was forwarded to the Geological Survey, where it was recognized as alunite. Samples were also sent to Howard F. Chappell, an industrial chemist, who recognized the possible value of the material. Custer authorized Gillen to locate as many claims as possible that might contain alunite, with the result that previous locations which had been allowed to lapse were relocated for alunite on January 1, 1911. Chappell soon examined and purchased these claims, which have since been known as the Custer group. He also located contiguous claims within the next 2 years. The Mineral Products Corporation was organized for exploitation of the deposit, with interest divided among Chappell, the Armour Fertilizer Works, and the United States Smelting, Refining and Mining Co.

Little was done until 1915, when the great increase in the price of potash made it apparent that the deposit could be worked commercially. The lower tunnel on the Custer No. 1 claim had reached the vein by 1913, but later explorations were largely confined to an upper tunnel 208 feet higher. Though a lens of alunite about 60 feet wide was exposed on the surface, it soon disappeared in the upper tunnel. This tunnel was continued, however, another lens of alunite reached, and sufficient reserves were blocked out to justify construction of a recovery plant. An aerial tramway having a capacity of 12½ tons an hour was built to take the crude alunite from the mine to a point on Cottonwood Creek about 1,800 feet lower, whence it was hauled in wagons 3½ miles to the mill. The recovery plant, constructed in 1915, was built a short distance east of the mouth of Cottonwood Canyon and 5 miles south of Marysvale. All parts of the plant were in operation by October 19, 1915, and the first shipment of 28 tons averaging 95.39 percent of potassium sulphate was made on October 22, 1915. The initial capacity of the plant was 100 tons of alunite daily, and as much as 25 to 30 tons of potassium sulphate was recovered daily.

Alum has long been obtained from foreign deposits of alunite by heating the alunite to a red heat, leaching the calcines in water, and crystallizing alum (hydrous potassium-aluminum sulphate) from the solution on evaporation. As a result of simple experiments in the laboratory of the United States Geological Survey 92 percent of the available potash present in the alunite was obtained as potassium sulphate by ignition at a higher temperature than red heat and subsequent leaching. Part of the sulphur trioxide and water was driven off by the ignition, and a residue of alumina was left after leaching. A commercial process utilizing this principle was developed and patented by Howard F. Chappell and was the only process used at the plant of the Mineral Products Corporation. The process as finally adopted is described . . .

At the mill the ore was dumped on the ground for storage or directly to a no. 6 gyratory crusher, where it was reduced to 1½-inch size. The crusher discharged to a 50-ton bin which fed a set of 16- by 36-inch rolls crushing to ¼ inch with no provision for return of oversize. The fine ore was elevated to a ¼ inch whip-tap screen with no oversize return, discharging into a 1-ton weighing hopper. The ore was then fed through a 6-inch water-jacketed pipe to a 6- by 130-foot rotary kiln with 9-inch fire-brick lining. The kiln was fired with pulverized coal.

Kiln gases were sent through a brick chamber with one baffle and thence escaped to the air. By means of a damper in the stack the gases could be drawn through two cyclone separators and a bag dust collector of local design. The gases from the cyclones were drawn through a series of air-cooled inverted U tubes to a second pair of cyclones and baggers. The cooled gases from the bagger were drawn back through the outside of the U tubes and heated before escaping to the stack.

The hot calcined ore was elevated to a steel clinker bin, which fed two 20-foot log washers. The discharge from the log washers was elevated to a d-disk Aikens classifier from which the coarse material was sent to waste and the fines and liquor to four Dorr thickeners–28, 32, 34, and 36 feet in diameter by 9 feet in depth. The thickener constituted a countercurrent leaching system, with the liquor from no. 4 tank going to no. 3, from no. 3 to no. 2, from no. 2 to no. 1, and from no. 1 to the evaporator. The thickened pulp was discharged to waste. The solution which contained the potash values was sent to a 12- by 5-foot Kelly filter press or a 48- by 48-inch 60-leaf Schreiber filter press and thence to eight wooden storage tanks 9 by 20 feet.

From these tanks the liquors went to three triple-effect Swenson vacuum evaporators heated by exhaust steam from the power plant. The condensed steam was returned as boiler-feed water. The salts from the evaporator were sent to open square wooden tanks, where the liquor was drained off and returned to the log washers for further leaching. The salts were centrifuged and bagged.

Originally the hot kiln discharge was digested with steam for 40 minutes at 40 pounds pressure in two 10- by 20-foot autoclaves before filter pressing. This overloaded the press, and the practice was abandoned in favor of the log washers.

The filter cake and the discharge from the thickener constituted the raw alumina, which was stored on the surface. A refined product was never made, although this was contemplated. The crude Al_2O_3 was marketed only for experimental purposes.

Slack coal was delivered at the mill for $6.56 per ton. It was stacked in piles on the ground, whence it was taken to a 5- by 50-foot cylindrical dryer, thence by an 18-inch belt conveyor to an 18- by 18-inch roll discharging to an elevator feeding a hopper over two 48-inch pulverizers. From these the coal was blown to the kiln.

Water was obtained from Cottonwood Canyon and delivered through 2,000 feet of redwood pipe at the rate of one-twentieth cubic foot per second.

Numerous difficulties were encountered in the treatment process. Losses during calcination were high, due to (1) incomplete calcination, leaving alum in the discharge, (2) overcalcination, resulting in volatilization losses, and (3) decrepitation and dusting of the ore when suddenly heated.

Excessive water was necessary for complete extraction, thus increasing evaporation costs. The tailings contained a high percentage of moisture, thus carrying considerable K_2SO_4 to waste. Under certain conditions, salts would precipitate in the evaporator tubes and make trouble. Alum and aluminum sulphate corroded the tubes, necessitating frequent replacements.

With several important interruptions, the mine and plant of the Mineral Products Corporation continued in operation from October 1915 to late in 1920. On November 2, 1916, the headhouse and other buildings at the mine burned, with the result that the cables on the tramway had to be replaced. According to a State report, during 1916 the production was 2,772.38 tons, presumably of potassium sulphate (K_2SO_4), the gross income was $610,266, the expenditures were $539,782, and the net return was $70,488. The capacity of the mill was increased to 175 tons of alunite daily, and 250 men were employed. On October 25, 1917, the main building of the plant was burned after an explosion. The rebuilt mill, with capacity increased to 200 tons a day, was in operation in April 1918. The maximum daily production of K_2SO_4 was 40 tons. Early in 1919 the Armour Fertilizer Corporation purchased the interests of the other owners and closed the plant. However, operations were resumed during the summer and continued until late in 1920, though the official closing date was January 1, 1921. Mr. Touroff, who had been mine superintendent since 1917, has remained in charge of the property. The equipment was kept in repair until 1928. A large part, if not all, of the K_2SO_4 produced was shipped to the Armour Fertilizer Works at Jacksonville, Fla.

Though the Mineral Products Corporation was the only well-organized, well-equipped, and successful operator in the region, many other alunite properties were developed to some extent. The large group of claims of the Florence Mining & Milling Co., adjoining the Custer claims of the Mineral Products Corporation on the northwest, had already been located for gold prospecting. Alunite was found along the ridge in a continuation of the zone exposed on the Custer claims, and most of the alunite veins now known had been prospected by 1914. After much delay a calcining plant was built a short distance south of the railroad station at Marysvale and placed in operation in August 1917. Alunite was hauled in wagons from the Sunshine mine to the mill, which had a capacity of 80 tons of alunite a day. The plant produced alunite calcines, which without further refinement were shipped to the Carraleigh Fertilizer & Phosphate Works at Raleigh, N. C. Later a potash plant of 100 tons capacity was built at the mine and completed in October 1918. Though reverberatory furnaces rather than rotary kilns were installed, no potash is known to have been produced. There was little subsequent development.

In 1918 Swift & Co. became interested in the alunite on the Bradburn claims, adjoining the Mineral Products property on the north, put up cabins and compressor, developed a large lens of alunite, and shipped alunite to their plant at Harvey, La.

In the area north of Marysvale the Yellow Jacket group of claims was developed by the American Smelting & Refining Co., and some alunite was shipped to its alum plant, erected in 1918 at Murray, Utah. The Utah Potash Co. took alunitized rock from large quarries on what are now the Marys Lamb and Santa Francis claims. This material was shipped from Vaca station to a plant at Trenton, N. J., where recovery by the Detwiler process was attempted. No production was reported. The Pittsburgh-Utah Potash Co., organized in 1916, constructed 3,600 feet of spur track from Belknap to its property at the mouth of Deer Creek and assembled some second-hand equipment on the ground but never reached the producing stage. The Aluminum-Potash Co. of America in 1919 took over the Copper Butte group of claims on Deer Creek, 2 miles from the railroad, built a camp called Winkelman at the mount of Deer Creek, assembled some equipment, and started the erection of an aerial tramway 9,100 feet long from the quarries to the railroad. The old Florence Mining & Milling Co.'s mill at Marysvale was taken over for experimental purposes, but no appreciable quantity of potash salts is known to have been produced.

The Close In property, which had been prospected by Tom Gillen in 1915, was included with the White Hills property in an operation planned by the Industrial Potash Co. in 1920. Many other properties were explored to a small extent during this period, and small shipments were made for experimental purposes to plants in various parts of the country or to the old Florence Mining & Milling Co.'s mill. Small shipments have been made almost every year up to the present time.

No complete information on output of alunite or of its refined products is available. Mr. Touroff (oral communication) estimates that 250,000 tons of alunite were taken from the mine of the Mineral Products Corporation. . . 12,000 tons of alunite (are estimated) as the product of the Sunshine mine of the Florence Mining & Milling Co. Other properties perhaps yielded a total output of a few thousand tons of alunitic material . . . The output for the last 3 months of 1915 is not given. It was limited to potash salts, as only experimental shipments of the alumina were made. Small lots of this material have recently been shipped for use in copper refineries as a mold wash. The tailings dump at the Mineral Products mill is estimated to contain 45,000 tons of alumina.

It is generally conceded that the cost of producing potash as the sole product of the alunite deposits is too great to permit them to compete with the present low-cost American producers in California, Texas, and New Mexico. Production was maintained only under the stimulus of high prices. The price of K_2SO_4 rose from $48.07 a ton on December 28, 1914, to $140 a ton on March 29, 1915, to $205 a ton on June 28, 1915, and to $440 a ton on January 3, 1916. A

break in price in 1919 caused the initial closing of the plants, but it was found that imports did not enter in large quantity until late in 1920, when high-cost producers were compelled to close. The production table shows that the alunite deposits yielded a maximum of only 7.1 percent of the total potash output in the United States, even before the development of the present large resources. Attempts to make fertilizer in competition with other materials have apparently not been successful. Though the production of metallic aluminum was considered from the beginning of the development of the Marysvale deposits, it is only recently that serious efforts are reported to have been made to produce the metal experimentally. This outlet is regarded by most people as the sole hope of further exploitation of the alunite.

In 1936 Arthur Fleischer, Salt Lake City, was developing the Kalunite process to recover alumina with potash and sulfur byproducts; he obtained alunite from the White Horse deposit, which he controlled. With the onset of World War II and the interruption of bauxite supply from the Caribbean region, a plant utilizing the Kalunite process was constructed at Salt Lake City by the Defense Plant Corp. to obtain alumina. Some 12,000 tons of alunite-bearing altered rock, almost entirely from the White Horse replacement deposit, were mined and treated in the Salt Lake plant. The other alunite deposits were not mined, but were trenched, drilled and sampled by the U. S. Bureau of Mines and U. S. Geological Survey (Hild, 1946, p. 1-74). The work led to a total estimate of 3,740,000 tons of alunitic material containing 19 percent Al_2O_3 (U. S. Bureau Mines and U. S. Geological Survey, 1948, p. 69). Parker (1964, p. 152-154) quotes the same estimate for material containing 54 percent alunite and quotes an earlier estimate by Thoenen (1941, p. 38) of more than 26 million tons of material containing at least 20 percent alunite. When imported bauxite again became available, the plant was closed and alunite mining ceased.

The discovery of uranium minerals in the Antelope Range in 1949 by P. Seegmiller, R. Smith and L. Anderson stimulated a brief period of intensive prospecting. The major veins were located and development work was begun by Bullion Monarch Mining Co. and the Vanadium Corp. of America. The U. S. Atomic Energy Commission began exploratory drilling and opened an ore buying station in 1950. In 1951 five mines were producing in the central district. By 1953 the Freedom and Prospector mines of the Vanadium Corp. of America had produced the bulk of the high-grade pitchblende ore. The major mines were closed by 1966 and prospecting and minor production have been sporadic since then. On the west side of the Tushar Mountains in the Newton district, uranium minerals were discovered. The Mystery Sniffer mine on Indian Creek was the principal development (Callaghan and Parker, 1961b). In 1951 Kerr began an intensive study of the central uranium area which was published in 1957 (Kerr and others, 1957).

The most significant development in recent years was the extension of the long adit started about 1945 by Pat Henry to the projection of the ore body in the Deer Trail mine by Arundel Mining Co. Primary lead-zinc replacement ore containing gold and silver was found. Production began in 1960 and ceased with the closing of the Tooele lead smelter and Midvale mill in 1971. Pat Henry was one of a large company of promoters who operated at Marysvale over the past 100 years. During the depression years he raised money for driving long tunnels deep into the mountains near Marysvale. These included the Rainbow north of Bullion Canyon, the Valdasia on the south side of Cottonwood, the Trinity in Marysvale Canyon and lastly the Deer Trail. As far as the writer is aware, Pat Henry did not live to see ore come from his adits.

Presently the clay pits on the north side of the Tushar Mountains on Mill Creek and on the east side of the Sevier Plateau near Greenwich are worked seasonally.

Quartz-Carbonate-Gold Veins

Gold Mountain District

Annie Laurie Mine. Among the precious and base metal mines of the Marysvale region, the Annie Laurie mine, on the north slope of the Tushar Mountains between 8,600 and 9,700 feet in altitude, mainly in sec. 11, T. 27 S., R. 5 W., is second to the Deer Trail mine in production. The camp was named for P. L. Kimberly, who invested in the mine and mill about 1898. Lower Kimberly was at the mill and Upper Kimberly was at No. 4 level. Total production for the district shown in table 1 is more than one-half million tons of ore which yielded about $3.25 million at the $20.67 price of gold. Of these totals, the Sevier mine contributed some 76,000 tons that yielded $434,000. The remainder came from the Annie Laurie.

The maximum production was in 1902 when 78,946 tons were treated, yielding 23,306.8 ounces gold and 69,223 ounces silver or slightly less than 0.3 ounces gold per ton (table 1). When Lindgren visited the property in 1904, 59,586 tons were treated yielding 18,427.8 ounces gold and 56,647 ounces silver or 0.3 ounces gold per ton. His account follows (1906):

The deposits occur in well-defined quartz veins cutting through the core of this old volcanic district. As far as known, no deposits occur in the rhyolite or in the great masses of rhyolite tuffs to the north of the Annie Laurie. They are confined to the dacite already mentioned as occurring near the mines. The Annie Laurie vein courses nearly north and south and dips from 45° to 60° W. About a mile to the west is a parallel vein called the Sevier, on which the Sevier Mining Company is now erecting a mill. The extension of the Sevier

Table 1. Metals produced in Gold Mountain district, 1892 to 1917 (compiled by V. C. Heikes, *in* Butler and others, 1920, p. 541).

Year	Ore (short tons)	Gold		Silver		Total value
		Fine ounces	Value	Fine ounces	Value	
1892-1900	21,500[1]	7,740.00	$ 160,000	51,000	$ 33,507	$ 193,507
1901	50,000[1]	18,007.72	372,253	48,213	28,928	401,181
1902	78,946	23,306.80	481,794	69,223	36,688	518,482
1903	63,246	20,335.60	420,374	67,109	36,239	456,613
1904	59,586	18,427.80	380,936	56,647	32,430	413,366
1905	65,800	19,283.00	398,615	55,536	33,544	432,159
1906	73,909	15,854.75	327,747	52,126	34,924	362,671
1907	53,850	12,289.90	254,055	37,138	24,511	278,566
1908	13,341	3,075.00	63,566	9,425	4,995	68,561
1909	49	21.89	452	28	15	467
1910	6,090	563.51	11,649	1,358	733	12,382
1911	3,004	1,051.56	21,738	1,256	666	22,404
1912	310	144.43	2,985	455	279	3,264
1913	10,874	2,383.47	49,271	5,371	3,244	52,515
1914	131	279.54	5,778	1,510	835	6,613
1915	115	448.82	9,278	2,003	1,016	10,294
1916	87	213.58	4,415	923	607	5,022
1917	74	133.90	2,768	908	748	3,516
	500,912	143,561.27	$2,967,674	460,228	$273,909	$3,241,583

[1] Partly estimated.

toward the north is being sought for [sic] in the Holland tunnel.

The Annie Laurie vein is very poorly exposed on the surface, being largely covered by morainal material. There is, however, a large outcrop rising boldly above the Blue Bird tunnel, and this formed the point of discovery. The vein has not been found on the surface at any point north of this. Within a moderate distance north from the northernmost workings the Annie Laurie vein should enter the rhyolite. How this will affect the deposit is as yet problematical. On the surface none of the productive veins appear to occur in this rock.

The quartz forms an almost continuous sheet along the vein, rarely less than 3 feet in thickness and often expanding to a width of 20 feet or more. As a rule the walls are poorly defined and slickensides indicating motion are rare. In places it contains, parallel to the walls, streaks of iron oxides and black, sooty, manganese ores. Near the walls the vein very commonly shows brecciation, and the quartz here often contains abundant and sharply-defined inclusions of country rock. While it is almost impossible to obtain fresh rock at any place in the mine, and chloritization as well as carbonatization have frequently occurred, the rock is not changed very much in appearance, and the included greenish fragments are sharply outlined against the white quartz.

The mine workings have not penetrated below the zone of oxidation, and neither the quartz nor the country rock seem to contain any unoxidized sulphides. In only one place, in the crosscut of the lowest tunnel, was some fresher dacite found which contained specks of pyrite.

In addition to the regular vein, which is often referred to as the East vein, there is also in certain parts of the workings a smaller fissure which lies a short distance to the west and which differs in some respects from the former. Its quartz contains more gold, its vein is narrower, and slickensides appear sometimes on the walls. It is principally known from No. 3 tunnel, in the richest part of the vein.

Two faults with a throw of 20 and 40 feet are known on the Blue Bird and No. 4 levels, but on the whole the vein is little disturbed.

The ore consists of a white, normal vein quartz, often very friable, breaking easily into small fragments. It is sometimes drusy, but more commonly massive. Calcite is abundant in certain parts of the deposit, but has often been dissolved by surface waters, leaving a hackly or lamellar quartz of striking appearance. As a rule no ore minerals are visible, although on panning the quartz may yield a little visible gold. The pyrite which the ore contained is doubtless converted to limonite, while the decomposition of the carbonates has resulted in the formation of oxides of manganese as well as more limonite. A slight copper stain appears in places, especially where the ore is rich. Finely divided argentite is no doubt present, but only in small quantities. On concentration the ore yields a very small quantity of sulphides, which are extremely rich in silver.

The value of the gold in the ore exceeds that of the silver. Samples of ore of the East vein yield, for instance, gold, $12; silver, $2.30; or gold $5.60; silver, $2.05. Samples from the West vein contain, for instance, gold, $11; silver, 32 cents; or gold, $4.80; silver, 68 cents. The richest ore is stated to assay from $15 to $18 per ton, odd samples frequently rising to $100 per ton. The average value of the ore is said to be between $7 and $8 per ton. The bullion obtained from the zinc boxes is stated to be 0.925 fine. One analysis shows 230 parts of gold, 695 parts of silver, 65 parts of zinc, and 10 parts of copper, the zinc being derived from the shavings in the boxes. The average bullion would contain about 750 parts silver and 250 parts gold.

The ore shoots of the Annie Laurie vein have an ill-defined lenticular form when projected on the plane of the vein, and appear to pitch 45° or less to the north. Some of them at least have cores consisting of bunches of rich ore, gradually decreasing in tenor toward the outside. On No. 3 level in the shoot the vein is in places 23 feet wide.

According to a mining engineer's report loaned to the writer by M. C. Godbe III, the mine was oper-

Table 2. Production of the Annie Laurie mine, 1931 to 1935.

Year	Tons		Ounces/ton Gold	Ounces/ton Silver
1931	159.8	Crude	286.49	1,246.73
1932	409.178	Crude	395.84	1,402.38
1933	95.48	Crude	149.71	636.16
		Bullion	12.76	8.08
	14.76	Concentrate	44.93	132.04
1934	504.49	Crude	756.25	3,314.88
		Bullion	833.21	787.17
	32.72	Concentrate	651.89	3,389.96
1935	165.02	Crude	125.59	721.00
		Bullion	1,434.80	2,875.66
	14.94	Concentrate	201.49	1,776.51

ated on a small scale from 1931 to October 1935. Production is shown in table 2.

Compared to other data, the high ratios apparently indicate a high degree of selection of crude ore shipped. They probably are not diagnostic of ore remaining in the mine.

Table 3 records the tons milled and average assays from 1935 through September 1937. Recovery is not shown.

If processing losses are discounted, the assay of 0.22 ounces gold per ton gives a value of $7.70 per ton at $35.00 per ounce.

The writer visited the mine in July 1936 and mapped a portion of the Blue Bird No. 3 level in the upper reaches of the mine (plate 5). At that time the No. 4 tunnel was opened and the leasing company had concentrated on the area between the No. 4 and Blue Bird levels along a strike length of 200 feet. They were mining primarily ore in the vicinity of old stopes which consisted of white quartz and lamellar calcite with sporadically distributed pyrite grains. When they moved into supposedly unmined ground, the operators broke into old stopes after a few rounds. They scavenged remnants of ore in and around the old stopes and mined primary ore, especially in 1971 when, even by selective mining, the gold content dropped to $6.00 per ton. All entrances to the mine were caved and closed in 1972.

Data for the Annie Laurie mine are summarized as follows:

Property: The Annie Laurie and Sevier mines and numerous prospects, including 145 patented claims, are consolidated in a property of some 3,000 acres now

Table 3. Tons milled and average assays, 1935 to 1937, Annie Laurie mine.

Year	Tons milled	Heads assay Gold	Heads assay Silver
1935	13,913	0.22	2.42
1936	17,841	0.227	1.90
1937	20,518	0.169	1.55

held by the Kimberly Gold Mines Co. The claims are mostly in secs. 2, 3, 10 and 11, T. 27 S., R. 5 W., but reach into adjoining sections (figure 19).

Location: The property is on the north slope of the Tushar Mountains between the altitudes of 8,000 and 10,500 feet. From paved State Highway 4 in the canyon of Clear Creek, it is reached by a well-maintained Forest Service road up Mill Creek and past the mine to the valleys of Deer Creek, Beaver Creek and eventually to Marysvale. From the highway to the Annie Laurie mine is 8 miles. The stope area of the Annie Laurie mine is in a ridge between branches of Mill Creek in NW¼ sec. 11, T. 27 S., R. 5 W., and is covered by the National 3207, Senator Stewart 3207, HSS 3207, Overland 3207, Lillian 3207, Minnie Maud 3207, Overland Fraction 4586 and Blue Bird 3488 patented claims (figures 19 and 20). The mill, built in 1899 (Lindgren, 1906, p. 87) and located on a slope above a basin behind a terminal moraine, was served by a haulage tunnel 3,000 feet long to the lowest level (No. 5), which was about 1,000 feet below the vein outcrop on the Blue Bird claim (figure 21).

Mine Development: Outcrops of the vein were discovered on the Blue Bird claim in 1890; although glacial debris and talus covered the remainder of the slope, development of the mine proceeded until 1898 when a cyanide processing mill was built. The mill was in full production by 1901. Major production ceased in 1908 and minor production, apparently by lessees, continued at least to 1917. Minor production was resumed in 1931 and continued to 1937 when 20,518 tons were reported as mined. Most of the later production came from old workings and seemingly no significant new development was undertaken. Old maps show stopes ran 2,000 feet along the vein system and from sublevel A below the No. 4 level to the surface, a vertical distance of some 600 feet (figure 21). The haulage level (No. 5) was reached by a 427-foot incline at a slope of 61° from the No. 4 level. Old maps indicate the vein system was explored for 1,200 feet on No. 5 level, but apparently no mining was done. Following the early operations, the No. 5 caved and became water filled, and all subsequent mining was on or above the No. 4 level. In spite of the chloritic alteration of the wallrock, the ground in the mine was not especially heavy, according to early reports. The large

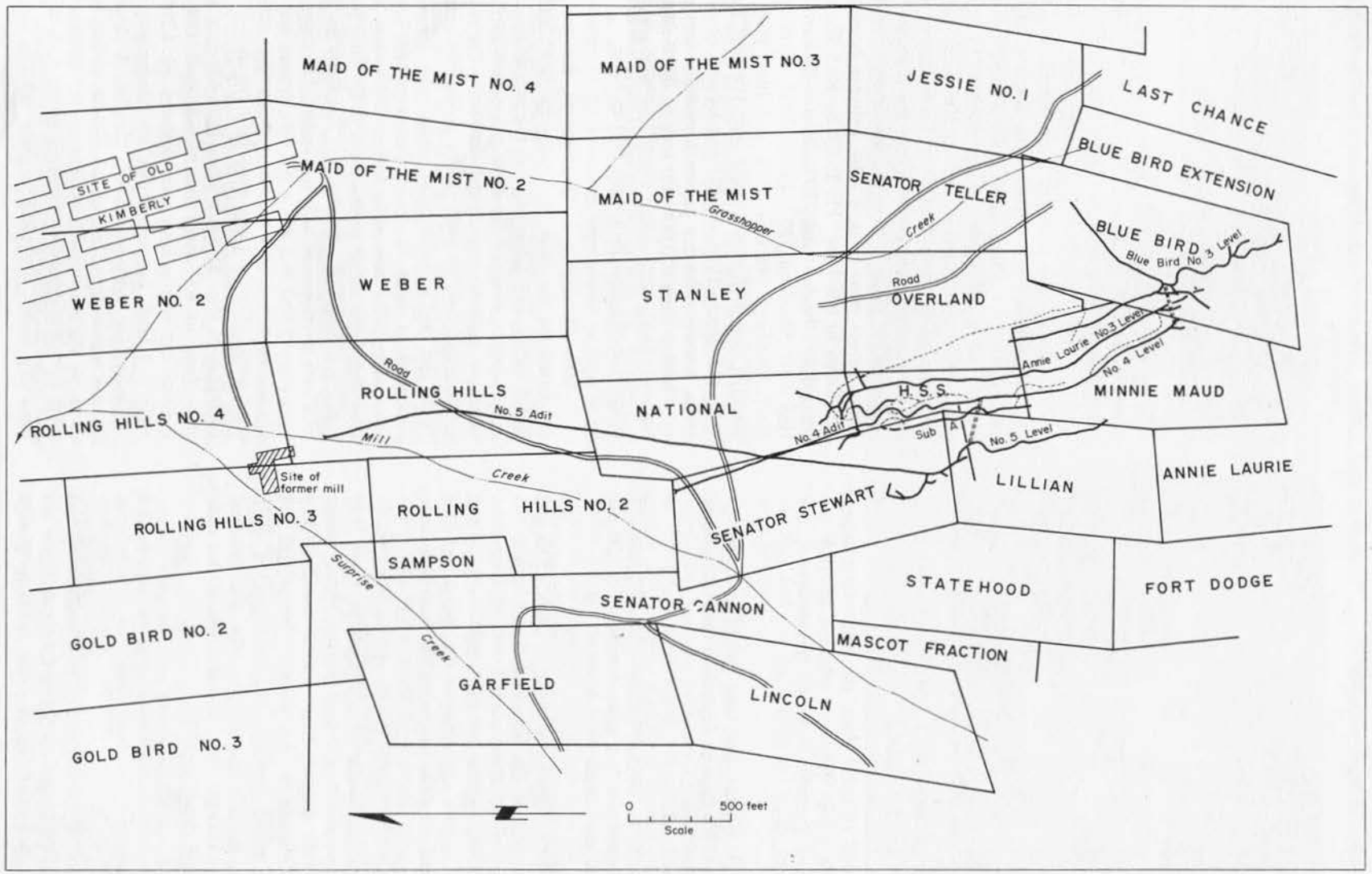

Figure 19. Outline map of Annie Laurie mine showing positions of mine levels and relation to patented claims.

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Figure 20. Annie Laurie mine area (1938). Mill tailings in foreground; dump of lower (No. 5) adit of Annie Laurie mine right of center (shown as site of former mill in figure 19). Old Kimberly at left.

stopes were timbered with square sets which, when rotted out, permitted slabs to fall from the hanging wall. Low dip in parts of the mine facilitated the caving process. As the adits penetrated water-filled glacial debris, they caved readily. The caved stopes at the surface trap much snowmelt and rainwater so the mine is wet during spring and early summer.

Country Rock: The country rock of the vein system in the Blue Bird No. 3 level is blocky flow latite of the Bullion Canyon Volcanics. Lindgren (1906, p. 88) called the rock dacite and does not mention any other rock, although he noted the monzonitic rocks at the Sevier mine. The latite is altered in the vein zone to an aggregate of chlorite, quartz and carbonate minerals with remnants of the original feldspar, biotite and hornblende. Pyrite is distributed sparsely in altered rock. Exposures are insufficient to indicate the primary or tectonic structure of the country rock or its position in the sequence of the Bullion Canyon Volcanics. The vein did not continue to the contact with the rhyolite, a point which concerned Lindgren in 1904.

Vein System: The primary ore, which the writer saw in 1936, consisted of white quartz and lamellar calcite with included fragments of country rock. Sparse pyrite was noted. Lindgren (1906, p. 89) saw the ore as it occurred in the richest part of the mine on the No. 3 level. The groundwater moving down through the vein had removed the calcite and pyrite, leaving the quartz with cavities occupied by manganese and iron oxides. Some of the quartz is sugary and breaks up easily. Lindgren noted a copper stain in a few places where the ore was especially rich. Neither gold nor silver minerals were seen, although some gold was recovered by panning. Old assays marked "stope wall" show gold content up to 0.46 ounces, although most are about 0.2 ounces. Some gold mineralization may penetrate altered country rock, especially where gold was released through leaching of calcite.

The Blue Bird No. 3 level (plate 5) shows the vein system as consisting of quartz lenses with diverging splits. One drift ends abruptly which may indicate a fanning of the vein near its south end. Old mine maps show an abrupt termination of the commercial ore at the north end of the mine. Lindgren does not mention a fault there and was impressed that only two faults displaced the vein as much as 40 feet. An old mine map of No. 4 level shows a crosscut intended to cut the vein at the north end, but no vein was encountered. The map represents the vein as curving to the northwest and pinching out. Gouge seams occur along the course of the vein. Lindgren (1906, p. 89) described the vein as a continuous sheet of quartz rarely less than 3 feet in width and in many places thickening to 20 feet or more. The strike of the Blue Bird or south part of the vein system is about N. 20° W. whereas the Annie Laurie portion strikes N. 5° to 10° W. Sections taken from old mine maps (figure 22) indicate a width of 25 to 40 feet; this may include sheets of country rocks between quartz sheets or lenses. The dip of the vein on the Blue Bird No. 3 level is 60° W., but Lindgren records dips of 45° to 60° W. The sections suggest a sinuous surface on the hanging wall of the vein, but a more regular footwall. In 1936 the operators found the highest gold content at the margins of the vein in the Blue Bird area.

Evaluation: The gold content of the Annie Laurie vein system provided incentive for a full-fledge mining operation in the first eight years of the 20th century and minor activity through 1917. Work on a small scale was resumed in the period 1930 to 1937. No base metals were recovered and a slight copper stain was noted in a few places. Probably 90 percent of the metals recovered came from part of the vein nearest the surface where most of the carbonate was leached from quartz-carbonate vein material. The ore was enriched in proportion to the weight loss of the carbonate and some gold may have migrated, possibly into the altered wallrock. Available records indicate the ore mined in the early days ran about 0.33 ounces gold per ton, but the gold content of ore mined in the mid-1930's, mainly from an area of old stopes between the No. 4 and Blue Bird levels in the south portion of the mine, ran 0.22 and even 0.17 ounces. From the extent of the drift on No. 5 level, the vein is apparently continuous between the No. 4 and No. 5 levels. However, no record of assays is available to the writer. Drilling from the surface is perhaps the least expensive way to obtain critical data.

For future development to be feasible, a profit must be made on low-grade vein material from the

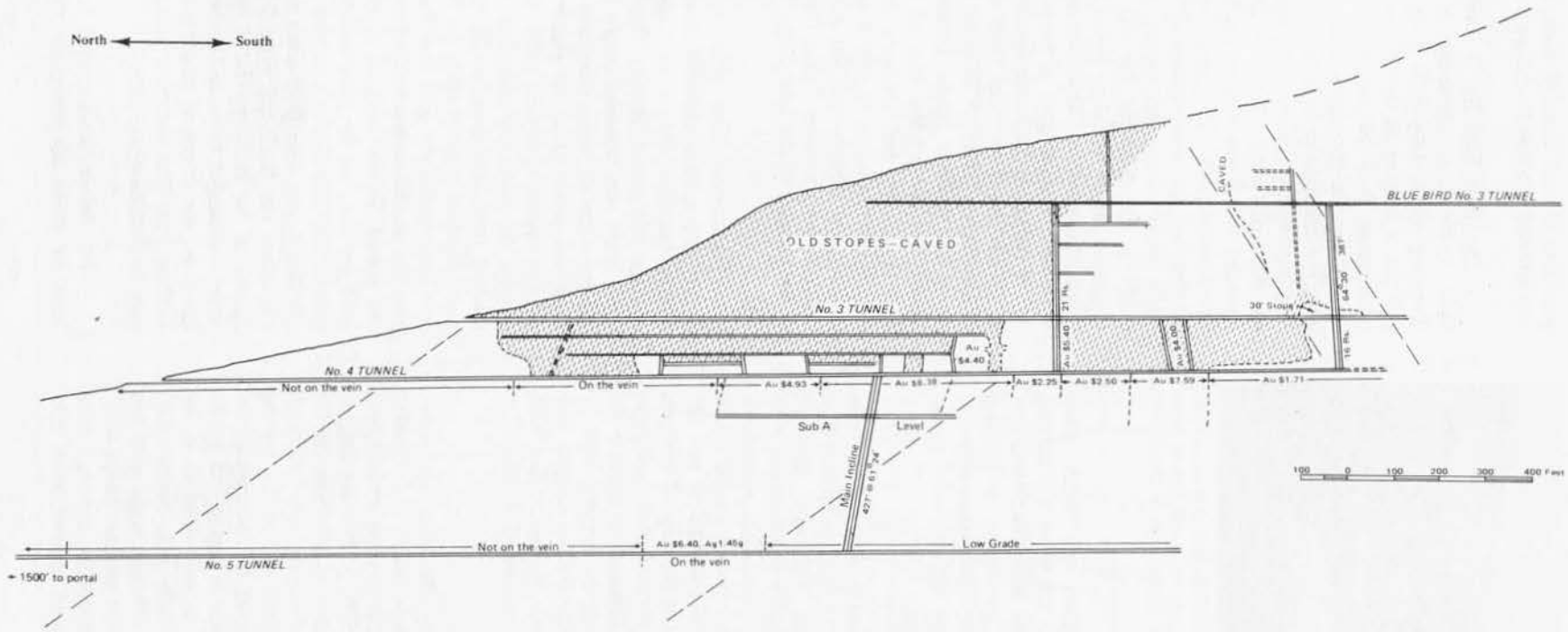


Figure 21. Longitudinal projection of Annie Laurie mine from old maps and reports. Assays at gold price of $20.67.

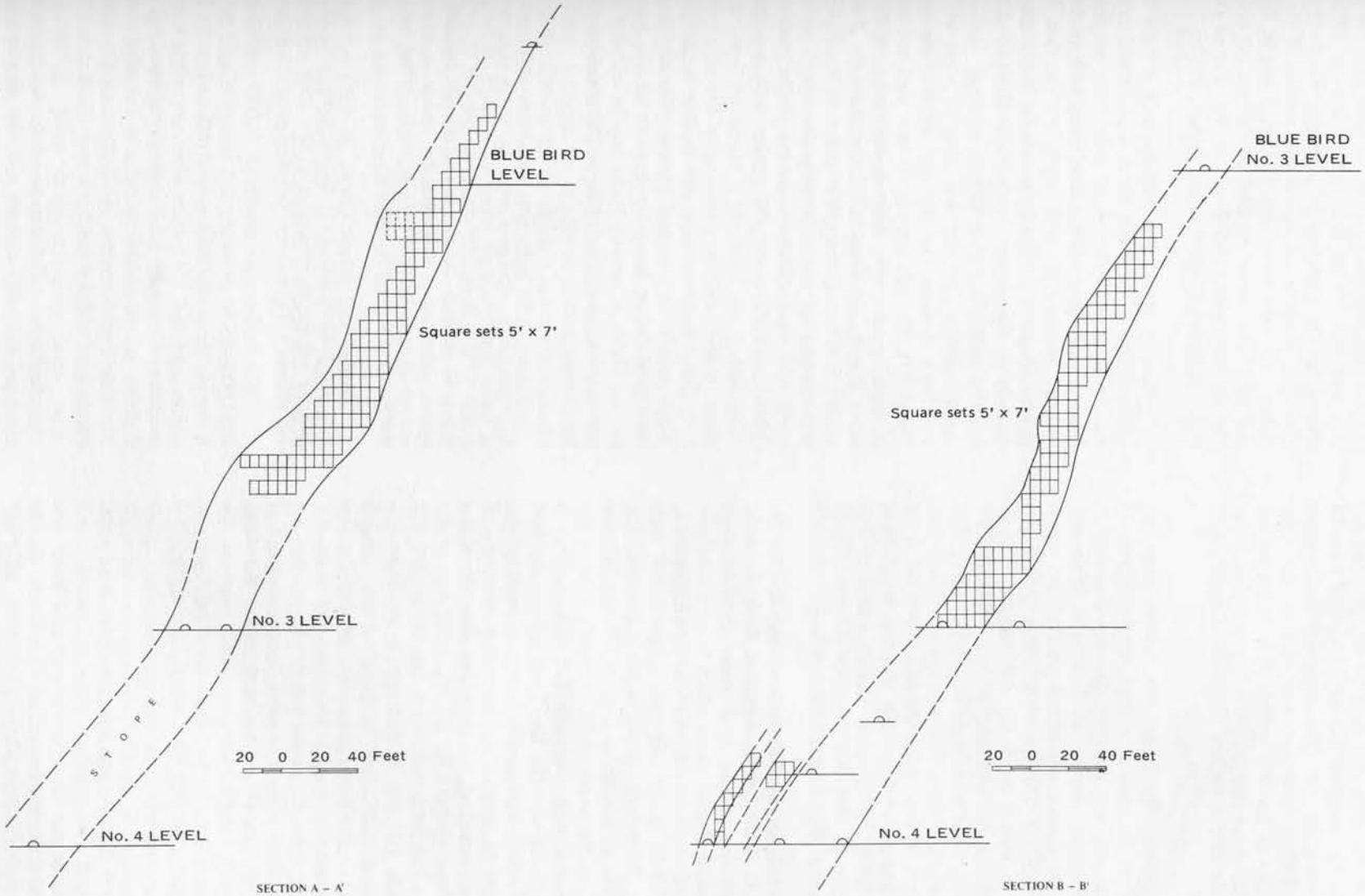


Figure 22. Two sections through stopes in Blue Bird area of Annie Laurie mine. Locations are shown on plate 5. From old map.

deep part of the mine and possible areas around old stopes where the wallrock and remaining vein material constitute low-grade ore. The areas could be determined by drilling from the west side of the ridge against the dip of the vein system. Pits on the surface of the tailings dump suggest it has been sampled often. One assay list gave a 40-foot sample as averaging 0.02 ounces gold.

Sevier Mine. The Sevier vein system crops out prominently at the crest of a ridge steeply sloping on the east side and was probably the first discovery in the Gold Mountain district. U. S. Mineral Monument No. 1 for the district was placed on the vein which was covered by the patented claim Sevier 37. According to Heikes (*in* Butler and others, 1920, p. 540) the district was organized in April 1889 and the discovery may have been made somewhat earlier. The Sevier mine is 1½ miles west northwest of the Annie Laurie mine in the center of W½ sec. 3, T. 27 S., R. 5 W. and is reached by jeep road on steep slopes from the Annie Laurie. A 10-stamp pan-amalgamation mill was completed in 1892 and produced 100 ounces gold and 398 ounces silver from 210 tons of ore.

An article in the *Salt Lake Mining Review* for December 30, 1902, shows a map of the mine workings and the vein system. It does not show workings on the General Connor claim which is on a continuation of the Sevier vein system to the north northwest. The No. 3 adit at the mill level (about 9,100 feet) strikes in a S. 290° W. direction for 1,163 feet. The No. 2 adit, at an altitude of about 9,350 and 550 feet S. 109° W. of the portal of No. 3, was a crosscut for 100 feet and a drift for some 500 feet on what is called the Front vein. The No. 1 adit, at an elevation of about 9,400 feet, was driven east to intercept the Back vein on the crest of the ridge. The occurrence of porphyry was noted at this time. The Erie tunnel is a crosscut whose portal is S. 27° W., 3,100 feet of the portal of No. 3 level, and which was driven 800 feet since 1902 in a N. 69° E. direction; it lies at an altitude of about 9,350 feet or directly below the hill (9,875 feet) on the Sevier mine ridge labelled Tip Top on the topographic map. It intersects two veins 200 and 300 feet from the portal and should intersect the main Sevier Back vein. The other two veins, the Erie and Blue, were mainly on the west side of the ridge. The Back and Middle veins apparently were at the crest of the ridge. On this basis the total length of mineralization, including the General Connor, is 3,000 feet.

In 1905 the 10-stamp mill was replaced by a mill that employed concentration, plate amalgamation and cyanidation. It was in a dry canyon and water was piped in from the headwaters of Fish Creek. At the time of Butler's (Butler and others, 1920, p. 555) visit in 1911, ore was mined from an open cut. The property was inactive in the 1930's, but in 1972 the owners of the consolidated property, Kimberly Gold Mine Co., made a cut across the outcrop of the vein system and were re-opening the No. 3 adit at the old mill level. The writer sampled part of the cut in 1972. The regional geology is shown on the map of Delano Peak quadrangle (Callaghan and Parker, 1962a).

Country Rock: The country rock is latite of the Bullion Canyon Volcanics which is penetrated by dikes and small intrusive bodies of monzonite porphyry, a light to dark gray, fine-grained rock with prominent feldspar phenocrysts and augite rather than hornblende. Quartz is scattered through the groundmass. At the surface the country rock adjacent to the veins is not altered greatly and is firm.

Vein System: In the cut on the vein system (figure 23), the vein zone is 70 feet wide and consists of eight quartz veins from a few inches to 17 feet wide. The dip is 54° to 75° E. and the strike is N. 10° to 20° W. The regional strike is almost N. 10° W. The veins shown are not necessarily continuous and they pinch and swell along the strike. Butler and others (1920, p. 555) credit the system with a length of 3,000 feet.

The vein material at the surface is quartz from which calcite was leached leaving platy cavities. The veins tend to be banded and much of the quartz is porous. Plates of country rocks may be included in the quartz veins. Lindgren (1906, p. 89) comments on the Sevier mine ore:

> The ore of the Sevier mine is in general similar to that of the Annie Laurie, although a drusy structure is more common; in places well-crystallized masses of amethyst-colored quartz appear. It is said that 22 percent of the gold values and 7 percent of the silver are recovered on the plates in the amalgamation, which here is the preliminary process. A considerable amount of argentite is present in finely divided form, and panning also yields a little fine gold.

Butler and others (1920, p. 555) mention the occurrence of adularia in the vein and note some material was silicified country rock.

The Sevier mine produced 76,000 tons valued at $434,000–$5.70 or nearly 0.3 ounces of gold per ton. A sample from the main vein at the surface ran 0.115 ounces gold and 1.9 ounces silver, according to an old assay list. No assays from underground workings were available to the writer. Samples as indicated in figure 23 taken by the writer in 1972 ran trace and 0.13 ounces gold and 0.4 and 0.3 ounces silver.

Evaluation: The extent of the veins, the abundance of vein fill material and the association with

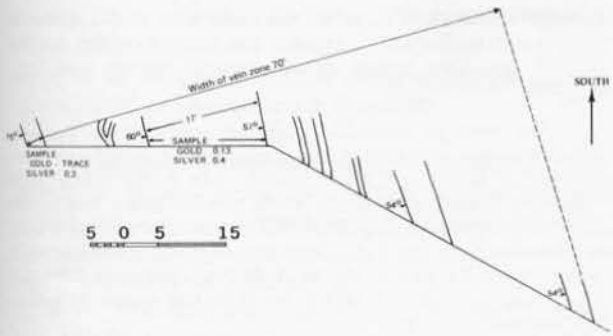


Figure 23. Veins exposed in face of cut on Sevier vein system.

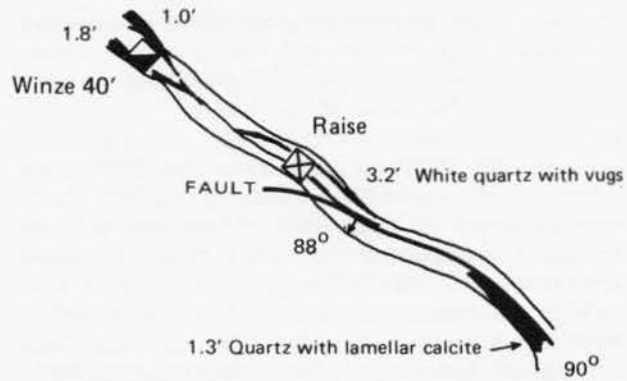


Figure 24. Butler and Beck mine, upper adit at ore bin.

intrusive bodies favor finding additional low-grade gold ore. The eastward dip and the steep slope on the east side should facilitate testing the vein system by drilling. The price of gold and the cost differential are determining factors.

Other Mineral Occurrences: Many veins were prospected in the vicinity of the Annie Laurie and Sevier mines, particulary south and west of the Sevier mine where the Bullion Canyon Volcanics are exposed and the cover of rhyolite is removed. Some are as much as 10 feet wide and consist of quartz with lamellar calcite. In some the quartz is shattered, but in places the quartz stands out prominently at the surface. Some contain minor amounts of fluorite. Most strike in a northerly direction and dip steeply east or west. From the small amount of work, the grade is considered low.

Prospects and patented claims continue into the Deer Creek drainage. On the lower part of Deer Creek a property known as the Butler and Beck includes adits that followed veins in a small monzonitic intrusive. Figure 24 shows a part of a vein which was explored by an adit 95 feet long in a northwesterly direction and by raises and winzes. A series of vuggy quartz lenses up to 3.2 feet wide and dipping nearly vertically are shown. Lamellar calcite appears at the portal. No sulfide minerals were noted.

Clearing away debris from old surface pits and sampling the veins will be warranted, when the price of gold justifies mining material containing 0.1 ounces per ton of gold.

Ohio Mining District

The boundary between the Ohio mining district to the north and Mt. Baldy district to the south is drawn at the drainage divide between the Pine Creek and Twomile Creek and the Cottonwood Creek drainage (plate 2). Many quartz-carbonate veins, occasionally with fluorite and small, although unknown amounts of gold, occur in the Pine Creek drainage area west of Bullion Falls. Some are small lenses, others are a few hundred to 3,000 feet long plus or minus 10 feet in width. A few were prospected by pits, but rarely by adits. The associated belt of altered rock is generally a few feet wide. Some areas of weathered argillic altered rock do not contain appreciable veins. Similar mineralization extends into the Beaver Creek drainage, but on a much reduced scale.

Similar mineralization occurs on the north slope of Mt. Brigham and Aetna (Edna) Peak; the area contains the Wedge mine.

Wedge Mine. In spite of a relatively small production, the Wedge mine, discovered in 1898, was a spectacular gold occurrence; large pea-sized nuggets were recovered.

The mine is covered by a patented claim in the forested area at the head of Twomile Creek on the north slope of Aetna (Edna) Peak at an altitude of 11,000 feet. Butler (Butler and others, 1920, p. 556) noted that the Wedge is a quartz-carbonate-adularia vein in volcanic rock and that rich gold-silver ore had been shipped. About 1937 N. Touroff opened the mine to apply for an R. F. C. loan, but the examining engineer did not approve it and the mine was closed immediately. The dumps are reported to have been reworked. Kennedy (1963a, p. 219) reproduces a diagram by Bethke listing the minerals as early and late quartz and pyrite, carbonate, bornite, tetrahedrite, gold and silver. Adularia is not listed. No details concerning the vein are available to the writer. In spite of the presence of a little sulfide, it appears that the Wedge belongs to the quartz-carbonate-gold group of veins. Many other prospect pits and adits were excavated in the adjacent ground in the hope of locating additional veins, apparently without success.

Evaluation: Known rich ore apparently was worked out and prospects for additional ore are dim. The vein undoubtedly was a small one, but an increase

in the price of gold may provide incentive for future exploration.

Mt. Baldy Mining District

The Mt. Baldy district includes the drainage area of Cottonwood Creek, the front of Deer Trail Mountain and several drainages south of Cottonwood Creek. No mines of significant output are known to exploit quartz carbonate veins, although many such veins were located and prospected to a small extent. Many of them continue over the ridge from the Pine Creek drainage to Cottonwood Creek drainage and several occur in Bullion Canyon Volcanics on the crest area of Deer Trail Mountain known as Horseheaven. Many were prospected on the west slope of Alunite Ridge in sections 17, 20 and 21. South of Cottonwood Creek the veins become relatively sparse, but they tend to continue, especially near the mountain front.

Newton Mining District

Numerous prospect pits and mine workings occur in Bullion Canyon Volcanics and a body of quartz monzonite at the west base of the Tushar Mountains between South Fork of North Creek and Wildcat Creek, 6 to 10 miles northeast of Beaver in Beaver County. The area was mapped in 1937 to 1938 (Callaghan and Parker, 1961b) and again by Wyant and Stugard (1951) in connection with intensive uranium prospecting. According to Heikes (*in* Butler and others, 1920, p. 543) the district was organized in 1892 and in 1893 a 10-stamp amalgamation was in operation on ore from the Rob Roy claim. Bullion valued at $800 was recovered. Some $9,000 worth of gold was treated by late 1893, but the deposit was soon exhausted. Butler's (Butler and others, 1920, p. 557-558) comments follow:

> The Rob Roy mine is near the contact of the intrusive quartz monzonite porphyry and the overlying volcanic rocks, both of which have been fissured and the fissures filled with vein quartz. Adjacent to the veins the rocks have been extensively altered and in many places silicified and pyritized. The Rob Roy vein strikes about north and dips west at a rather low angle. The mine has produced a little rich gold ore.
>
> The Sheep Rock mine is about 3 miles south of the Rob Roy . . . the geologic conditions are as follows:
>
> The country rock is andesitic porphyry, which is all more or less sericitized and pyritized and in places is highly silicified. At the bottom of the Sheep Rock shaft (300 feet deep) the sericite rock contains patches of calcite and fluorite. The rock on the surface is largely reduced to "float." This float contains much vein quartz, and is surprising that it has led to so little prospecting.
>
> The Sheep Rock vein, which alone has been prospected and developed, strikes north to N. 20° E. and dips 65° to 70° E. The vein matter is quartz, in part slightly amethystine and containing remnants of unreplaced calcite, and preserves in part the shattered structure of the country rock. The quartz is full of cavities lined with crystals and is characterized by the hackly structure where partly replaced calcite has been removed.
>
> The only ore minerals recognized are pyrite (or limonite pseudomorphs), native gold, and a fine dark material said to be argenite or cerargyrite (horn silver). The pyrite forms small cubes and grains both in the white comby quartz and in the silicified porphyry. The gold and silver minerals were seen only in pannings from the high-grade ore, although specimens with visible gold were seen in Mr. W. A. Wilson's office in Salt Lake City. Some ruby silver is said to occur in thin seams. Tellurium also has been reported.
>
> The vein is all oxidized, so far as it has been worked, to the 300-foot level. Ore has been mined from the surface, where it was 5 feet thick, down to the 300-foot level, where its maximum width is 25 feet. The ore of shipping grade occurs in shoots, and is usually found associated with prominent black stains of hydrous manganese oxide. Pick samples of this ore have assayed more than a thousand dollars a ton, but the average shipping ore probably ranges from $50 to $100.
>
> The parts of the vein inclosing [sic] the high-grade shoots and also the adjacent pyritized rock carry some gold and silver in pyrite and at the time of visit were being treated in an experimental 5-stamp mill with encouraging results.
>
> Placer ground in the vicinity of the Sheep Rock mine has been prospected recently, but no definite results have been reported.
>
> Veins containing tungsten in the form of wolframite are reported as occurring near the head of North Creek.

No work later than the uranium exploration is known to the writer. The Sheep Rock alunite deposit, adjacent to the Sheep Rock mine, was mapped by Callaghan and Willard in 1942. Mine openings and adjacent surface geology are shown on figure 71, page 118.

Evaluation: The persistence and size of the vein in the Sheep Rock mine noted by Butler, with an increase in gold price, should justify careful mapping and sampling that hopefully would lead to drilling for minable gold ore shoots.

Henry Mining District

The Henry Mining district includes the Antelope Range and the adjoining strip along the Sevier River north of Marysvale (plate 2). It is noted for alunite, uranium, iron and manganese deposits rather than for gold and base metals, although several shafts were sunk and two groups of claims were patented (figure 17). One group, mainly in secs. 16 and 21, T. 26 S., R. 3 W., northwest of Sage Flat, includes the Antelope mine where altered rock and quartz veins occur in Bullion Canyon Volcanics. The other group of patented claims crosses the common corner of secs. 22, 23, 26 and 27. Pits and shafts were sunk to explore quartz veins in altered rock. An opening in or near the quartz mon-

zonite was called the Royal Purple because it reportedly contained fluorite. The area was later involved in intensive uranium prospecting. No production of gold or base metals is recorded.

A prospect in metamorphosed quartzite and conglomerate at the north end of the exposed mass of quartz monzonite on the east side of Marysvale Canyon is covered by patented claims centered on the common corner of secs. 20, 21, 28 and 29, T. 26 S., R. 4 W. The area was explored by Pat Henry in the late 1930's; he called the adit entering the base of the steep slope east of the river the Trinity. Kerr and others (1957, p. 168-179) mapped and described in detail the surface and underground. No quartz veins with gold were found, but some thin streaks of pyrite with chalcopyrite were cut in the main adit 630 feet from the portal. One hundred feet from the portal the adit was driven due east for 1,100 feet. With branches to the south, the total of workings mapped by Kerr is 2,115 feet.

Lead-Zinc-Copper Veins

Ohio Mining District

Bully Boy Mine. The Bully Boy or Bully Boy and Webster mine is the most extensively developed of all the base and precious metal properties in Bullion Canyon, and probably was discovered in 1868. The *Salt Lake Mining Review* (May 15, 1899) states the No. 1 adit had been driven 1,600 feet and an article in the *Review* by A. O. Gates for June 30, 1922, reports that most of the workings were fully extended by that date. The upper workings, long inaccessible, are said to have been stoped to a much greater extent than shown in the longitudinal section (figure 25). A mill was operated prior to 1914, but was burned that year or a year earlier. Essentially nothing was done until 1922 when a Philadelphia group with Michael Barnett as manager built a mill, much of which is still extant, and did some development work and perhaps some mining. A drill hole put down 1,200 feet from the bottom of a winze 240 feet below the No. 1 level reportedly penetrated the contact of the quartzite and the underlying shale. When the writer visited the property in 1936 it was in litigation; nothing had been done for some years. He mapped the No. 1 and No. 2 levels in November 1938 (plate 6). In 1972 the portal of No. 1 adit was caved and the mine was inaccessible. The Deer Trail Mining Co. recently acquired the property.

No record of output has come to the writer's attention. The notes of a former engineer, Jacob Young, mention $500,000 which is not reflected in the total for the district (*in* Butler and others, 1920, p. 542). Proctor (1943) does not quote quantitative data. The small amount of stoping shown in the undated longitudinal section could not be the source of large production. Available data concerning the Bully Boy mine are summarized below:

Location: The Bully Boy mine penetrates the steep south wall of Bullion Canyon 1½ miles from the mouth of the canyon and 7 miles by road from Marysvale. It is covered by some of the earliest patents issued in the state. The vein follows closely the east side of sec. 5, T. 28 S., R. 4 W. The portal of the No. 1 level is at an altitude of 7,900 feet, about 50 feet above the glaciated floor of the valley, and the mill building is at the edge of the mine dump. The outcrop of the vein appears on the east side of a tributary canyon some 2,300 feet above the No. 1 level and follows the canyon for some distance up the slope.

Mine Development: The sketch plan and longitudinal section of the mine (figure 25) from an undated original indicate the extent of the workings which explored the Bully Boy vein on two principal levels and some short tunnels high on the slope. The length of workings is given as 6,000 feet, including raises, winzes, levels and crosscuts, with 3,200 feet attributed to No. 1 level, 2,300 feet of which is on the actual level (plate 6). Also explored by a crosscut on No. 2 level, by the Wright tunnel (crosscut) and two drifts, is the East vein at an angle to the Bully Boy. The vertical distribution of workings above No. 1 level is about 600 feet and the No. 1 winze went 240 feet below the level. All the workings are presently inaccessible.

Country Rock: The Bully Boy vein follows one of many faults trending northerly across Bullion Canyon. Regionally the quartzite (Navajo Sandstone) slopes north and disappears under the cover of the Bullion Canyon Volcanics along the footwall of the Tushar fault, a short distance above the mouth of Bullion Canyon. A series of northerly trending faults depresses the blocks progressively westward to an axis a few hundred feet west of the Bully Boy. Thence the northerly faults drop the blocks of quartzite and overlying tuff east with the highest block at the Bullion Falls of Pine Creek. From there the volcanics dip west and the quartzite does not reappear. In the mine as a consequence of normal fault movements, the hanging wall of the vein or westward block drops west. With the northward slope at the contact, the dropped block accounts for the occurrence of the well-bedded tuff in the lower Bullion Canyon Volcanics on the west wall opposite the quartzite and eventually, for the appearance of quartzite on both walls, 310 feet from the south end of No. 1 level (plate 6). Butler noted this circumstance during his 1911 examination (Butler and others, 1920, p. 556):

> . . . The principal workings of the Bully Boy and Webster mine have been on two veins, striking generally north and

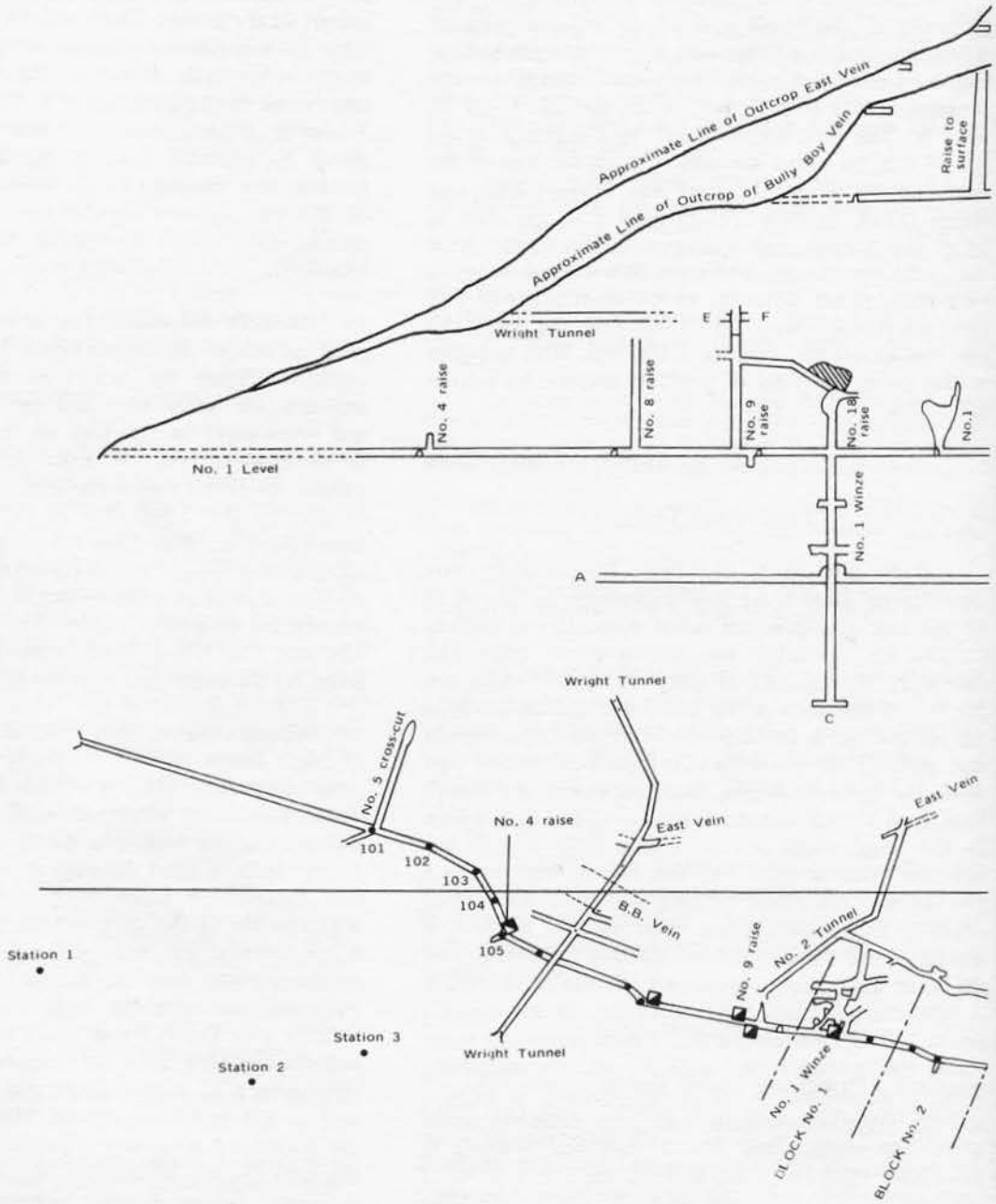
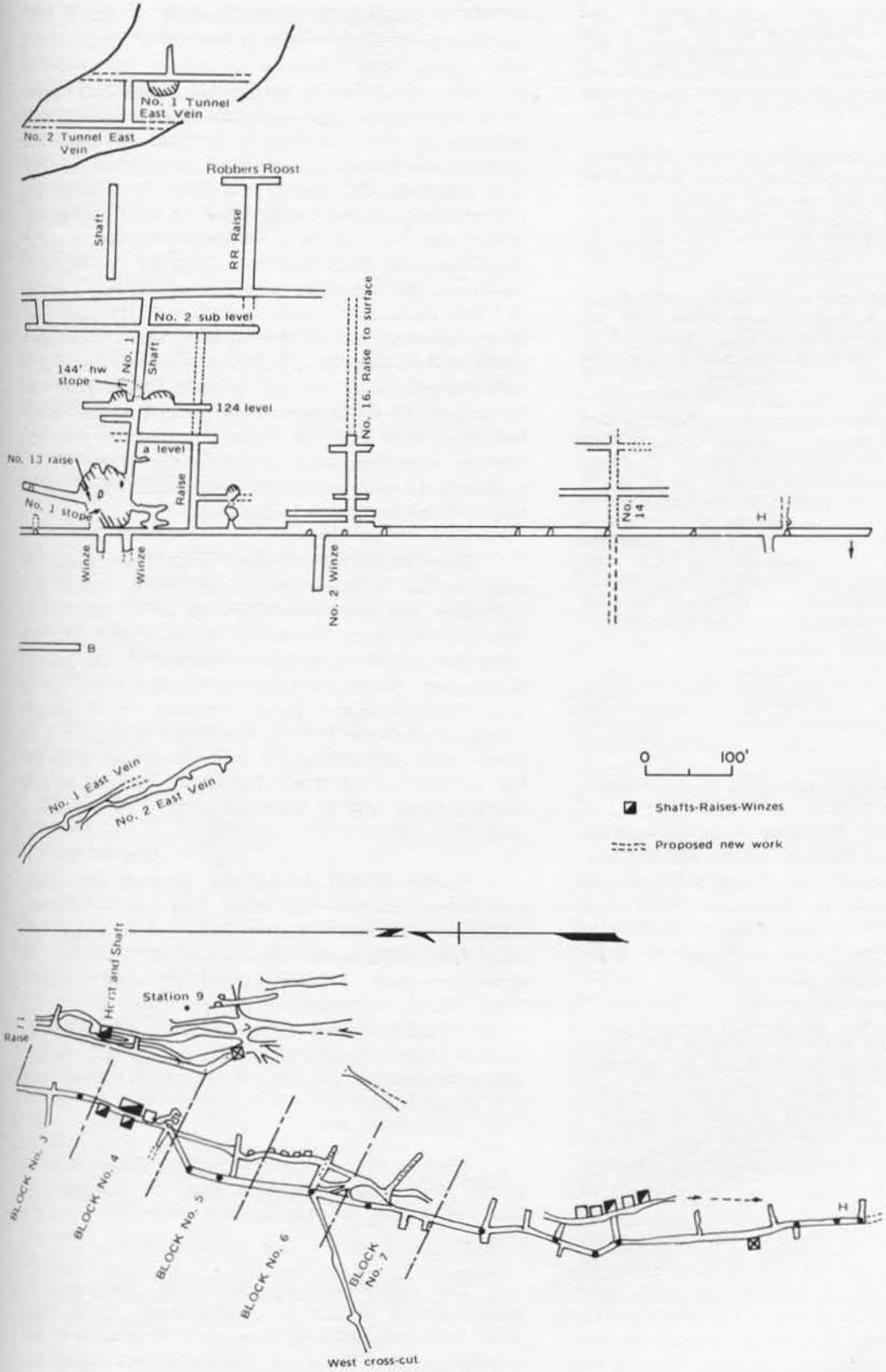


Figure 25. Plan and longitudinal section of Bully Boy mine, modified slightly from old map.


No. 1 Tunnel East Vein
No. 2 Tunnel East Vein
Robbers Roost
Shaft
RR Raise
No. 2 sub level
No. 16. Raise to surface
No. 1 Shaft
144' hw stope
124 level
a level
No. 13 raise
No. 1 stope
Raise
Winze
Winze
No. 2 Winze
No. 14
H
B
No. 1 East Vein
No. 2 East Vein
0 100'
Shafts-Raises-Winzes
Proposed new work
Hoist and Shaft
Station 9
Raise
BLOCK No. 3
BLOCK No. 4
BLOCK No. 5
BLOCK No. 6
BLOCK No. 7
H
West cross-cut

dipping steeply west. The country rock is quartzite and porphyritic lava. The veins evidently occupy fault fissures, for in the west vein the quartzite has been faulted against the lava in a part of the developed area. The vein is in part inclosed [sic] in the volcanic rocks, in part lies between quartzite and lava, and at the south end of the tunnel is wholly in quartzite.

The vein filling is mainly quartz, with subordinate amounts of carbonate, fluorite, and barite. The carbonate in places becomes abundant. The vein is in many places indistinctly banded, indicating that it was formed in an open space. The pay ore is in irregular shoots that occur in any part of the vein.

The ore varies considerably in mineralogy and metal content. The west vein contains lead and some copper, gold, and silver. The east vein is richer in gold and in the upper levels, at least, contains less lead. The upper levels have yielded some very rich gold-silver ore.

In the upper levels the ores have been oxidized, the lead and copper being present largely as carbonates. In the lower levels the lead is galena and the copper minerals are chalcopyrite and tetrahedrite. Manganese is abundant in all parts of the mine but especially in the quartzite on the lowest level of the west vein. In most parts of the mine it is present as hydrous oxide, but in the south end of the lower tunnel the vein is made up largely of a brown carbonate that yields oxides of iron and manganese on weathering. In the rich gold ore the gold is in part native and in part probably combined with silver as telluride and selenide. Both tellurium and selenium are present in the ore.

The ore at present developed in the mine is of milling grade. A mill was built on the property in 1913 and some ores concentrated. It was later destroyed by fire.

All of the upper workings of the mine, including the No. 2 level, are in tuff on both walls. The dip of lamination in the tuff is 20° to 45° westerly near the vein. At the south end the vein strikes nearly north; the central portion strikes N. 20° E. and the north end appears to curve more to the northeast. The average dip is about 73° W. As shown by figure 25 the East vein strikes N. 20° W., but tends to parallel the Bully Boy at the north part of the mine.

Vein System: The Bully Boy vein on the No. 1 level is quartz vein throughout. In places it consists of a breccia of quartzite fragments cemented by quartz. In other places large fragments or slabs of quartzite appear suspended in the vein. At one point the vein appears to end against a mass of shattered quartzite but picks up 80 feet farther along the vein as shattered quartzite cemented by quartz. Some 40 feet farther the vein changes to massive white quartz which is more likely to contain sulfide minerals than the quartz-cemented breccia. In general, the vein varies from place to place in the proportion of white quartz, which is believed to have filled large openings, in contrast to breccia of quartzite cemented by quartz. Where the vein is in tuff, fragments of the tuff may be included in the vein. Post-mineral fractures and gouge seams cut the vein or follow the walls; in places vein material is shattered without recementation.

The 50-foot width of the vein on the No. 1 level in the central section continues for 800 feet, terminates for 80 feet against a mass of shattered quartzite, then continues somewhat diminished for 240 feet. The final 200 feet of the No. 1 level show the vein changing to two parallel veins 10 to 15 feet apart; at the end, one vein is 4 feet wide and the other 3 feet. Where the Bully Boy vein is wholly in tuff, it is narrowed; the maximum width noted on No. 2 level, 275 feet above No. 1 level, was 20 feet. The East vein in the crosscut on the No. 2 level has a maximum thickness of 3 feet, but pinches to one foot. The dip is variable, but nearly vertical. In spite of the post-vein movement on the gouge seams parallel to the Bully Boy vein, only one seam crossed the vein in a northwesterly direction; with a dip on the seam of 70° northeast the vein has an apparent displacement of 15 feet with the north side to the east.

The mineral assemblage varies from place to place in the vein, changing with depth. Where the Bully Boy vein was observed by the writer, the sulfide minerals were mainly in streaks or small shoots in the white quartz and not uniformly distributed. The spotty distribution of stopes tends to confirm this. In a memorandum report dated February 1936, Jacob Young commented that the ore shoots were from 1 to 8 feet wide and averaged 5 feet. The length given by him is 200 to 700 feet. The writer has not seen a standard assay map of the mine or even of the No. 1 level.

Proctor (1943) divided the minerals into three successive stages. The early stage consists overwhelmingly of quartz as crustified bands, drusy surfaces lined with small crystals and dense cherty or chalcedonic areas. Within the quartz are small blades of barite which, under the microscope, appear etched by quartz. Quartz crystals radiate from the barite blades. Proctor noted hexagonal crystal plates and prisms which he identified as apatite in samples from the deep part of the mine.

Fluorite and carbonate consisting of calcite intergrown with iron carbonate occur in veinlets and fractures cutting the quartz; they constitute a second stage.

The sulfide minerals which fill fractures and replace quartz constitute a third stage. Where they occur they may make up as much as 50 percent of the volume of the vein material, but no massive sulfide has been reported. Pyrite is the most abundant sulfide and occurs in the veins and in altered tuff adjacent to the

vein. It is early in the sequence of sulfides and may be partly replaced by later sulfides. Sphalerite is not conspicuous, but occurs as scattered small groups and areas. It invades pyrite but is itself embayed by tetrahedrite and chalcopyrite. Tetrahedrite occurs as crystal aggregates and disseminated grains with the other sulfides. Chalcopyrite is associated with tetrahedrite and commonly embays and replaces pyrite. Proctor (1943) observed it was abundant in the lowest levels of the mine. Galena is not conspicuous on the No. 1 level, but Proctor reported it as being the most abundant sulfide on the intermediate levels.

Some quartz that is later than the sulfides was noted. Gold may have been introduced in a final stage of mineralization. Some ore reportedly in the long inaccessible upper workings ran as much as 2 ounces in gold. In this area, of course, the vein material would be enriched by abstraction of sulfides and soluble minerals through leaching by groundwater.

Even on the No. 1 level, sulfides not fully protected by quartz have been variably attacked by groundwater. Malachite, azurite and chrysocolla are the most conspicuous supergene minerals, but anglesite, cerussite and wulfenite were noted as well as hydrous iron oxides. The secondary copper sulfides, chalcocite and covellite, were observed in a few places.

The assays quoted in table 4 are from a memorandum report by Jacob Young, February 1936. They indicate the high proportion (50 to 1) of silver to gold as compared to the proportion in the Annie Laurie gold mine (10 to 1). The base metal content is shown for three samples.

Evaluation: The Bully Boy vein system follows the course of a normal fault which places overlying tuff against underlying quartzite. It was followed nearly one-half mile underground and is said to have been traced for a mile on the surface. In its high proportion of silver and base metal content, it contrasts with the quartz-carbonate-gold veins, such as the Annie Laurie, which are without significant base metal content and which contain a much lower proportion of silver to gold. The Bully Boy and associated vein deposits could be part of a central zone of higher temperature and increment of base metals as compared to the broad outer zone of quartz-carbonate veins.

The vein system has been explored extensively; complete mapping and sampling is needed to determine its worth in the light of present and projected metal prices and demand.

If the drill hole from the bottom of the No. 1 winze reached the bottom of the quartzite in 1,200 feet, the Toroweap Formation, which contains the Deer Trail ore body, could be some 2,700 feet below the bottom of the drill hole or 4,100 feet below the No. 1 level. Changes in the demand for metals may make future exploratory effort feasible.

Iris (Deseret) Mine. The Iris (Deseret) mine is 600 feet east of the Bully Boy and the main adit enters the south side of the canyon about 50 feet below the No. 1 level of the Bully Boy. The main or No. 1 adit (plate 7), as mapped by the writer in 1938, reaches the vein 210 feet from the portal and follows it for 800 feet. A map dated July 1969, loaned by E. M. Garrick, Salt Lake City, shows this level caved 305 feet from the portal. Two higher adits are shown, one 80 feet above No. 1, which enters the slope 170 feet south of No. 1 portal, and an adit 140 feet above No. 1, which enters the slope about 270 feet south of the No. 1 portal. A raise connects the levels 300 feet from the portal on the No. 1 level. The levels explore the vein for 130 and 195 feet, respectively. As shown by the map of No. 1 level (plate 7), the strike for 550 feet averages N. 22° W., but the south part curves north-south then N. 22° W. to the face where there are only quartz veinlets in quartzite. The width of the vein varies along its course on the No. 1 level; for much of its length, it is 10 feet wide expanding to 15 feet and narrowing to 5 feet. Some 20 feet from the face, it changes to quartz stringers in quartzite. The dip is mostly 70° to 85° E., but in places it dips steeply west. According to Garrick's section the vein branches upward and there is an unexplored branch to the south on No. 1 level near the north end of the vein.

The No. 1 level is close to the contact between quartzite and overlying laminated tuff, which tends to dip to the northeast near the vein. The north part of the drift shows quartzite in the foot or west wall and tuff on the east wall. About 640 feet from the portal, quartzite is on both walls. Tuff, however, appears on the east wall for 200 feet beginning 780 feet from the portal, but the face of the drift is in quartzite. The inference is that the Iris vein follows a steep normal fault, which is down on the east in contrast with the nearby Bully Boy fault, which is down on the west; the strike is northwesterly in contrast with the northeasterly strike of the Bully Boy. The throw on the fault appears much less than on the Bully Boy. Except for some shattering and cementation by quartz veinlets, the quartzite is not affected by mineralization, whereas the tuff is impregnated with pyrite which on weathering released acid and changed the altered tuff to clay where groundwater penetrated.

The vein material is similar to that in the Bully Boy–a white banded and vuggy quartz with narrow streaks of base metal sulfides, in places leached and oxidized. Bismuth was reportedly found in the vein. A

Table 4. Assays of ore from the Bully Boy vein system (from memorandum report by Jacob Young, 1936).

Date	Description	Ounces		Lead (percent)	Value
		Silver	Gold		
No. 2 Tunnel					
6/20/31	Oxidized material in face and 10 to 15 feet back from face on east side of tunnel	10.74	0.18	[1]	$14.62
8/12/31	Twenty-five feet south No. 1 raise	13.82	0.68	[1]	33.51
8/12/31	14 inches carbonate ore, 20 feet north No. 2 raise	11.84	0.20	[1]	16.07
8/12/31	8 feet north of No. 2 raise	17.50	0.20	[1]	20.56
9/23/31	18 inches brown carbonate ore, bottom tunnel 10 feet south No. 1 raise	26.56	0.20	[1]	27.58
No. 1 Raise					
6/22/31	Lead carbonate ore, 12 inches wide, above 144-foot level (12/8/28)	15.32	0.08	[1]	14.67
6/22/31	18 inches lead carbonate ore, raise, 75 feet below No. 2 tunnel (12/8/28)	18.02	0.18	[1]	20.26
6/22/31	18 inches lead carbonate ore, 75 feet below No. 2 tunnel (6/26/29)	9.14	0.06	[1]	9.18
11/11/31	Big lump from dump of No. 1 raise	23.56	0.30	37.0	48.73
8/1/34	14 inches lead carbonate and sulfide ore, 25 feet below No. 2 tunnel level	19.02	0.20	[1]	21.74
No. 3 Tunnel Dump					
	Average seven samples, sulfide and carbonate ores, sorted	15.53	0.346	[1]	24.14
Upper Croppings (above No. 18 ore shoot)					
6/22/31	West seam of ore	20.54	0.36	[1]	28.51
6/29/31	West seam of ore	16.18	0.46	[1]	28.64
No. 1 Tunnel					
6/29/31	Sulfur ore ¼ to 2 inches wide at bottom face No. 18 drift, approximately 1,950 feet in tunnel	21.52	0.36	[1]	29.27
6/29/31	No. 18 drift to south, ½ to 2 inches wide along bottom of drift	18.46	0.50	[1]	31.80
10/14/31	Galena ore No. 18	16.92	0.08	19.0	26.11
6/6/34	Face No. 1 Tunnel 2,300 feet, 12 inches manganese oxide and quartz	0.83	0.18	[1]	7.04
6/6/34	Face No. 1 Tunnel 2,300 feet, 30 inches manganese oxide and quartz	0.80	0.04	[1]	2.02
No. 1 Winze				Copper	
7/10/31	Better grade of ore from dump portal No. 1 Tunnel 75 feet down winze	24.42	0.14	5.75	32.37
6/14/34	Gray copper ore, 70 feet down winze, south side. Bunches in vein.	53.12	0.32	[1]	52.37
Homestead Shaft (pillar at south side)				Lead	
6/29/31	8 to 12 inches mixed sulfide and carbonate ore along east wall	15.12	0.52	[1]	29.92
6/29/31	30 to 36 inches manganese oxide and quartz next to sulfide	7.54	0.20	[1]	12.84
8/12/31	1 to 2 inches carbonate seam on west side manganese oxide and quartz	9.86	0.14	[1]	12.54
8/12/31	8 to 12 inches top of ledge	25.02	0.52	[1]	37.59

[1] Not determined.

Table 4. (continued)

Date	Description	Ounces Silver	Ounces Gold	Lead (percent)	Value
East Vein					
2/6/35	Streak ore in lower tunnel face	4.84	0.16	[1]	9.35
2/6/35	South opening, C. C. tunnel to vein, brown ore	47.48	4.12	[1]	190.99
1/16/36	South raise No. 1 Tunnel, up 15 feet, 4 to 6 inches wide	6.70	0.41	[1]	19.54
4/24/34	No. 1 Tunnel bottom of stope at pit, east side, south end, 2 inches wide	342.00	24.00	[1]	1,105.05
3/24/34	North point east vein above portal No. 2 tunnel, 4 feet wide	2.28	0.12	[1]	5.96

[1] Not determined.

few assays were made available to the writer by E. M. Garrick (table 5).

Evaluation: The mine should be sampled adequately, and the present and future market evaluated to determine the need for further exploration.

Cascade Mine. The Cascade mine is in a group of adits penetrating the steep south side of Bullion Canyon some 1,500 (?) feet east of Bullion Falls where Pine Creek drops about 400 feet over a steep glaciated slope on the highest and farthest west fault block of quartzite (Navajo Sandstone). A succession of blocks of quartzite and overlying bedded tuff is dropped eastward toward an axis 1,000 feet or so west of the Bully Boy mine. Veins occupy the faults or related fractures. The Cascade vein, on the west side of the steep ravine of Cascade Creek at an elevation of about 8,400 feet, is exposed by two adits (figure 26), one about 50 feet above the other for a distance of 580 feet. The Shamrock adit (plate 8) is about 360 feet S. 75° E. of the Cascade at about the same elevation and the Glen Erie (figure 27) is about 500 feet southeast of the Shamrock and higher. The veins on the Gold Strike claim, east of the Glen Erie, were among the first discovered in the earliest days of prospecting activity. Butler (Butler and others, 1920, p. 556) commented as a result of his 1911 visit:

> The Cascade mine is developed in a vein in quartzite that strikes west of north and dips steeply west. The vein filling is quartz, with some carbonate, as in the other veins of the district. The sulphide minerals are chalcopyrite, tetrahedrite, galena, and sphalerite, all of which are partly oxidized. The ore, as in the other mines, contains gold and silver. It is reported that some has been shipped. The deposit is developed by several hundred feet of tunnel, with raises and winzes.

Table 5. Assays of ore from the Iris (Deseret) mine.

Sample	Ounces Gold	Ounces Silver	Percent Lead	Percent Copper
9½ feet Upper Iris	0.05	6.6	none	0.41
Intermediate level	0.09	3.0	0.25	0.31
South crosscut, face	0.07	5.31	none	0.31
5 feet, face	0.03	3.13	none	0.21
Upper drift	0.04	10.52	none	0.36
Top 4 raise, intermediate level	0.18	12.24	none	0.46
Right-hand drift	0.06	10.75		

Other prospects and patented claims are on the rugged and timbered slope drained by Cascade Creek. The Cascade and Shamrock are reached by a mine road which follows the south side of Pine Creek. The three mines were mapped by Callaghan in 1938 and again in part by Callaghan and Jared Haselton in 1972. E. M. Garrick furnished the maps and data he assembled on the Cascade in 1968 and 1971.

The upper and lower adits of the Cascade (figure 26) are in quartzite. The strike of the vein system is N. 5° W. and the dip is mostly between 65° and 70° W. The vein material in places is mainly shattered quartzite cemented with quartz, but in others is a vein filling of white quartz. The white quartz more likely contains streaks or shoots of sulfides. Garrick found the ore shoots limited to the first 120 feet from the portal in the upper adit and from 200 to 290 feet from the portal of the lower adit. Each of the portions has been stoped irregularly for 5-foot widths from 15 to 30 feet above the back of the drift. The final 140 feet of the vein contain pockets and stringers of sulfide minerals, but has a maximum width of only a foot and ends against converging gouge seams. At the portal the vein consists of stringers in quartzite with sulfide grains.

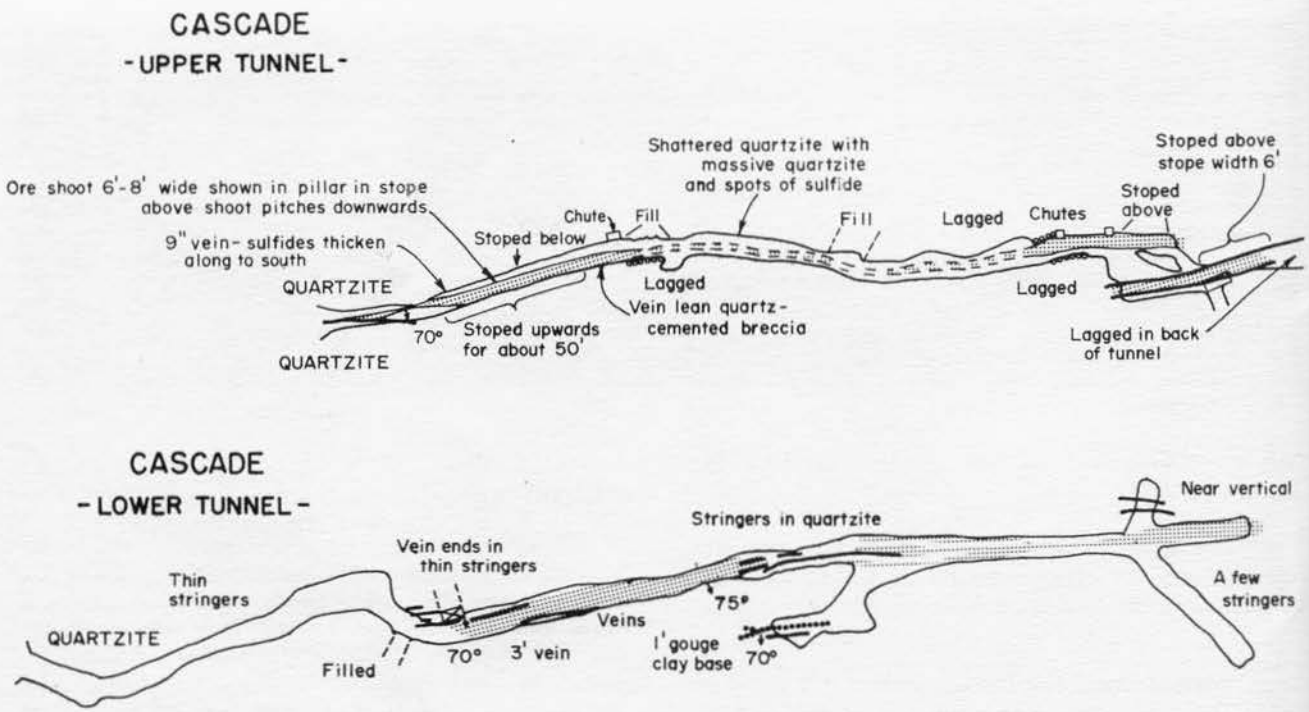


Figure 26. Geologic map of upper and lower adits of Cascade mine (surveyed 1938 by E. Callaghan and modified in 1972 by E. Callaghan and Jared Haselton).

The local strike is N. 20° W. and the dip 53° W. However, the vein is cut by closely spaced joints or shear structure which also strikes N. 20° W. but dips 48° E. On the lower level the vein is as much as 5 feet wide, but in places consists only of stringers of quartz in quartzite.

Typical ore consists mainly of three generations of quartz: (1) dense white quartz in streaks and even angular blocks with few openings or vugs and little penetration by sulfide grains; (2) a light gray porous quartz in crustified bands or irregular areas with streaks and pockets of sulfide grains mostly less than 1 mm in diameter; few grains are as much as 2 mm in diameter. The sulfide is mainly sphalerite with somewhat less galena. Enough copper, probably as tetrahedrite, is present to stain the vein material on exposed surfaces. (3) The final generation consists of crusts of small crystals lining vugs or filling veinlets.

A sample from an ore dump at the surface assayed by Union Assay Office, Inc., gave the following results:

Gold	0.12	ounces per ton
Silver	14.0	ounces per ton
Copper	0.768	percent
Lead	1.9	percent
Zinc	1.8	percent

A sample 5 feet wide across the south end of the second stope taken by E. M. Garrick was reported by Crisman and Nichols as:

Gold	0.06 ounces per ton
Silver	3.75 ounces per ton
Lead	none
Copper	0.09 percent

A sample taken at the end of the Upper Cascade adit returned 0.01 ounces gold, a trace of silver, no lead and 0.41 percent copper. No data are available from the stoped adit.

Evaluation: As for other occurrences of precious and base metals in Bullion Canyon, the metal content in the Cascade mine ores has been too low and the size of deposits insufficient to make them attractive for a sustained mining operation. A consolidated operation plus a rise in demand and price of the ores is needed to permit their operation at a profit. They require exploratory drilling and careful sampling of reopened workings to locate material of commercial grade.

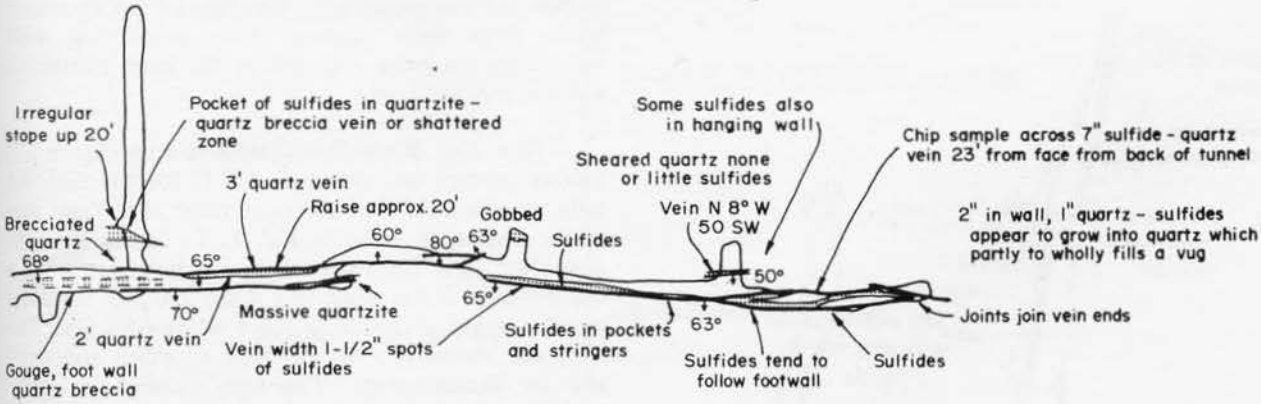


Figure 26. (continued)

Shamrock Mine: The Shamrock mine lies on the west side of the Shamrock patented claim on the east side of Cascade Creek at an altitude of about 8,350 feet. In 1970 some work was done at the portal and a small ore bin constructed. A road was extended to the portal, but was blocked in 1972 by flood debris at Cascade Creek.

The main adit was mapped by the writer in 1938 (plate 8) and the outer portion remapped in 1972. As shown by the map, the main adit, which penetrates the side of the canyon for a total of 1,680 feet, explores a system of small veins in quartzite rather than following any single strong vein. Thus considerable parts of the workings are crosscuts in search of minable veins. In the first 240 feet of the adit, the vein strikes N. 10° to 23° W. and dips 55° to 82° W. It was stoped for most of its length 12 to 20 feet above the drift and consisted in places of sheared quartzite with quartz stringers. Narrow streaks of sulfide along the vein had a maximum width of 3 feet. A crosscut 40 feet west reaches another vein group striking north, dipping 52° to 68° W. and continuing for 300 feet. The veins are measured in inches and no appreciable sulfides were found. The next 330-foot interval is mainly crosscut. The next section follows a vein for 280 feet striking N. 11° W. and dipping 72° to 80° W. This section shows up to 3 feet of vein material with a fairly generous distribution of sulfide grains. A crosscut 100 feet east reaches another vein system which is exposed for 450 feet and which strikes N. 20° E. and dips steeply east and west. The width is mostly less than 1½ feet and sulfide grains are not conspicuous. The final 240 feet are a crosscut which intersect some nineteen veins and a mineralized zone. The veins dip steeply, some east and some west, and are commonly about 1 foot wide. Some contain a little sulfide and several contain black calcite in quartz with scalen rather than lamellar calcite in the quartz or lining vugs.

A sample from an ore dump at the portal assayed by Union Assay Office, Inc., showed gold 0.07 ounces and silver 17.0 ounces per ton with 6.4 percent lead, 0.64 percent copper and 8.3 percent zinc. No other assays were available to the writer. Butler (Butler and others, 1920, p. 556) commented on the mine:

> The Shamrock mine is in a vein of quartzite that strikes northwest and dips steeply southwest. The vein filling is quartz and some carbonate with chalcopyrite, tetrahedrite and galena. The sulphides have been partly oxidized. The ore occurs as irregular shoots in the vein. Development has been by two tunnels, about 70 feet apart vertically, with raises and winzes in the ore shoots. It is reported that a few carloads of ore have been shipped from the mine.

Evaluation: The gold content in the sample is low, but silver, lead and zinc are relatively high. The thinness of the veins and their scattering through as much as 160 feet of quartzite preclude cheap mining considering the grade of the ore. A considerable increase in price of silver and trace metal is needed to create a profitable situation.

Workings above the Shamrock. Several veins exposed in adits enter the timbered slope above and south of the Shamrock (figure 28). The largest, the Tushar or Ethridge white quartz vein, is followed S. 22° W. for 100 feet for the full width of the drift. At the south end it dips 49° W. and enters the east wall of the drift; it was not followed. A parallel vein 2 feet wide and dipping 56° W. was cut in a short crosscut 15 feet east of the main vein. Quartzite occurs on the east or footwall side of the main vein and bedded tuff on the west wall. The remainder of the adit is in bedded tuff which strikes northwest and dips 25° to 42° NE. No sulfide minerals were noted in the vein and the manganese stain indicates a carbonate content.

Three Shamrock adits and a 55-foot adit called the Star lying west of the upper Shamrock all show

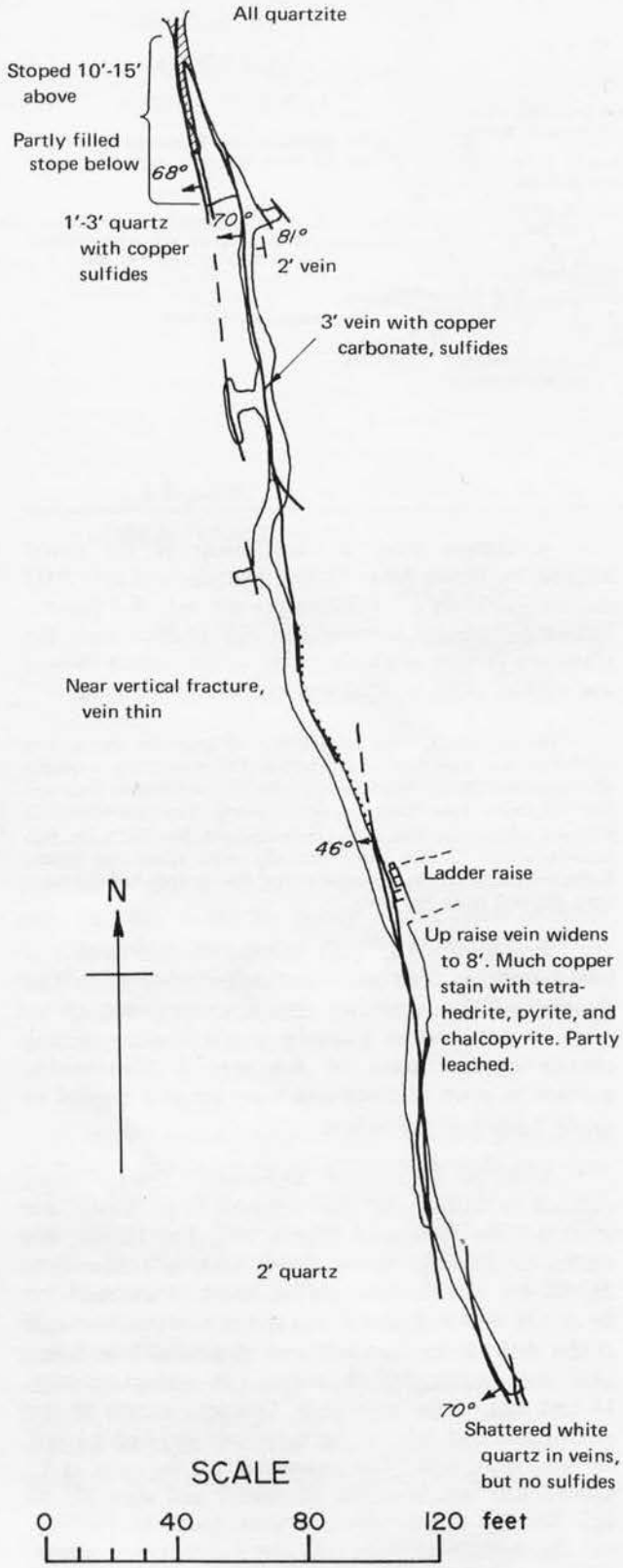


Figure 27. Geologic map of Glen Erie mine (surveyed 1938 by E. Callaghan).

copper and manganese stain and two of the Shamrock levels show some stoping. Their positioning with respect to the veins exposed in the main Shamrock adit was not surveyed.

Glen Erie Mine. The Glen Erie adit (figure 27) follows another vein system S. 12° E. for 435 feet. An early patented claim of the same name at the east side of the Shamrock claim in sec. 5, T. 28 S., R. 4 W. covers the adit. The veins, all in quartzite, are from a few inches to 3 feet wide; at a point 270 feet from the portal a stope 20 feet long has a width of 8 feet. The veins dip about 70° W. and tend to pinch and swell and be discontinuous. The vein material is partly leached and copper carbonate minerals are prominent. No assays are available to the writer. The vein material closely resembles that in the Cascade and Shamrock with a higher proportion of copper minerals.

Evaluation: The gold content in the ore is judged to be low as in the neighboring veins so that the incentive to mine narrow, discontinuous veins is not great. Price and demand for the contained metals will dictate future operations.

Great Western Mine. The Great Western mine is an old property in the Ohio district and is included in Wheeler's list of 1872 (Butler and others, 1920, p. 541). It is covered by a patented claim 200 feet wide and 3,000 feet long trending northeasterly up the rugged north side of Bullion Canyon and in the southwest quarter of sec. 32, T. 27 S., R. 4 W. on the east side of Warnick Gulch. Also on this side of Bullion Canyon a succession of quartzite fault blocks and overlying bedded tuff is tilted eastward and dropped to the east on the west side of a synclinal axis a few hundred feet east of the mine.

The mine workings are on the rugged slope at an altitude of about 8,350 feet and are reached by a steep jeep road. They are represented in a map made in 1950 and published by Evans (1953, p. 102-108). E. M. Garrick made available maps and assays he prepared. The mine was mapped (figure 29) by the writer in 1938 and again in 1972. Packard adit, which enters the base of the slope a short distance west of Warnick Gulch at an altitude of about 8,200 feet and which is presumed to explore the westward of two veins exposed in the mine workings, was mapped in 1972. The relation of the Great Western workings to the Packard adit is shown in figure 29, somewhat modified from a survey made available by Garrick. According to the survey, the Great Western mine level is 138 feet above the Packard tunnel and 33 feet below the upper adits, which were open in 1938.

As shown in figure 29, the main working is an adit 220 feet long east of two nearby veins that were

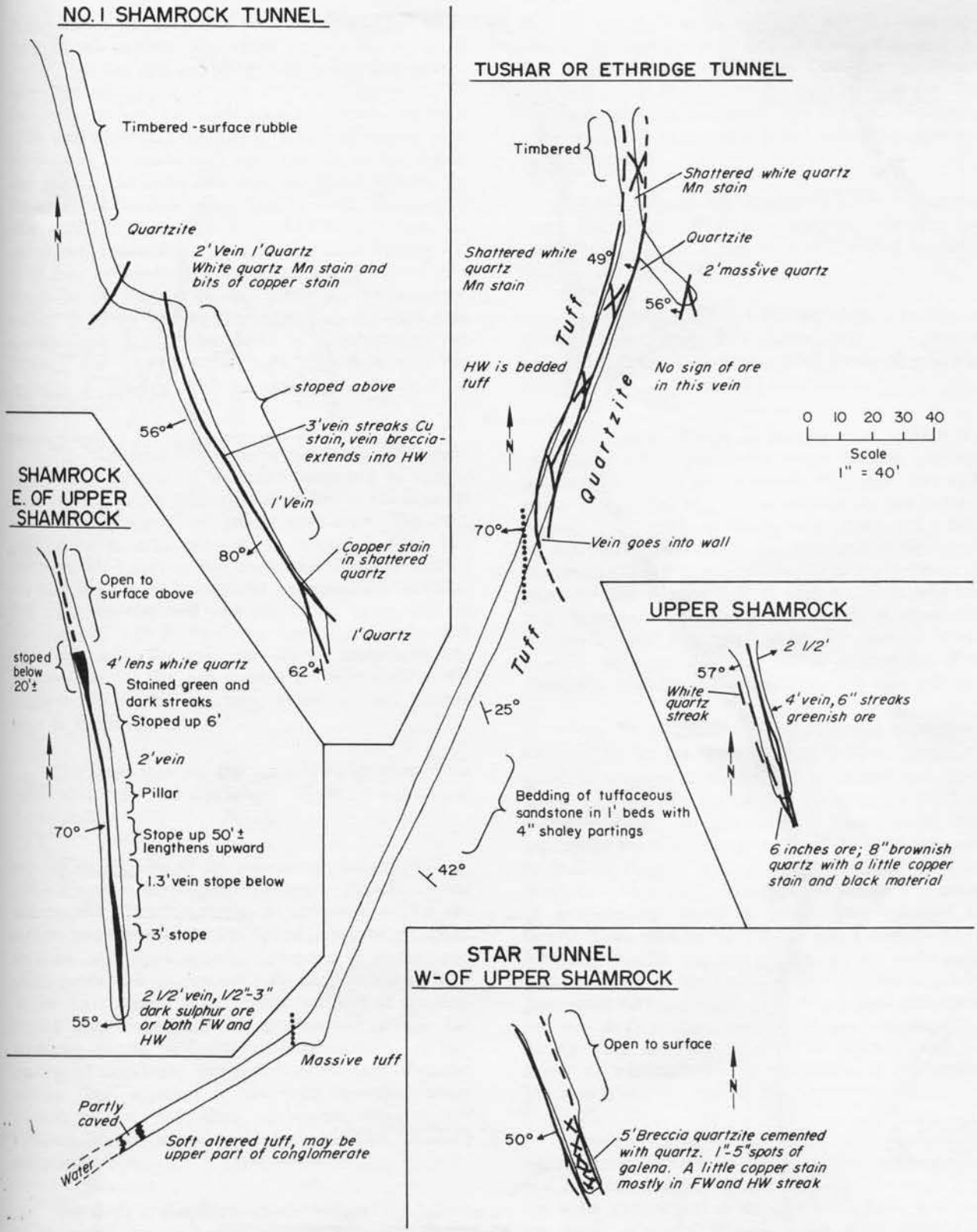


Figure 28. Geologic map of mine workings above the Shamrock mine (surveyed 1938 by E. Callaghan).

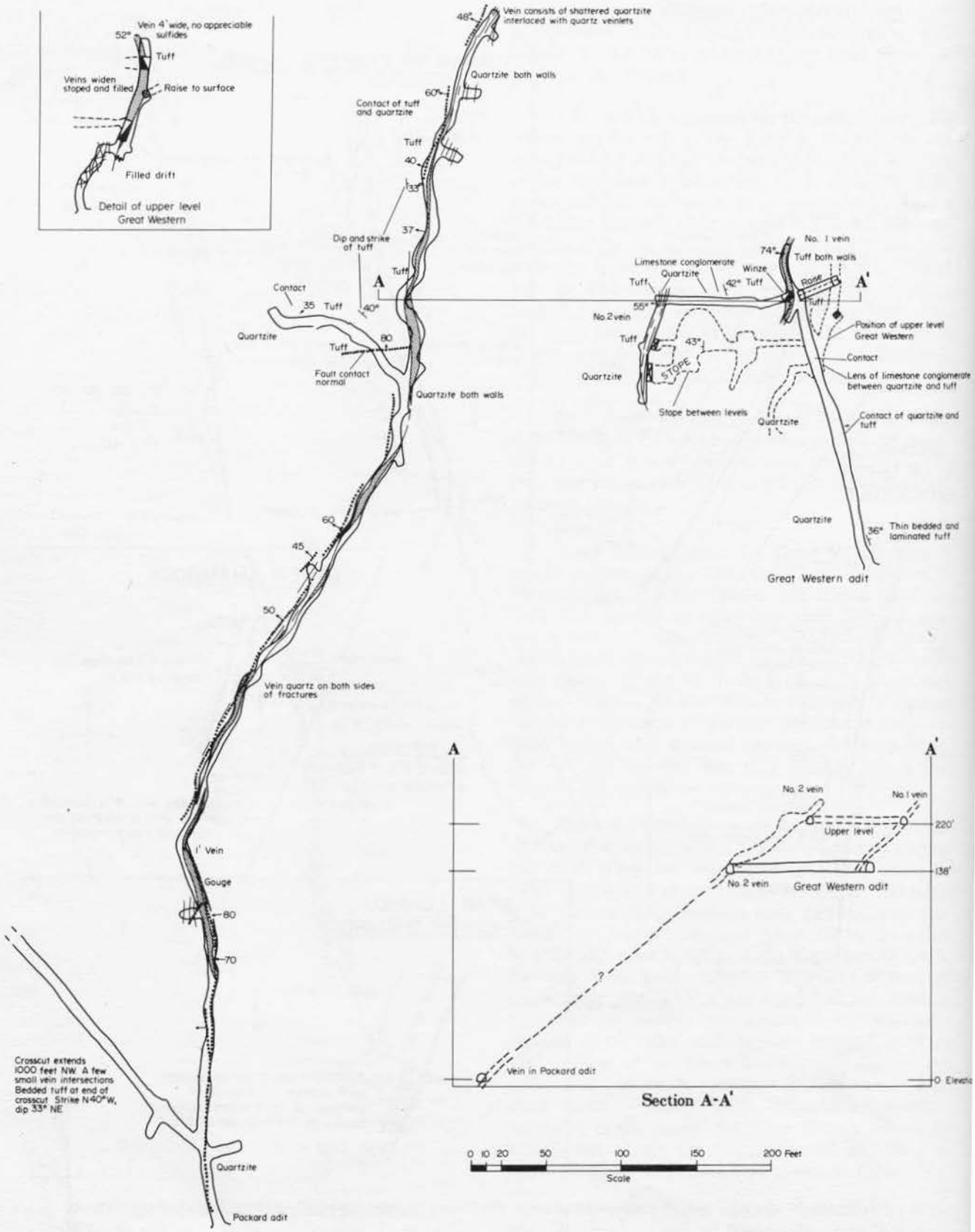


Figure 29. Geologic map and section of Great Western mine and Packard adit (adapted in part from surveys by E. M. Garrick and from surveys by E. Callaghan in 1938 and by E. Callaghan and Jared Haselton in 1972).

stoped above this level and from the upper level essentially to the surface. The stope lengths are about 50 feet so that the two ore bodies have a pipe-like appearance. The stopes are 3 to 6 feet wide. The stope on the west vein on the main level was mined between 1938 and 1950 and reportedly produced mainly lead. No records of production are available to the writer. The part of the main adit near the portal follows the strike of bedded tuff which dips 36° NE. The contact with underlying quartzite is reached 70 feet from the portal and followed all the way to a fault dipping 70° N. A lens of limestone conglomerate is preserved in a trough in the surface of the quartzite. The quartzite contact is offset 65 feet to the west on the north side of the fault and a thin layer of conglomerate lies between the quartzite and tuff. The west vein lies between a hanging wall of tuff and a footwall of quartzite.

The east vein in the outer portion of the upper tunnel is a breccia of quartzite cemented by quartz some 30 feet wide. Some pyrite occurs in the material as well as veinlets of coarse carbonate. The vein extending north widened to about 5 feet, but narrowed to 4 feet at the north end where it entered the tuff and where it contained no appreciable sulfides. The stope on the west vein was served by an adit 58 feet long N. 12° E. The vein was stoped above and below the adit. The east vein on the main level was followed for 50 feet and appears on both sides of the east-west fault; the structure, therefore, was present prior to mineralization.

The west vein on the main level stretches from N. 5° to 15° E. and dips about 50° W.; it was stoped to the surface.

In an account of the mineralogy, Evans (1953, p. 106-108) notes early quartz, siderite, fluorite, calcite and pyrite. Galena is the most abundant of the ore sulfides and tetrahedrite was found in crystal groups in fractures and open spaces. Sphalerite is sparse, and chalcopyrite was recognized only in polished surfaces of ore. Late crystal quartz covers surfaces of openings in the ore. Supergene or groundwater attack has produced azurite, malachite and chrysocolla. A thin coating of chalcocite was noted on surfaces of earlier sulfides. Tuff adjacent to the veins contains disseminated pyrite and silica, carbonate, chlorite and kaolinite. Weathering of pyrite has produced bleaching and argillization.

The drift in the Packard adit (figure 29) follows fractures and shattered quartzite cemented with quartz for 265 feet to a bend where the vein structure widens and the strike changes to N. 22° E. and N. 7° E. The dip is variable, but mainly about 50° W. The outer part of the drift is in quartzite, but the inner part reaches the contact with tuff. A crosscut starting 60 feet from the portal was driven 1,000 feet northwest and north; it is in quartzite for most of its length, but a branch near the end penetrates the tuff. Numerous small veins and an ore zone 8 feet wide are intersected by the crosscut.

A map (figure 30) showing locations of samples taken in the Great Western workings in 1967 and the corresponding assays (table 6) were provided by E. M. Garrick, Salt Lake City.

Four samples labelled Packard show a maximum of 0.05 ounces gold, 5.75 ounces silver, 3.55 percent lead and a trace of zinc; two show traces of gold and silver and less than 1 percent base metals.

Evaluation: Assays of samples mainly from the margins of old stopes in the Great Western workings indicate the metals are essentially lead and silver with minor copper and zinc and a consistently low content of gold. Two small ore shoots were mined, and a drift on a probable extension of the vein beneath the mined ore shoot did not reveal ore in spite of the presence of quartzite and bedded tuff as wallrock. Evidently the only exploration possibility is a search of significant mineralization northward from the present Great Western workings. A strong future demand for silver eventually may make the area attractive economically.

Tate Prospect. Several prospects and mineralized fractures lie on the north side of Bullion Canyon. A group of fractures in bedded tuff in the cliff face, west of the Packard adit and east of the quartzite block at Bullion Falls, is particularly conspicuous, but apparently has not been prospected. In the lower part of Bullion Canyon west of the prominent block of quartzite which disappears under volcanics is a group of workings all closed in 1972. They belonged to Dewitt Tate, who in the 1930's was a survivor along with Max Krotki and Jim Bolitho of the early prospectors. No maps are available. The workings evidently penetrated tuff and quartzite and may have penetrated post-ore rhyolite dikes which crop out conspicuously. Strong faults should go through the property, but the degree of mineralization is not known to the writer. The area is not included in the patented claims.

Copper Belt Mine. The Copper Belt was an early mineral location with its own U. S. Mineral Monument and a patented claim, Copper Belt 44. The claim is in the south central part of sec. 29, T. 27 S., R. 4 W., on the north side of California Gulch at an altitude of 10,150 feet. Ten patented claims were extended in an east-northeast direction down to the base of the mountain front in Revenue Gulch to the east side of sec. 28.

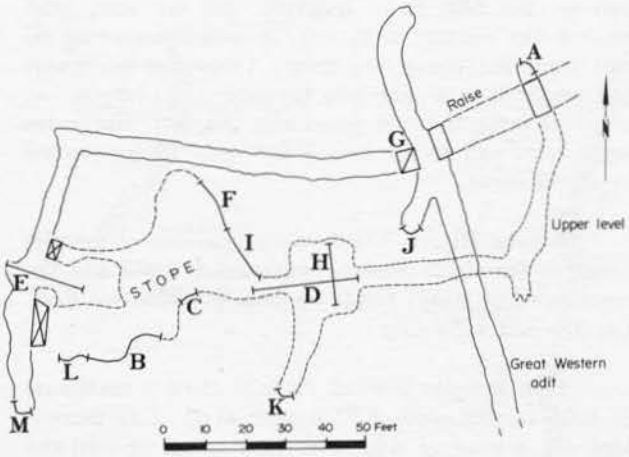


Figure 30. Map of Great Western workings showing locations of samples for assays shown in table 6 (adapted from map by E. M. Garrick).

Heikes (*in* Butler and others, 1920, p. 541) states that the property was developed in 1882 by a shaft 300 feet deep, and that the ore was treated in a 10-stamp mill in Bullion Canyon; 20 tons were shipped before June 1880. When the area was mapped in 1938, several pits and short tunnels, all closed, showed weathered rock and quartz vein material. As shown on the geologic map (Callaghan and Parker, 1962a) the mineralized zone strikes N. 75° E. A post-ore rhyolite dike is shown paralleling the mineralized zone. In the early 1930's Pat Henry drove a long tunnel from Revenue Gulch at an altitude of about 7,950 feet to reach a supposed downward extension of the Copper Belt. The distance would be some 6,000 feet. In 1972 it was reported the adit was cleared of caved material for 1,600 feet.

Mt. Baldy Mining District

Clyde Mine. The Clyde mine is on patented ground on the north side of Cottonwood Creek 2,000 feet west of its confluence with North Fork and at the west side of sec. 22, T. 28 S., R. 4 W. A number of workings entered quartzite and quartzite interbedded with shale, some of which dips steeply. The workings were closed at the time of the writer's investigations. Butler's (Butler and others, 1920, p. 557) comments are as follows:

> The Clyde mine is developed on a fissure vein striking west of north. The mine was idle at the time of visit and the workings were not examined. The ore on the dump consists of pyrite, chalcopyrite, tetrahedrite, sphalerite, and wurtzite in a gangue of quartz with some carbonate. The vein is developed by a winze from a tunnel several hundred feet above the bottom of Cottonwood Canyon. A second tunnel was driven near the bottom of the canyon, but no ore is reported. The mine is reported to have shipped a few carloads of copper-silver-gold ore.

Table 6. Assays of ore from the Great Western mine.

Sample no.	Length	Ounces/ton		Pounds/ton		
		Gold	Silver	Lead	Copper	Zinc
A	4	0.02	4.0	0.9	0.65	1.75
B	20	0.12	6.7	9.1	0.44	1.95
C	4	0.13	5.5	9.1	0.11	1.8
D	28	0.07	3.95	2.85	0.76	1.95
E	21	0.03	1.15	0.00	0.33	0.00
F	13	0.14	7.45	5.05	0.54	0.4
G	5	0.07	4.95	–	0.65	–
H	15	0.11	6.7	8.1	0.76	2.85
I	15	0.22	10.0	8.2	0.54	2.85
J	5	0.01	0.9	0.0	0.11	0.25
K	5	0.02	1.9	0.0	0.33	0.0
L	5	0.15	12.65	8.0	1.09	1.45
M	5	0.05	5.55	4.95	1.15	2.85

Crystal Mine. Three patented properties, Crystal, Park and Monte del Rey, were developed on the slope or ridge on the south side of Cottonwood Creek. The Crystal is at the top of a cliff of quartzite overlain by limestone conglomerate at the southwest corner of sec. 21 and the northwest corner of sec. 27, T. 28 S., R. 4 W. An adit entered the quartzite and a shaft and several pits entered the conglomerate. All were bulldozed out in recent years. The mill constructed in early years was dismantled. Butler (Butler and others, 1920, p. 557) noted that lead occurred with gold and silver in veins in quartzite. A comment in the *Salt Lake Mining Review* for 1900 indicates more than 1,000 feet of work were done on the property.

Park Mine. The Park mine is in the southwest corner of sec. 23 and the adjoining corner of sec. 22, T. 28 S., R. 4 W. Shafts, adits and pits penetrated the Bullion Canyon Volcanics 100 feet or so above the contact with underlying quartzite. The volcanics are altered on the ridge top above the workings. A concealed fault east of the workings drops the volcanics on the east side some 750 feet. Nothing is known by the writer of the configuration of the deposits or their metal content. The Valdasia tunnel driven from Cottonwood Creek southward in the 1940's by Pat Henry probably was designed to reach a downward extension of the mineralization at the surface.

Monte del Rey Mine. The Monte del Rey workings on the end of the ridge between Gold Gulch and Cottonwood Creek overlooking the Marysvale Valley in sec. 12, T. 28 S., R. 4 W. are covered by a group of patented claims. The geology is unusually complex. The quartzite (Navajo Sandstone) makes up most of the mountain front. It is overlain by limestone and other sedimentary rocks of the Arapien Formation which dips south on the north side and westward on the south side of the ridge at angles of 15° to 35°. The Jurassic formations are overlain unconformably by the Tertiary limestone conglomerate which dips gently

westward. A thick sill of intrusive latite was emplaced between the conglomerate and volcanics or perhaps within the upper part of the conglomerate. The veins trend northwesterly cutting the intrusive sill and a block of volcanics. Shafts and adits follow the veins. Data on the character of the ore are not available although a little gold and silver probably occurred with small amounts of base metal sulfides or their weathered equivalents.

Evaluation: The favorable situation of mineralized properties in relation to alteration of the enclosing rock should favor precipitation of ore minerals. The limitation of size suggested by the amount of development indicates an insufficient supply of ore elements to the fractures and bedding.

Lead and Zinc Replacement Deposits

Mt. Baldy Mining District

Deer Trail Mine. The Deer Trail mine, mainly in sec. 11, T. 28 S., R. 4 W. on the lower slope of Deer Trail Mountain (figure 31), has been and, except for the present smelter shortage problem, continues to be the principal producer of metals in the Marysvale region.[1]

The ore body, which has been explored and mined at intervals since its discovery in 1878, is remarkable in its configuration. The stopes form an almost continuous ribbon for the full length of the mine–some 4,000 feet. The width is mostly 100 feet or less, but in some places expands to 200 feet and in one area to 400 feet. For the first 2,400 feet the stopes are wide, but they narrow to less than 50 feet in the final 800 feet; they were reached by an incline or winze below the haulage level with levels extending to the ore. Flats and rolls in the footwall surface necessitated driving the haulage level in quartzite well below the ore. The overall trend of the axis in the workings is N. 45° W., but locally the trend is in a series of "dog legs" extending for as much as 1,000 feet N. 70° W. and 400 to 700 feet N. 8° W.

For most of its length the ore body followed the crest of a small northwest-plunging anticline and replaced three thin beds of limestone. The limestone is separated by intervening quartzite layers in the Toroweap Formation of Permian age immediately overlying a 500-foot thick bed of quartzite called "Coconino"

Figure 31. Lower part of Deer Trail Mountain at Deer Trail mine from southeast. Cliff of Permian Queantoweap of Talisman Quartzite near base at left; cliffs of Kaibab Limestone at left center. Plunging anticline at Deer Trail mine at right center. Dump of working level of Deer Trail mine at lower center.

by Kerr and others (1957, p. 12; 1963, p. 125; 1968, p. 1026), but called "Talisman" in this report. The ore ranged from 2 to 40 feet thick and consisted of the weathering products of replacement sulfide ore. The ore as mined looked like yellow soil and consisted of sericite, kaolinite, silica and jarosite with iron oxide, finely divided gold and silver, and some residual lead. Little gold could be panned. The ore was most persistent along the lowest of the beds next to the thick Talisman Quartzite, but in parts of shoots the ore crossed upward into other beds. The degree of mineralization decreased toward the limbs of the fold. On the surface above the mine, the dips on the limbs of the fold are as much as 45° E. on the east limb and 25° W. on the west limb. Whether the crest began to plunge near the collar of the inclined winze or the ore zone to turn down the west limb is not clear. The stopes in the area narrowed to 40 and even 20 feet. In spite of the tendency of the ore body to parallel the mountain front, the old workings are some 800 feet below the surface.

In 1945 Pat Henry obtained control of the Deer Trail property and started a long adit in the alluvium southeast of the old mine and some 600 feet lower. When the adit reached the vicinity of the old mine a raise was put through to the surface. The excavation was continued by Arundel Mining Co. through the thick quartzite and into the ore horizon. The ore at this level is lead and zinc sulfide with silver and a little gold, but is confined to a narrow ribbon as in the old workings. The ore body had departed from the crest of the fold and turned down the west limb. The ore departed from the upper surface of the Talisman Quartzite and climbed in the succession of thin beds of limestone and quartzite of the Toroweap Formation as the mine was deepened. Gypsum beds are preserved in

[1]Q. F. Treseder, vice president and manager of the Arundel Mining Co., which leases the property from the Deer Trail Mine Development Co., is preparing a detailed report on the property. The report will be published by the Utah Geological and Mineralogical Survey sometime in 1973-1974 so only a brief summary is presented here.

the unweathered Toroweap. The Talisman was shattered and mineralized in places along the course of the adit. No connection was made to the old workings so as to exclude the accumulated gas from the deep mine.

According to Heikes (*in* Butler and others, 1920, p. 542), from 1878 to 1882 the Deer Trail and other mines in the Mt. Baldy district produced 335 ounces gold and 321 ounces silver from 434 tons of ore. Butler (Butler and others, 1920, p. 556) estimated the value of all ore taken from the Deer Trail to 1917 was $150,000. Development, however, had continued and a mill was constructed near the portal of the lower or haulage level and placed in operation in 1918. Production as a company-type operation continued to 1923. Evidently, the mine was extended the full length of the broad stopes or 2,400 feet during this time.

Production during the period of company operation 1918 to 1923 was divided as shown in table 7.

From the averages, the gold content of ore that is fully oxidized is definitely higher than that of primary or incompletely oxidized ore.

Following this operation, lessees removed and shipped remnant ore from the stopes. U. S. Smelting and Refining Co. leased the mine in 1927, explored the farther reaches of the ore from the incline or winze and through 1929 shipped a small amount of ore to the smelter which averaged 0.5 ounces gold, 1 to 2 ounces silver and 0.1 percent copper. No lead was recovered. During the depression years, a considerable number of lessees worked in the mine removing pillars, scalping stope walls and sweeping the floors.

The production of the Arundel Mining Company from the sulfide portion of the ore body was in part recorded and distributed as shown in table 8. All the ore was treated at the Midvale mill.

The recoverable metal content per ton through 1969 is:

Gold	0.09	ounces
Silver	8.5	ounces
Copper	2	percent
Lead	5	percent
Zinc	10.1	percent

Production of sulfide ore is compared to production of fully oxidized crude ore from 1918 to 1923; a ton of oxidized ore has much greater volume so a greater gold content is expected.

Following the Midvale custom mill closing in November 1971, shipments were terminated although 16,000 tons of developed ore were known to remain in the mining faces. Unproved speculative ore projected at further depth is estimated at 64,000 tons or a total of 80,000 tons. At a rate of 10,000 tons per year, 8 years of production reasonably remain.

Table 7. Production of the Deer Trail mine, 1918 to 1923.

	Tons	Ounces/ton		Lead (percent)	Net smelter returns
		Gold	Silver		
Millheads	121,794	.465	9.64	2.45	
Crude	16,629	8.096	25.08	9.2	$552,658.87
Total	138,423				
Concentrates	7,789.59	2.454	41.07	17.47	687,674.43
Precipitates	89.893				924,329.27
					$2,164,662.57

	30 percent of shipments	70 percent of shipments
Composition of crude ore		
Ounces/ton		
Gold	1.44	0.533
Silver	28.66	23.54
Percent		
Copper	0.3	0.3
Lead	2.51	12.06
Zinc	1.0	2.7
Iron	10.0	7.0
Sulfur	2.0	6.0
Lime	2.5	4.5
Insoluble	54.0	45.0

Table 8. Production from the sulfide portion of the Deer Trail ore body, 1960 to 1962 and 1964 to 1971.

Year	Ore (tons)	Ounces		Pounds			Calculated value
		Gold	Silver	Copper	Lead	Zinc	
1960	376	62	3,871	8,800	15,000	66,700	$ 18,875
1961	2,197	407	16,322	12,600	122,300	477,600	100,636
1962	1,209	72	9,065	5,200	97,800	113,800	36,041
1964	6,987	545	33,764	10,100	557,900	1,009,400	137,278
1965	9,066	1,190	47,617	6,700	763,100	1,658,700	466,805
1966	10,428	886	58,067	21,100	945,500	2,045,900	553,289
1967	4,193	522	36,032	12,200	573,400	1,000,300	297,532
1968	4,836	287	57,932	29,700	600,700	997,800	362,005
1969	10,619	637	159,304	86,400	1,708,900	2,811,700	1,017,821
1970	10,150	362	165,676		1,863,500	2,890,800	1,040,057
1971	9,873						
Total	69,934						$4,030,339

The old mine was extremely dry and no appreciable water was found in the haulage level of the deep mine. Water, however, was reached some 200 feet below the haulage level. The mine is being kept open, air continues to be pumped from the shaft, and the timbering is maintained (1972).

Pluto Mine. The Pluto mine is near the top of the cliff of Kaibab Limestone at an altitude of 8,482 feet or about 1,000 feet above the lower tunnel of the Deer Trail and 2,000 feet to the south. It is covered by the Pluto 46 patented claim. When visited by the writer in 1937, the mine was essentially a quarry in the cliff face with overhanging rock supported by pillars. Penetration into the cliff face along the bedding was for a relatively few feet. Heikes (*in* Butler and others, 1920, p. 542) quotes Huntley as follows:

> The Pluto mine is on the mountain side above the Deer Trail. It was located in June 1879. It is a 20-inch vein in limestone. The ore contains horn silver in which particles of gold are visible. Seven tons of the sorted ore had been shipped and averaged about $100 gold and $200 silver per ton.

No other information on the property was obtained.

Quicksilver Replacement Deposits

Mt. Baldy Mining District

Lucky Boy Mine. The Lucky Boy mine was discovered prior to 1884. It yielded 213 flasks of mercury by retort during 1886 to 1887 and, as far as is known, is the only U. S. deposit of the selenides of mercury to be operated commercially. The mine is covered by patented claim Deer Trail 42A held by Deer Trail Mine Development Co. It is on the face of Deer Trail Mountain about 300 feet above the base, and the workings, which consisted of a drift and an open pit, are 900 feet S. 12° W. of the lower or haulage tunnel of the old Deer Trail mine.

Bethke (1957) wrote a comprehensive thesis on the geochemistry of sulfo-selenides of mercury based on Lucky Boy ore samples. Butler's account (Butler and others, 1920, p. 151-152) is quoted below:

> The quicksilver deposit of the Lucky Boy mine has been described. . . as follows [from a letter by J. E. Clayton, president of the Salt Lake Mining Institute, to G. J. Brush, of the Sheffield Scientific School, dated October 6, 1884]:
>
> The mine is situated about 5 miles southwest of Marysvale, 200 miles south of Salt Lake City. It is on the east face of a mountain slope and near a profound fault extending north and south. To the east are eruptive rocks, including porphyry and trachyte. Underlying the ore beds to the west is quartzite of unknown thickness, over this about 400 feet of gray limestone, and in contact between these the Deertrail vein is situated, carrying gold, silver, lead, and a little copper. In the upper portions of the limestone the selenide of mercury is found in a bed of shaly limestone 15 to 20 feet thick. The vein has been traced north and south about 100 feet along the outcrop and dips in the mountain at an angle of about 15° below the horizon. The ore occurs in masses intermixed with the shaly limestone, crystals being very rare. The accompanying minerals are barite, oxide of manganese, quartz, and calcite. The ore bed is overlain by a yellowish sandy lime shale carrying sub-Carboniferous fossils.
>
> The locality was visited by the writer in 1910. . . The workings of the Lucky Boy mine just north of Cottonwood Canyon form a bowl-shaped open cut about 100 feet in diameter and 60 feet deep, a drift to the west about 80 feet in the mountain following the gently dipping bedding planes, a tortuous winze from the face of the drift turning back and coming out on the mountain side about 50 feet below the open cut, and a shaft at the bottom of the open cut, now filled with broken rock, reported to have been sunk about 40 feet on a north-south narrow nearly vertical vein carrying barite and some cinnabar. The cinnabar ore, it seems, was of low grade, and the commercial ore was mainly of onofrite and to a smaller degree of tiemannite, the sulphoselenide and the selenide of mercury, which were found in a deposit from 2 to 8 inches thick, following the bedding planes and impregnating the impure dark-gray limestone. Tiemannite was reported also from the barite vein, and the fissure here may have been the channel for the ore solution. The intersection of this fissure with the bedding vein would be about where the open cut now is, and indeed much of the original deposit has probably been eroded away. The deposit was evidently superficial, for the life

of the operations was short, the total output small, and it is now difficult to find even samples of ore in the workings. The occurrence is of especial interest as being the only deposit of the selenides of mercury in the country ever worked on a commercial scale, however small. The reduction was by two retorts operated in Cottonwood Canyon to the south of the mine. In the Deertrail gold mine, several hundred feet vertically below the Lucky Boy, and along the gently westward-dipping bedding planes at the quartzite and limestone boundary, cinnabar with pyrite was reported in a small lens. The deposition of quicksilver minerals in both properties may have been due to solutions arising through the same vertical north-south fissures thought to extend parallel to the great Sevier fault, and may have been localized by transverse fissures similar to those known elsewhere in the district.

. . . the production of mercury from the mine [is estimated] as 213 flasks, valued at $8,308.

According to Bethke (1957, p. 28-107), the mercury selenide minerals occurred in a limestone lens in the Toroweap Formation about 210 feet stratigraphically above the top of the Talisman Quartzite which is the horizon of the Deer Trail ore body. The ore bed dips about 15° westerly into the face of the mountain and is underlain by a quartzite bed 15 feet thick. The ore horizon is cut by a vertical north-south fissure of slight displacement which is filled with barite and contains mercury minerals. Bethke believes that the open pit was excavated to follow the vein rather than the mineralized bed which is 19 feet thick. In the limestone bed the ore minerals occurred in small masses and lenses parallel to the bedding, probably mainly in the lower portion. A small amount occupied fractures crossing the bedding. The ore minerals were concentrated in thin shaly layers, but expanded into and replaced portions of the adjoining fine-grained limestone. Some of the calcite of the limestone was leached and made into a porous aggregate with limonite coating, possibly a weathering effect. Barite, quartz and calcite developed in the limestone as a phase of the mineralization. The ore minerals were almost completely removed from the containing layer and were not found in the drift driven along the ore bed. Samples for study were retrieved from the slope below the mine where they presumably bounced out of the chute which conducted the ore to the base of the slope.

The minerals consist of (in order of deposition): barite, pyrite, sphalerite, minerals of the metacinnabar series—tiemannite, onofrite and metacinnabar—cinnabar, calcite and quartz. Pyrite and sphalerite occur in small amounts. Barite possibly was deposited throughout most of the mineralization epoch, but was found to cut minerals of the metacinnabar series which are cut by quartz and calcite. Cinnabar seems to be an associate of quartz. The minerals of the metacinnabar group form a solid solution series from mercuric selenide (tiemannite) through mercury sulfur selenide (onofrite) to mercuric sulfide (metacinnabar) which is black rather than red. Cinnabar is the red variety of mercuric sulfide which contains 86.2 percent of mercury. The mercury content of mercuric selenide is between 71.20 and 75.49 percent.

The Lucky Boy is the only known occurrence of mercury selenide extracted commercially in the United States, but early miners noted the occurrence of quicksilver in ore of the Deer Trail, Annie Laurie and Bullion Canyon mines. Bismuth was noted in the Iris ore, and antimony as stibnite is relatively abundant in the Coyote district some 25 miles from the Mt. Baldy and Ohio mining districts. These elements are characteristic of late phases of volcanic activity; selenium ordinarily is subordinate to sulfur so the dominance of selenium in the Lucky Boy is unique. Tellurium also has been reported in the Marysvale region.

Evaluation: The Lucky Boy deposit of mercury and selenium is worked out and other leads to deposits are not known. Any metal occurrence in the area, however, should be tested for these comparatively rare elements. Mercury in November 1972 was valued at $3.34 per pound, selenium $9.00 per pound, tellurium $6.00 per pound, antimony $0.57 per pound, and bismuth $4.00 per pound.

Uranium Veins and Disseminated Deposits

Henry Mining District

At the height of activity in the Marysvale area where uranium was discovered in 1949, some 2,000 claims were located; profitable mining, however, was confined largely to about ten mines. Eventually about 10 miles of underground workings were excavated. Radiometric responses were widespread, but the major production was confined to a group of veins in an area some 3,000 feet long and 1,500 feet wide in intrusive quartz monzonite and associated granite and neighboring rhyolite in the Antelope Range a short way north of Marysvale (figure 32). The primary ore mineral is pitchblende in veins tested by drilling some 1,500 feet below the surface and mined to depths of 600 feet. Oxidation uranium minerals formed within 100 feet of the surface, but pitchblende associated with dark fluorite, quartz, pyrite, adularia and some magnetite is the principal ore mineral. To 1967, the estimated production is 275,000 tons averaging 0.20 percent U_3O_8.

Nearly all aspects of the geology and occurrence of uranium at Marysvale are treated comprehensively by Kerr and others (1957, 212 p.) and by Kerr (1963, p. 125-135 and 1968, p. 1020-1042). El-Mahdy (1966) treats wallrock alteration and ore genesis in the Freedom No. 2 and adjacent mines.

Figure 32. Northeast view of uranium mine area in Antelope Range from Beaver Creek road. Red ignimbrite variety of Mt. Belknap Rhyolite in near part of mountains; quartz monzonite in distance.

Uranium and its dissociation products are pervasive elements and occur in a wide variety of situations. The pitchblende at Marysvale was dated at 10 to 13 my or the end of the Miocene or beginning of the Pliocene. It is younger, therefore, than all the formations, except the Sevier River Formation and accompanying basaltic lavas. The uranium mineralization and associated alteration is younger than the quartz-chlorite-sericite-carbonate alteration preceding or accompanying the precious metal-base deposits, and all the alunite alteration, except for the possible small amount that may have accompanied the uranium mineralization. This means that uranium mineralization has been superimposed on older rocks, structures or mineral deposits. Because the weathering products of uranium minerals move readily with groundwater into faults, older mineral deposits, spring deposits and porous rocks or opal layers, such materials may display radioactivity detectable by sensitive devices. This situation led to location of many mining claims containing no commercial uranium deposits. The radioactive gas, radon, which strongly affects counters, accumulates in mine workings or other nonventilated areas and moves with the air from place to place.

A diagrammatic plan and section of the veins in the central mining area adapted from Kerr (1968, p. 1031-1032) is shown in figure 33. Mining eventually was systematized by sinking the vertical Vanadium Corp. shaft to the 300-foot level about 470 feet below the collar, or at an altitude of about 6,340 or 6,350 feet. The level was extended as a crosscut 1,050 feet northward to the Freedom No. 2 mine and south 1,000 feet to the Prospector mine. Workings in both mines extended above and below the 300 level and a depth of 1,500 feet below the surface might be reached by commercial operations. The veins trend N. 55° to 65° E. and tend to be nearly vertical. The ore-bearing portions of the veins or ore shoots range in length from less than 100 to 1,500 feet and tend to be vertical. The ore-bearing portion of the vein is 4 to 5 feet wide, although it was as much as 20 feet thick at vein intersections or at junctions of branches.

The productive veins were mainly in the quartz monzonite intrusive body but extended into granite and overlying rhyolite. The quartz monzonite intrusive with an isotopic age between 23.6 and 26.0 my was uncovered by erosion. Both Red and Gray facies of the Mt. Belknap Rhyolite, which have an isotopic age of 13.7 to 20 my, were deposited on the erosion surface. The red ignimbrite-type rhyolite covered the quartz monzonite and erupted through it. Glass or pitchstone dikes cutting through the granitoid rock were noted in many places in the mine workings. Aplite dikes which are closely related to the intrusive rock and are part of the same sequence also were noted underground. Where Red Rhyolite covered a channelway of uranium mineralization, the ore minerals and the accompanying fluorite were spread out through the fractures in the rhyolite–particularly at the Bullion Monarch open pit where rhyolite immediately above the contact with quartz monzonite was sufficiently mineralized to be ore. Several mineralized areas in rhyolite are shown on figure 33. In the Cloys-Potts area lens-shaped ore bodies 10 to 50 feet in diameter and as much as 30 feet high were found in the rhyolite. Other ore bodies have occurred in the rhyolite adjacent to the contact and in the vicinity of veins in the quartz monzonite. Some of the veins were not highly mineralized suggesting that they were channelways and that the ore fluids were drained into the highly fractured rhyolite. Penetration is about 50 feet above the contact. Occurrences of radioactive material in the Bullion Canyon Volcanics have not proved of minable grade. An occurrence in Paleozoic rock in the new tunnel of the Deer Trail mine was not productive.

Kerr (1968, p. 1039-1040) noted that argillic alteration, change of feldspar to clay or kaolinite, accompanied the uranium mineralization, and he assigned considerable areas of clay alteration to this epoch. He found that alteration in quartz monzonite associated with uranium veins varied in intensity and could be divided into stages which he summarizes as follows:

Stage 1: (Incipient alteration in quartz monzonite) In the vicinity of the veins, the quartz monzonite is a hard, resistant, tenaceous rock. However, altered andesine and pyroxene are common. Other minerals of the wall rock are essentially unaltered.

Stage 2: (Gray-green chloritic band) Chlorite completely replaces augite and replaces biotite in part. Montmorillonite and kaolinite form at the expense of andesine. Calcite veinlets are apt to form. The quartz and orthoclase of the quartz monzonite remain essentially unaltered.

Stage 3: (Gray-white argillic band) Kaolinite and montmorillonite form the major alteration. Orthoclase becomes partly sericitized. Thin veinlets of fluorite become evident. Chlorite tends to be replaced by the clay minerals.

Stage 4: (White argillic band) Andesine, augite, biotite and chlorite are largely replaced by kaolinite. Orthoclase is largely replaced by illite and sericite. Original quartz has largely disappeared and fine-grained recrystallized quartz is prominent. Fluorite is present.

Stage 5: (Pitchblende-bearing core) Pitchblende, black fluorite, and fine pyrite are present. Fine-grained quartz and sericite are prominent. Kaolinite and illite are present but have been partly replaced by quartz, sericite and pitchblende.

The stages may occur 10 feet or less from the center of a vein and may vary in width along the course of the vein. Alteration along veins in granite differs from that in quartz monzonite in that zones tend to be narrower in the granite and stage 1 is marked by partial sericitization of oligoclase and slight sericite encroachment on orthoclase. Biotite is bleached to chlorite, and pyrite and fluorite are introduced. Kaolinite and montmorillonite are introduced in stage 2, and in stage 3 all the plagioclase is changed to kaolinite and montmorillonite, and kaolinite veinlets are formed. The final or most intensive alteration in the granite is marked by maximum kaolinization of silicate minerals and introduction of cherty quartz, pitchblende and black fluorite. Dikes of brown glass may be altered to glass with a zeolite mineral, to montmorillonite or to montmorillonite and illite, and the dike may become a solid mass of clay. In a final stage pitchblende, pyrite, calcite and fluorite are introduced.

El-Mahdy (1966, p. 106-107) concluded that pyrite formed up to 15 percent of the primary vein material and that the alteration zone in the deep levels of the mines is mostly 2 to 7 inches wide in contrast to 6 to 8 feet in the upper levels. He regards the clay minerals as formed by supergene processes through alteration by sulfuric acid released from weathering of pyrite and kaolinite as having formed by leaching of montmorillonite.

The primary uranium mineral is extremely fine crystalline pitchblende intimately associated with pyrite and fluorite. It commonly is limited to blobs and veinlets, but rare masses a foot in diameter occur. Dark fluorite, quartz, pyrite, adularia and minor magnetite accompany the pitchblende as well as rock fragments in various stages of alteration. A new mineral, umohoite, a hydrated compound of uranium and molybdenum oxide, occurs in some places. Molybdenum is as abundant as uranium in the deposits, but is not saved in the treatment process in the mill. The primary minerals are subject to weathering through the downward percolation of air and groundwater and, within a depth of 50 to 100 feet or rarely 200 feet below the surface, are changed to a variety of oxidation minerals. They are listed by Kerr (1968, p. 1038) as (1) hydrated sulfate–uranopilite, (2) hydrated silicates–uranophane and beta-uranotite, (3) hydrated carbonate-schroekingerite, and (4) hydrated phosphates–autunite, metaautunite, metatorbernite and phosphuranylite. Of economic interest, the uranium content of the weathered zone remains the same as in the primary ore. No enrichment was noted. Kerr and others (1957, p. 60-98) list and describe the secondary minerals.

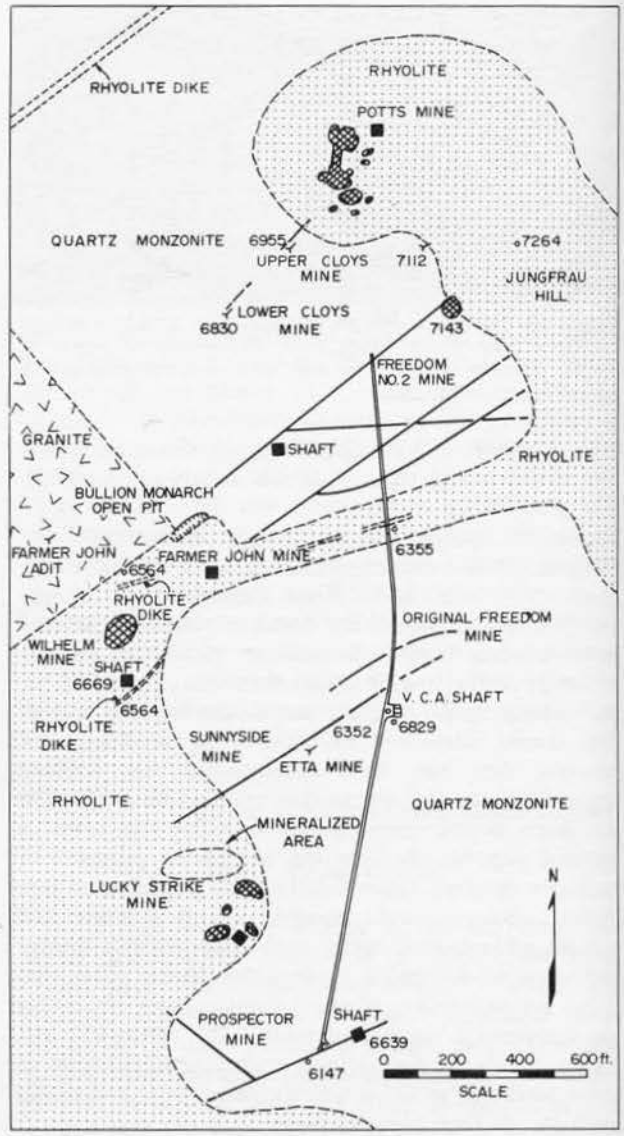


Figure 33. Sketch map of central uranium mine area near Marysvale. Surface projections of main veins shown by heavy lines and shallow workings in rhyolite are cross-hatched. Enlarged section (page 51) shows distribution of veins found in long crosscut from VCA shaft (modified from Kerr, 1968, p. 1031-1032).

Evaluation: Although all the known ore of commercial grade, as defined at the time of closing the operating mines in 1966, was extracted, demand and price increases could stimulate search for extensions of

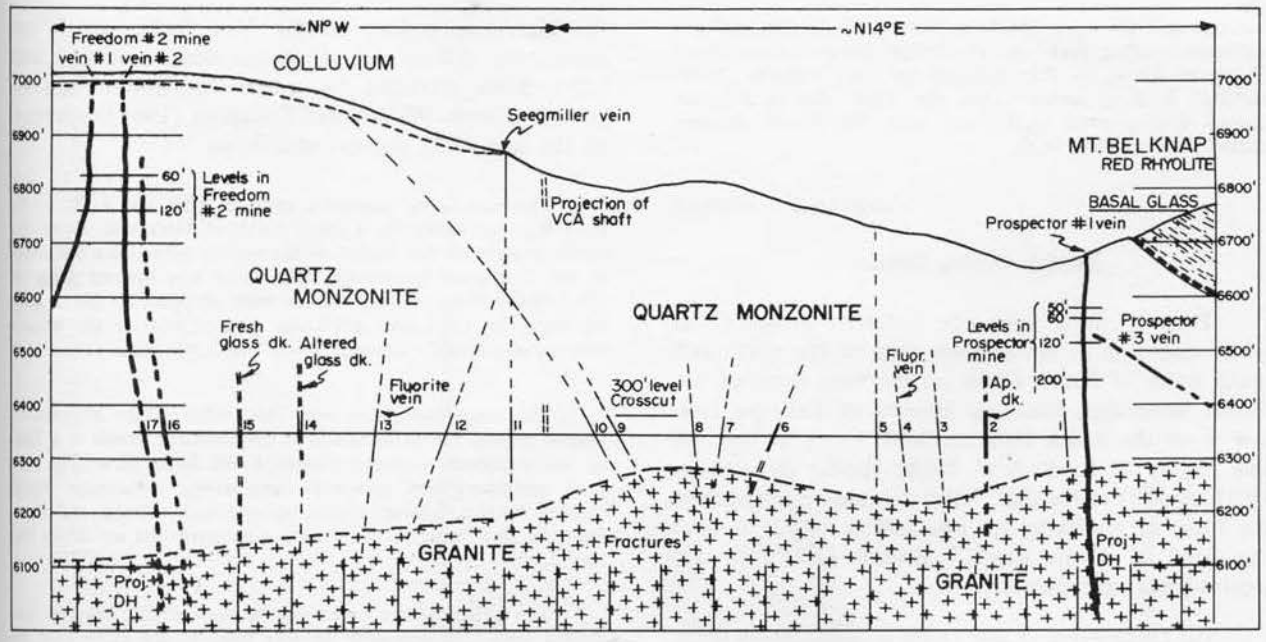


Figure 33. (continued)

old ore zones or for new bodies. Much drilling and exploratory drifting has been done, but the restricted dimensions of minable ore bodies makes them difficult to locate. More small bodies probably will be found when incentives are available.

Newton Mining District

The Newton district lies along the west base of the Tushar Mountains, 10 miles northeast of Beaver in Beaver County. Locations of the mine and prospects are shown in plate 2. The following is quoted from Callaghan and Parker (1961a):

> Uranium deposits occur in the canyons of Indian Creek and North Fork of North Creek. Prospects at Indian Creek were first described by Wyant and Stugard (1951). The following descriptions are based on a written communication by J. F. Powers and A. O. Taylor.
>
> In general, the uranium deposits occur in shear zones in the Mount Belknap rhyolite or in altered zones along faults in the Bullion Canyon volcanics. Uranium minerals in the deposits are chiefly secondary–autunite, torbernite, and minor uranophane (?). An unidentified mineral associated with pyrite in the lower workings of the Mystery-Sniffer mine may be pitchblende.
>
> Uranium mines and prospects and their locations are tabulated below:

Mystery-Sniffer mine	Sec. 28, T. 27 S., R. 6 W.
Little Sisters prospect	Sec. 33, T. 27 S., R. 6 W.
Prince prospect	Sec. 34, T. 27 S., R. 6 W.
U-Beva prospect	Sec. 10, T. 28 S., R. 6 W.
Big Sugar prospect	Sec. 9, T. 28 S., R. 6 W.
Canary prospect	Sec. 16, T. 28 S., R. 6 W.
KO prospect	Sec. 21, T. 28 S., R. 6 W.
HBH prospect	Sec. 21, T. 28 S., R. 6 W.

The principal uranium deposit in the quadrangle is the Mystery-Sniffer. In 1954 it had been explored by 975 feet of underground drifts and crosscuts and by six bulldozer trenches. The deposit is in an intensely argillized zone along a normal fault that separates latite of the Bullion Canyon volcanics from Mount Belknap rhyolite. The irregular zone trends east-west and dips 30° to 60° north for approximately 1,000 feet and ranges in width from 20 to 100 feet; it contains uranium minerals in lenticular shoots. Ore minerals are autunite, torbernite, and pitchblende (?) which occur with purple fluorite, pyrite, and quartz. Selected samples from underground workings ranged from 0.02 to 0.30 percent U_3O_8.

The U-Beva prospect, consisting of several hundred feet of bulldozer trenches, 90 feet of underground workings, and two pits, is in a fault zone in altered Bullion Canyon volcanics just below the contact with the overlying Mount Belknap rhyolite. The zone, which is only a few feet wide, can be traced for about 140 feet. At the surface a mineralized lenticular shoot containing disseminated autunite and torbernite averages 2 feet in width and is about 30 feet in length. Underground the shoot is about 10 inches in width and 14 feet in length. Surface samples averaged less than 0.05 percent U_3O_8, but underground channel samples across the shoot assayed 1.10 percent U_3O_8 for an 0.8-foot cut and 0.42 percent U_3O_8 for a 3-foot cut.

The KO, Canary, Big Sugar, and HBH prospects are all small prospects in altered zones along faults in the Bullion Canyon volcanics. Except for the HBH prospect in which no uranium minerals were identified, the deposits, like others in the area, contain autunite and torbernite. Selected samples assayed 0.095-0.225 percent U_3O_8 for the KO prospect, 0.032 percent U_3O_8 for the Canary prospect, 0.088 percent U_3O_8 for the Big Sugar prospect, and 0.012-0.019 percent U_3O_8 for the HBH prospect.

The Little Sisters and Prince prospects are small prospects that are entirely in the Mount Belknap rhyolite. At the Little Sisters prospect autunite and uranophane (?) locally coat

fractures and fill open spaces in brecciated rhyolite along a northwest-trending fault. At the Prince prospect uranophane (?) occurs locally as thin coatings on joint surfaces in the rhyolite. A grab sample from the Little Sisters prospect assayed 0.49 percent U_3O_8; one from the Prince prospect assayed 0.041 percent U_3O_8.

Tungsten Occurrences

Newton Mining District

Possibly more than one tungsten prospect has been uncovered in the drainage area of the north and south forks of North Creek on the west slope of the Tushar Mountains. The map location of Tungsten Hollow is on the South Fork of North Creek in secs. 24 and 25, T. 28 S., R. 6 W. Butler (Butler and others, 1920, p. 558) states that "veins containing tungsten in the form of wulfenite are reported as occurring near the head of North Creek." Everett (1961, p. 42) locates the Louise claims:

> The Louise group of four claims is on Pole Creek in the Fish Lake National Forest, Tushar Range, about 10 miles east of Beaver. The property is in T. 28 S., R. 6 W., and is reached by traveling the north fork of North Creek and then up Pole Creek. The claims are owned by P. A. Puffer and LeRoy Lessing of Beaver.
>
> Hubnerite has been found in quartz stringers ranging from 1 to 6 inches in width. The host rock is porphyry. The hubnerite is sparsely scattered through the quartz and in vugs. Workings include a 40-foot adit and surface pits which have caved and are partly filled. No ore has been produced, and there are no known ore reserves.

The geologic map of the Delano Peak quadrangle (Callaghan and Parker, 1962a) shows a small intrusive body in the South Fork near Tungsten Hollow and a larger body associated with areas of altered Bullion Canyon Volcanics at the head of Pine Creek between Pole Creek and South Fork. No intrusive is shown on Pole Creek, but some prospects in Bullion Canyon Volcanics occur on the south side of Pole Creek in sec. 22, T. 28 S., R. 6 W. No other information is available to the writer. This occurrence as far as known represents the east limit of tungsten mineralization which is prominent in the Mineral Range and other areas in Beaver County.

Evaluation: The small size of the veins precludes finding commercial tungsten deposits.

Iron Deposits

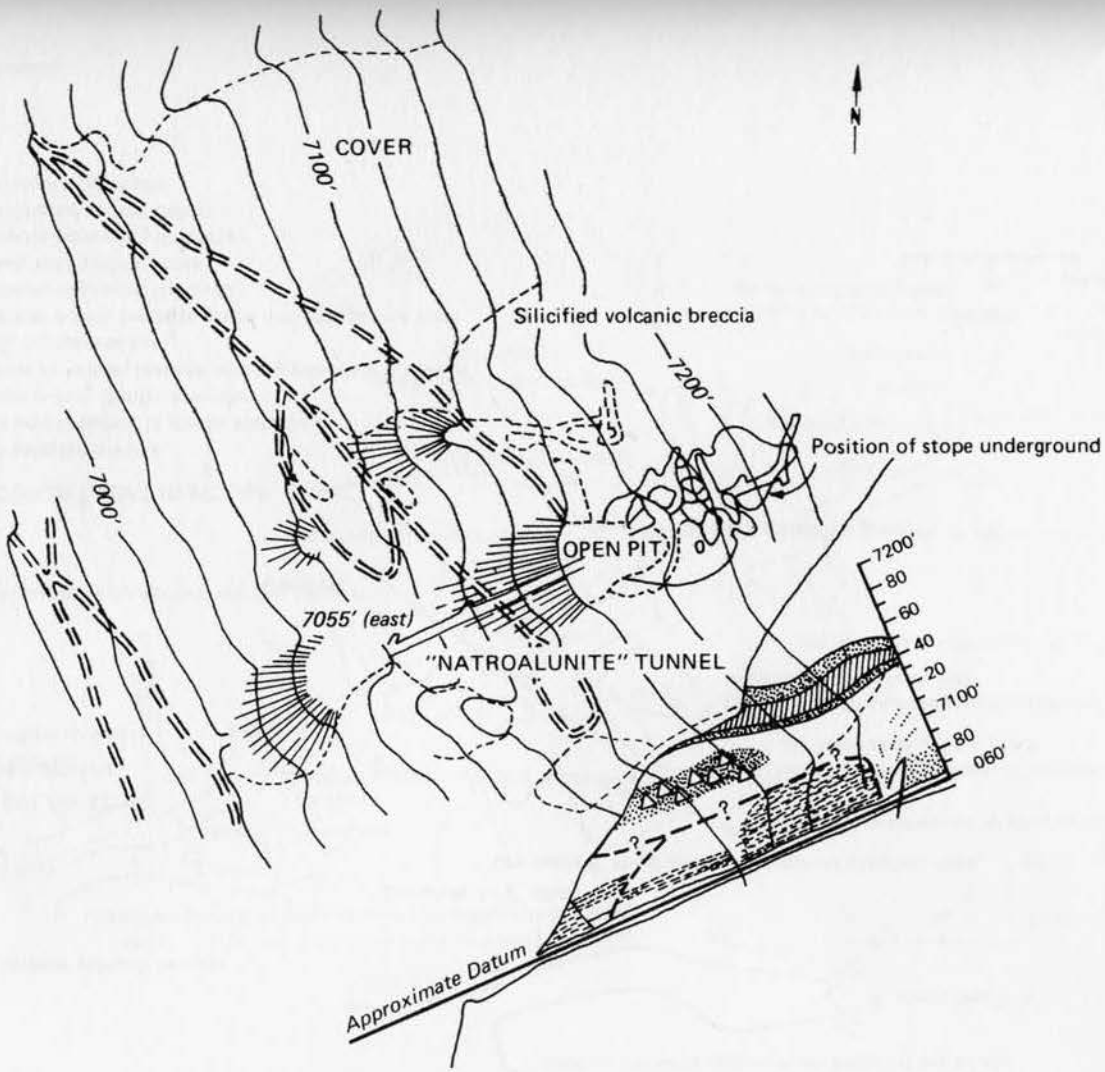
Henry Mining District

Multimillion-ton deposits of iron ore are associated with quartz monzonite intrusive bodies of Tertiary age in Iron County, Utah (Bullock, 1970, p. 23-63) and similar ores might occur near intrusives in the Marysvale region. In the Iron Duke, which was prospected and mined, magnetite was introduced into latite flows intruded by quartz monzonite and its granitic phases. Willard and Callaghan (1962) comment on the Iron Duke deposit as follows:

> The Iron Duke magnetite mine in SE¼ sec. 4, T. 27 S., R. 3 W., approximately 3 miles north of Marysvale, is on the south contact of the largest of the quartz monzonite intrusives in the Marysvale quadrangle. The mine was opened prior to 1911 and several carloads of ore were shipped to the smelter for flux. In 1911 and 1912 the greater part of the known reserves was mined—between 2,000 and 3,000 tons.
>
> The magnetite at the Iron Duke mine occurs in irregular-shaped masses and veinlets and as disseminated grains in a fine- to coarse-grained contact-metamorphosed latite flow. The contact metamorphism produced magnetite, orthoclase, light-colored biotite, quartz, augite, apatite, and titanite. All these minerals also occur in the quartz monzonite but are much less abundant.
>
> The principal ore body was nearly vertical, roughly lens shaped, and approximately 95 feet long. In the glory hole the lens was 10 feet wide; 40 feet below the glory hole the mineralized zone was 40 feet wide, but pinched sharply toward the ends of the lens.

Another iron deposit of completely different character, on a sharp peak capped by silicified volcanic breccia in sec. 15, T. 26 S., R. 3 W., was mined and the ore shipped to smelters in Salt Lake City area for flux. The deposit, called the Iron Cap, is described briefly by Callaghan and Parker (1961a) and by Bullock (1970, p. 72 and 74-75). A sketch map and section are shown in figure 34. The main ore body was a lens having its longest axis in a N. 67° E. direction, for a length of 120 feet at an altitude of approximately 7,140 feet. The width was about 30 feet maximum and the stope height reached a maximum of 14 feet. The west part was mined in an open pit, but the stope extended underground, first curving down and then curving up sharply east. Remnants of the ore preserved in pillars and around the margin consist of delicately layered soft yellow ochre interlayered with firm limonite. The layering was not horizontal but tended to conform to the shape of the body. Hard, stalactitic limonite occurs as porous masses at the margins of the stope.

For most of its 280-foot length, a crosscut tunnel driven about 70 feet beneath the stope shows variably altered volcanic breccia which is silicified only at the innermost 40 feet of the level. The breccia fragments are mostly white, but the matrix remains dark. The soft white material also occurs as veins through the altered rock, particularly in the inner 70 feet where there are several short drifts. If hammered, the dark or even white material leaves a red streak. The white material on analysis proves to be natroalunite.

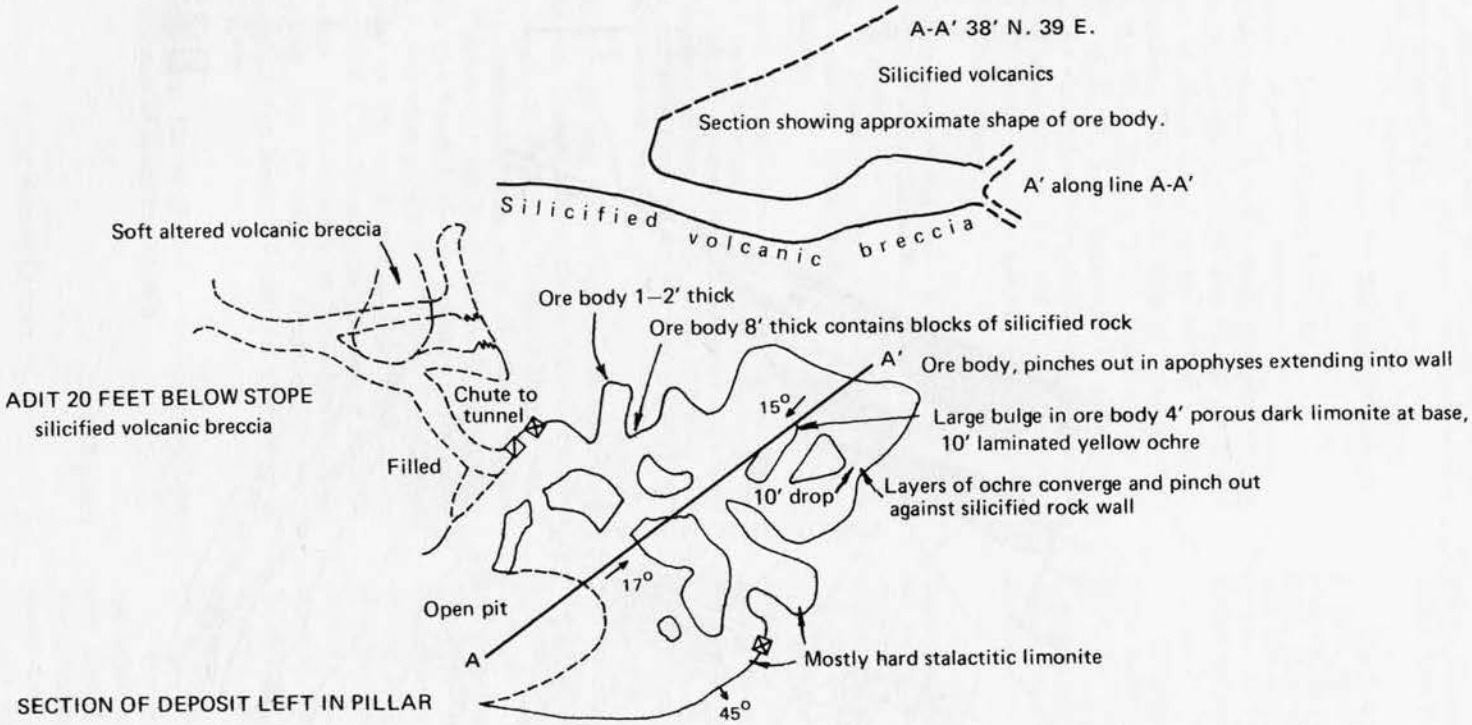


Iron ore
Silicified breccia
Alunite

0 50 100 Feet

Surface and Section
Contour Interval 20 Feet

Figure 34. Surface and underground geologic map of Iron Cap mine (continued on next page; surveyed 1938 by E. Callaghan).



SECTION OF DEPOSIT LEFT IN PILLAR

Top – silicified volcanic breccia
0.2' – porous crusty limonite in places stalactitic
0.4' – soft yellow ochre, thinly laminated
1.0' – hard yellow to brown banded ochre, apparently siliceous
0.5' – soft black manganese ore
0.5' – red to yellow ochre, tends to grade into manganese layer
0.4' – hard siliceous appearing limonite
1.0' – moderately soft yellow ochre
0.2' – hard siliceous appearing limonite
1.2' – thinly laminated yellow ochre
1.0' – porous siliceous aggregate
6.4' – Total

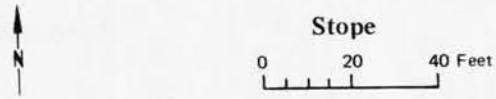


Figure 34. (continued)

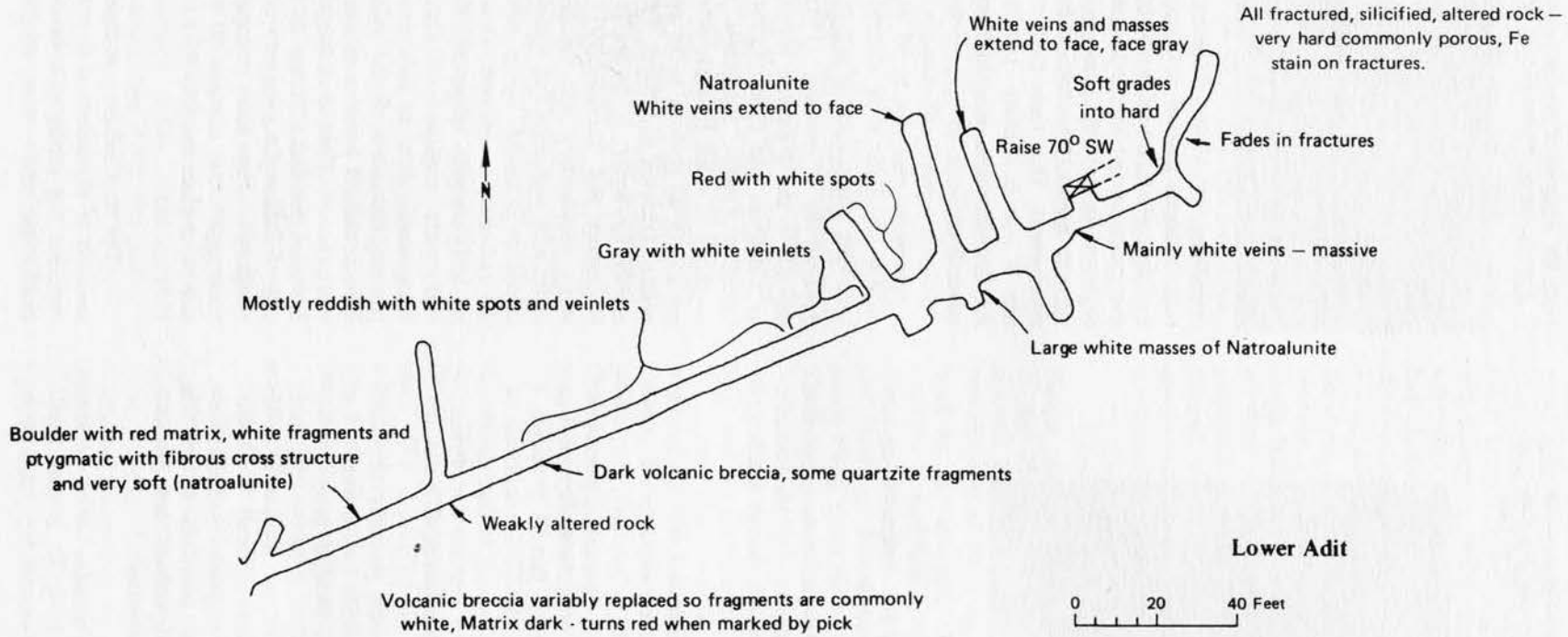


Figure 34. (continued)

Table 9. Chemical analyses of iron and manganese oxides from the Iron Cap mine (Michael Fleisher, U. S. Geological Survey, analyst).

	Yellow ochre	Soft black ore
SiO_2	1.30	0.42
Al_2O_3	1.32	none
Fe_2O_3	84.98	9.04
FeO	none	–
MnO_2	–	83.51
MgO	.48	.85
CaO	.18	none
BaO	–	2.77
K_2O	–	.80
Na_2O	–	.26
H_2O^-	.24	.22
H_2O^+	10.64	2.21
TiO_2	none	none
SO_3	none	none
MnO	.64	–
P_2O_5	.05	.35
Total	99.83	100.43

The compositions of the iron ore and of the manganese oxide layer (Callaghan and Parker, 1961a) are given in table 9. Table 10 lists analyses of samples of the iron ores.

Callaghan and Parker give the known production as 960 tons, mined and shipped by Max Krotki. Limonite was prospected in vein-like bodies in silicified rock continuing up the slope.

The hill is composed mostly of volcanic breccia and all the iron and natroalunite workings are in the breccia. The upper portion is silicified, but the workings below show the silica penetrating the underlying altered rock in root-like projections. Examination of the silicified material shows that it preserves a variety of structures, such as the fibrous structure of natroalunite veins. The interpretation is that silicification replaced rock altered by a previous and different type of solfataric activity, rather than fresh rock.

The limonitic iron deposits probably originated from the weathering of iron sulfide masses emplaced as part of the solfataric process, possibly prior to silicification. The origin of the layering in the iron oxide and the separation of a layer of manganese oxide essentially free of iron are more difficult to explain. The oxidation of the sulfide probably took place below the groundwater table providing a favorable situation for reorganization of material and the creation of a pseudosedimentary structure.

Evaluation: The limonitic ore bodies or their sulfide progenitors, compared to the present multimillion-ton sources for iron ore, are too small to be considered. The Carmel Limestone occurs in the Marysvale region as part of the Arapien, as it does in the iron deposits in Iron County, but contacts with intrusive rocks are not exposed. Although magnetite is concentrated in volcanic rock at the contact with large intrusive masses, the situation does not favor large-scale replacement. That these particular intrusive bodies are rich in iron is unlikely. Limestone conglomerate near the large intrusive mass in Marysvale Canyon was not mineralized.

Table 10. Analyses of samples of iron ores from Krotki iron deposit, Henry mining district (from Bullock, 1970, p. 8).

Location	No. of samples	Percent				
		Fe	SiO_2	S	P	Mn
Krotki iron deposit, Antelope Range, stalactitic massive ore	5	57.7	4.77	0.08	0.024	1.27
Krotki iron deposit, Antelope Range, ocherous ore in tuff	3	51.2	1.60	0.04	0.028	1.48

Manganese Occurrences

The occurrence of manganese in west Utah was detailed by Crittenden (1951, p. 1-62) and two deposits in the Marysvale region are mentioned briefly by Callaghan and Parker (1961a) and by Willard and Callaghan (1962). Manganese is a pervasive element occurring in small amounts everywhere. It averages 0.1 percent in all igneous rocks compared to iron at 4.6 percent (Hawkes and Webb, 1962, p. 22). Transported readily by water, it occurs in many spring deposits (Callaghan and Thomas, 1939, p. 905-920) and in many sedimentary and metamorphic rocks. It associates with carbonate and commonly is hidden in white calcite or dolomite, but is released as an oxide when the carbonate is removed. Thus the weathered parts of all hydrothermal epigenetic mineral deposits in the Marysvale region contain manganese residues. Manganoan calcite or dolomite may contain 5 to 25 percent manganese. Some calcite is black or brown from contained particles of manganese oxide. Manganese carbonate, rhodochrosite, which was noted on the dump of the Dalton mine on the slope on the south side of Bullion Canyon, may contain 25 to 48 percent manganese. The black manganese oxides are much richer; pyrolusite contains 60 to 63 percent manganese and psilomelane contains 47 to 51 percent (Crittenden, 1951, p. 10).

The steel industry at Provo could absorb certain amounts of manganese if it were available; Utah, however, has not produced substantially since 1945. The productive years were stimulated in part by the

demand of World War I, and in 1929 to 1930 by discovery of new ore. The federal stockpiling program during World War II, with discoveries in Juab County as an outgrowth of the exploration program of the U. S. Bureau of Mines and the U. S. Geological Survey, led to yields of 20,731 long tons in 1943 and 12,622 long tons in 1944.

The seven prospects listed in the Marysvale region did not produce proportionately in even the modest production of west Utah. The Georgia mine in Sevier County is credited with 150 long tons of 32 percent manganese grade in 1916, and 250 long tons of 50 percent grade in 1918. The Black Rock (Shotwell) deposit in Beaver County is credited with 12 long tons of 31.59 percent grade in 1943 (Crittenden, 1951, p. 4-5). Willard and Callaghan (1962) state that shipments of high-grade manganese ore were made during World War II from a deposit at Manning Creek southeast of Marysvale.

Crittenden (1951, p. 36) lists four occurrences in Sevier County which may in part be duplicated and none of which is located exactly. The Georgia mine or Loring property is said to be at the base of Monroe Peak, 6 miles south of Monroe in T. 26 S., R. 3 W. Manganese oxides occur in veinlets in volcanic rock of the Bullion Canyon Volcanics. The Jumbo prospect has about the same location. The Noonday prospect is placed 2 miles southeast of Monroe where brecciated andesite (latite breccia of Bullion Canyon Volcanics) contains veinlets of pyrolusite. A few hundred pounds were hand sorted. Seven tons of ore averaging 23.6 percent manganese is said to have been taken from the Yellow Hornet property near Monroe. The actual location is indefinite. The Iron Cap mine in sec. 15, T. 26 S., R. 3 W., which contained a thin layer of remarkably pure manganese oxide in iron ochre, is described in the Iron Deposits section of this report (page 52).

In Piute County, Willard and Callaghan (1962) noted numerous occurrences of manganese oxides in the Bullion Canyon Volcanics east of Sevier River, east and southeast of Marysvale. In many, the manganese oxide is accompanied by or disseminated in chalcedony which produces a bluish gray to black, hard rock. In some the manganese oxide occupies small spaces in fractures in volcanic rock or between fragments of volcanic breccia. Calcite may occur with the oxides. The volcanic rock adjacent to the mineral is not appreciably altered to the yellow argillized material produced by weathering of disseminated pyrite. Many occurrences were located as claims during World War II, and prospected by pits and trenches.

Several shipments of high-grade ore, which probably was hand cobbed to remove adhering rock, were made from only one deposit which is on the steep slope on the south side of the mouth of Manning Creek Canyon in sec. 33, T. 27 S., R. 2½ W. (Willard and Callaghan, 1962). The mine also is described by Crittenden (1951, p. 32) and identified as the Blackbird claims of Max Krotki and Don Stocks. The mineralization followed the bedding for a width of 5 to 10 feet in a bed of volcanic breccia having a maximum thickness of 12 feet. The crystalline and amorphous varieties of manganese oxide occurred in thin, alternating layers or were mixed. In 1942 the U. S. Bureau of Mines took a sample for 8½ feet across the manganiferous layer; it included rock and mineral, and assayed 17 percent manganese. At that time the deposit was estimated to contain several thousand tons averaging 5 to 10 percent manganese.

Farther south along the front of the Sevier Plateau near the mouth of Dry Creek Canyon in secs. 22 and 25, T. 26 S., R. 2½ W., some prospecting is reported by Crittenden (1951, p. 32) in the Dry Canyon claims as of 1942. An adit 60 feet long was driven on a vein averaging 2 feet wide and 250 feet long. The grade is estimated at 25 to 35 percent manganese and there may be a few thousand tons. Other nearby narrow veins are judged too small to mine. The Blue Miami Moon claim mentioned by Crittenden (1951, p. 32) is not located definitely, but was probably on the Sevier Plateau front north of Manning Creek Canyon. In 1942 the deposit was explored by a shaft 18 feet deep and an adit 20 feet long. At the cellar of the shaft, the grade was 20 percent manganese over a width of 2 feet, but declined to 10 percent at the bottom. The manganese oxide fills fractures in or adjacent to a fault. The Gilbert claims mentioned by Crittenden (1951, p. 33) probably were in Durkee Canyon, 2 or 3 miles east of Marysvale.

Crittenden (1951, p. 20) also locates the Black Rock (Shotwell) deposit in the south half of T. 28 S., R. 6 W. in the canyon of the South Fork of North Creek. The manganese oxide is mixed intimately with silica. Ore stockpiled in 1943 assayed 28 percent manganese, but faces of workings on veins a foot or less thick assayed 5 to 18 percent manganese. The property, however, is credited with an output of 12 tons which averaged 31.59 percent manganese (Crittenden, 1951, p. 5).

Evaluation: To be mined economically, manganese ore should have a content of 35 percent manganese, or should be inexpensively concentrated to that grade or better. Large profitable deposits of manganese oxides are sedimentary or residual, not small veins and disseminations in volcanic rocks such as occur in the Marysvale region. Only under the stress of war when supplies from abroad were interrupted were Marysvale

ores mined. Less than 10 percent of the U. S. manganese requirement is produced in this country, and a stockpile is maintained.

Antimony Deposits

Coyote Mining District

Antimony in the form of the sulfide, stibnite (71.7 percent antimony), and the oxidation products, cervantite and kermesite, were mined in small quantities from gently dipping sandstone beds of the Paleocene Flagstaff Formation on the north and south slopes of Antimony Canyon (formerly Coyote Canyon), secs. 15, 21 and 22, T. 31 S., R. 1 W. in Garfield County. Minor amounts of the arsenic minerals realgar and arsenolite (?) were reported, although not in close association with stibnite. Fluorite, rare pyrite grains, kaolinite and fine-grained silica also were noted. Sulfate minerals, gypsum, epsomite and alunogen may be associated with stibnite in considerable proportion.

The geologic map (plate 9) was compiled by the writer from the map of Williams and Hackman (1971) and the thesis map of Smith (1957) adjusted to the new topography for the area.

Butler (Butler and others, 1920, p. 562), referring to Huntley, says the deposits were located in May 1879 and that handpicked ore having a value of more than $100,000 was shipped. Mining in the early days by following the sandstone ledges and picking the "eyes" out of the deposits was concentrated on lenses of stibnite crystal aggregates containing as much as 55 tons. Lenses of disseminated low-grade material were left behind. Butler indicates that the high-grade lenses were largely exhausted by 1911. During November 1941 to January 1942, the U. S. Bureau of Mines and the U. S. Geological Survey conducted a joint investigation of two selected areas in which early mining had been concentrated; they were covered by contiguous patented mining claims, Albion, Nevada and Emma in one area, and Stebinite, Stella and Mammoth in the other. The object was to test the possibilities of low-grade material. Investigation was limited to portions in which ore minerals could be discerned. Bureau personnel trenched above and below vertical cliff faces to determine ore limits. A total of 541 samples from 96 trenches and eleven bulk samples from old mine dumps were taken. Survey personnel, D. C. Duncan and W. H. Myers, made topographic and geologic maps of the explored areas as well as geologic and ore sections. The maps and sections prepared by Duncan and Myers are reproduced in modified form as figures 35 to 38 and plates 10 and 11. A general account of the work with maps and results of assays was published by the Bureau in June 1949 (Traver, 1949) and the Survey maps were open-filed. In 1957, Smith (1957) described and interpreted the geology and mapped the area at a scale of 2,000 feet to the inch. The new topographic maps at the same scale did not become available until 1970 and, unfortunately, do not show mine workings. The new geologic map of the Salina quadrangle at 250,000-scale (Williams and Hackman, 1971) includes the Antimony area.

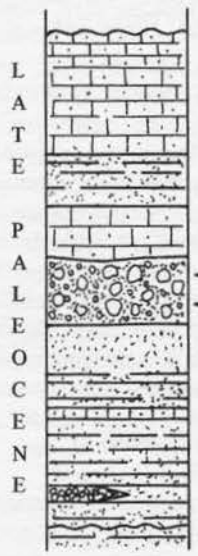
Antimony occurrences are confined to a nearly flat-lying sedimentary unit of conglomerate, sandstone and shale exposed in the steep walls of Antimony Canyon and its tributaries, and in the canyon of Dry Wash 3½ miles to the north (plate 9). The stratigraphic section prepared by Duncan and Myers (Traver, 1949, p. 6) and the section from Smith's thesis (1957) are given below.

Eocene (?) Wasatch (?) Formation

	Feet
1. Gray, green and tan shale and shaly sandstone with minor thin-bedded sandstone	730
2. Shaly sandstone with scattered massive sandstone lenses up to 20 feet thick, in which antimony occurs near the base on the south side of Antimony Canyon (Emily, Pluto and Picture Canyon claims)	150
3. Light gray limestone and calcareous sandstone forming cliffs on south side of Antimony Canyon	0-100
4. Interbedded shale and sandstone with scattered lenses of massive sandstone up to 30 feet thick. Lower 10 to 50 feet are principal antimony-bearing zone (Emma, Albion, Nevada, Alta, Winner No. 1, Mammoth, Stella, Stebinite and Star claims)	100-150
5. Conglomerate forming conspicuous cliffs	0-200
6. Sandstone with some interbedded shale	50-200
7. Red sandstone and sandy shale	210
Approximate total	1,500

Unconformity

Flagstaff (?) Formation



Unit "C"–Interbedded calcareous siltstone and silty limestone with a few "salt and pepper" sandstone beds at the base. 687+

Fossil zone–*Australorbis*, *Viviporidae* and *Physa*? fresh water gastropods.

Unit "B"–A massive conglomerate with a few "salt and pepper" sandstone lenses between irregular bedding. 0-102+

Unit "A"–Predominantly a fissile red siltstone that grades upward into a buff siltstone and sandstone. The sandstone is cross-bedded at the top. There are conglomerate beds at the base of the red siltstone. 297

Unconformity

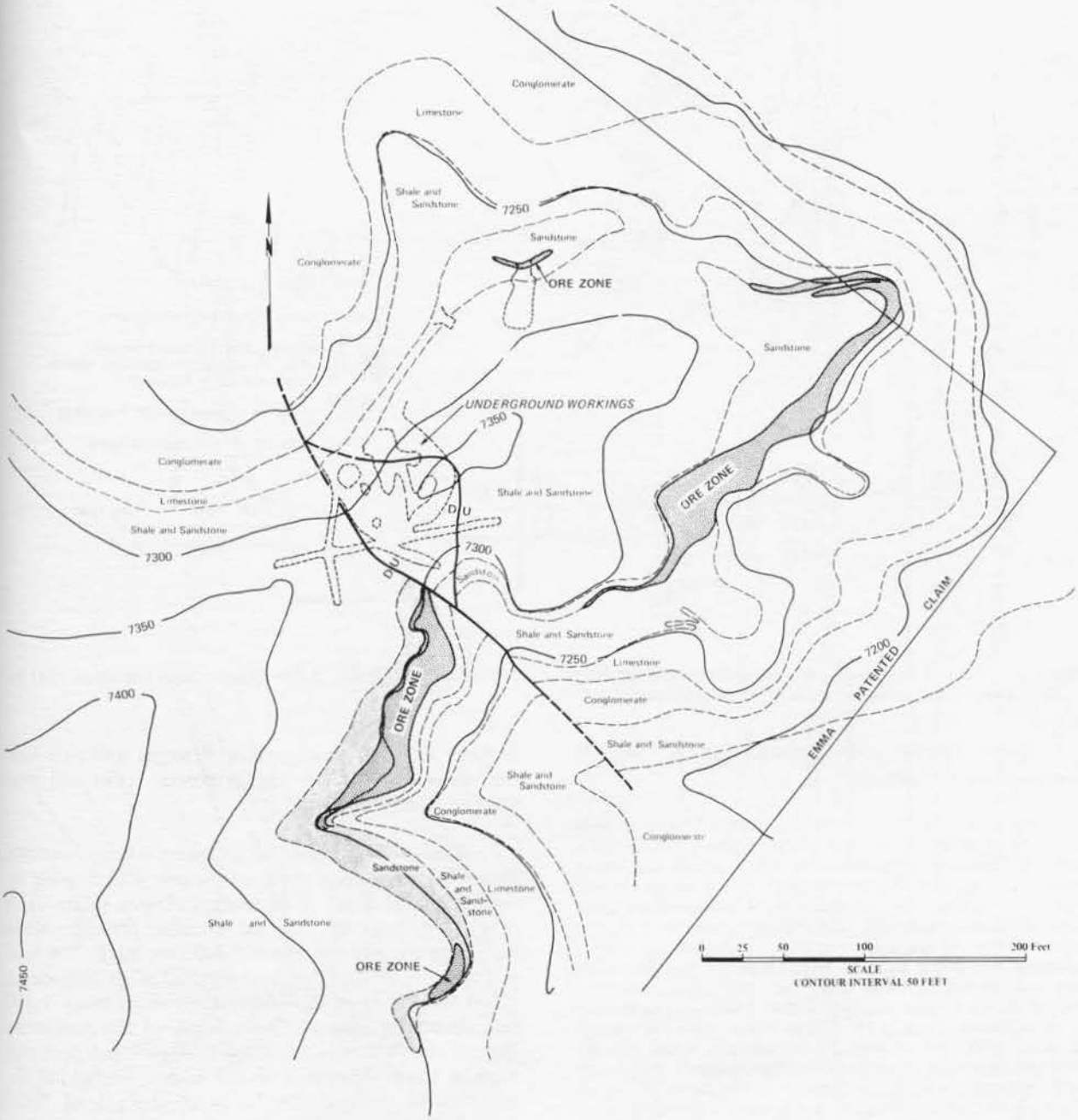


Figure 35. Geologic map of antimony deposit at northeast end of Emma (Little Emma) claim (modified from map by D. C. Duncan and W. H. Myers, U. S. Geological Survey; surveyed 1941; topography adjusted approximately to Antimony quadrangle, 1970).

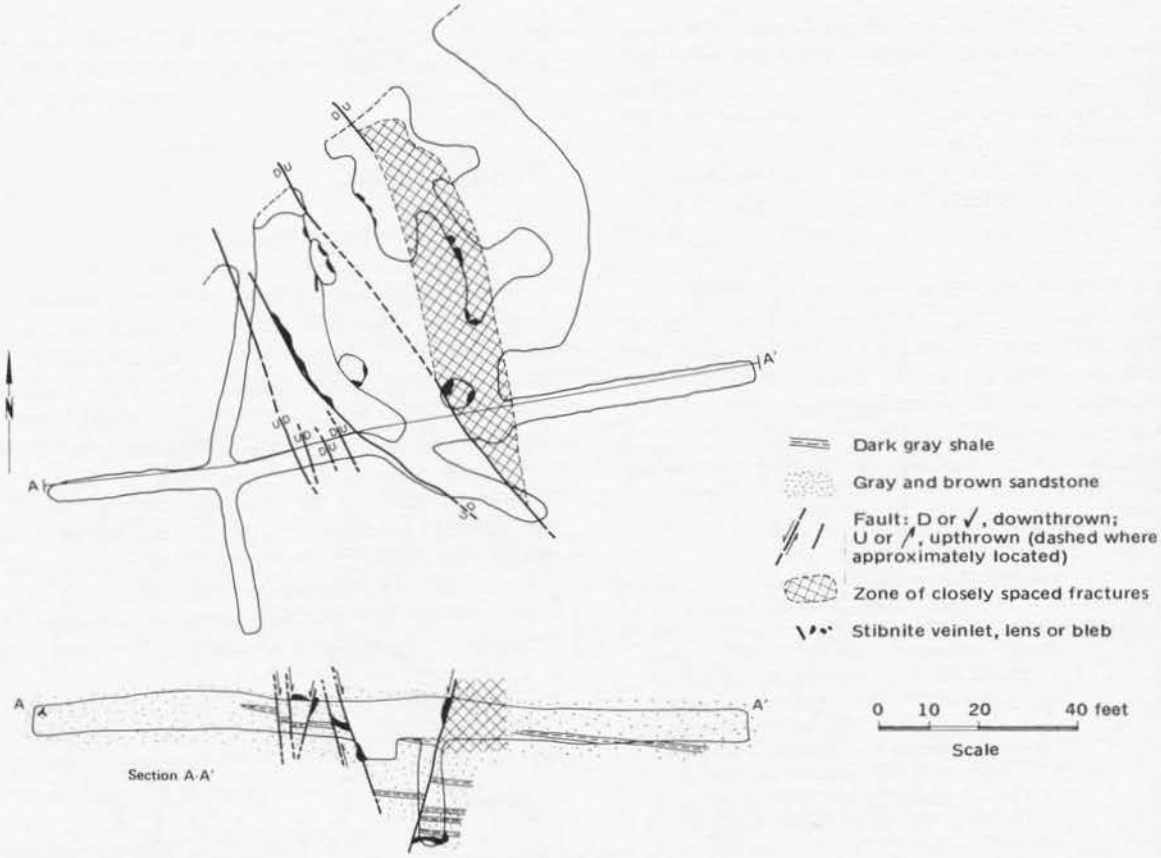


Figure 36. Plan and section of principal underground workings of northeast part of Emma (Little Emma) claim (surveyed 1941 by D. C. Duncan and W. H. Myers, U. S. Geological Survey).

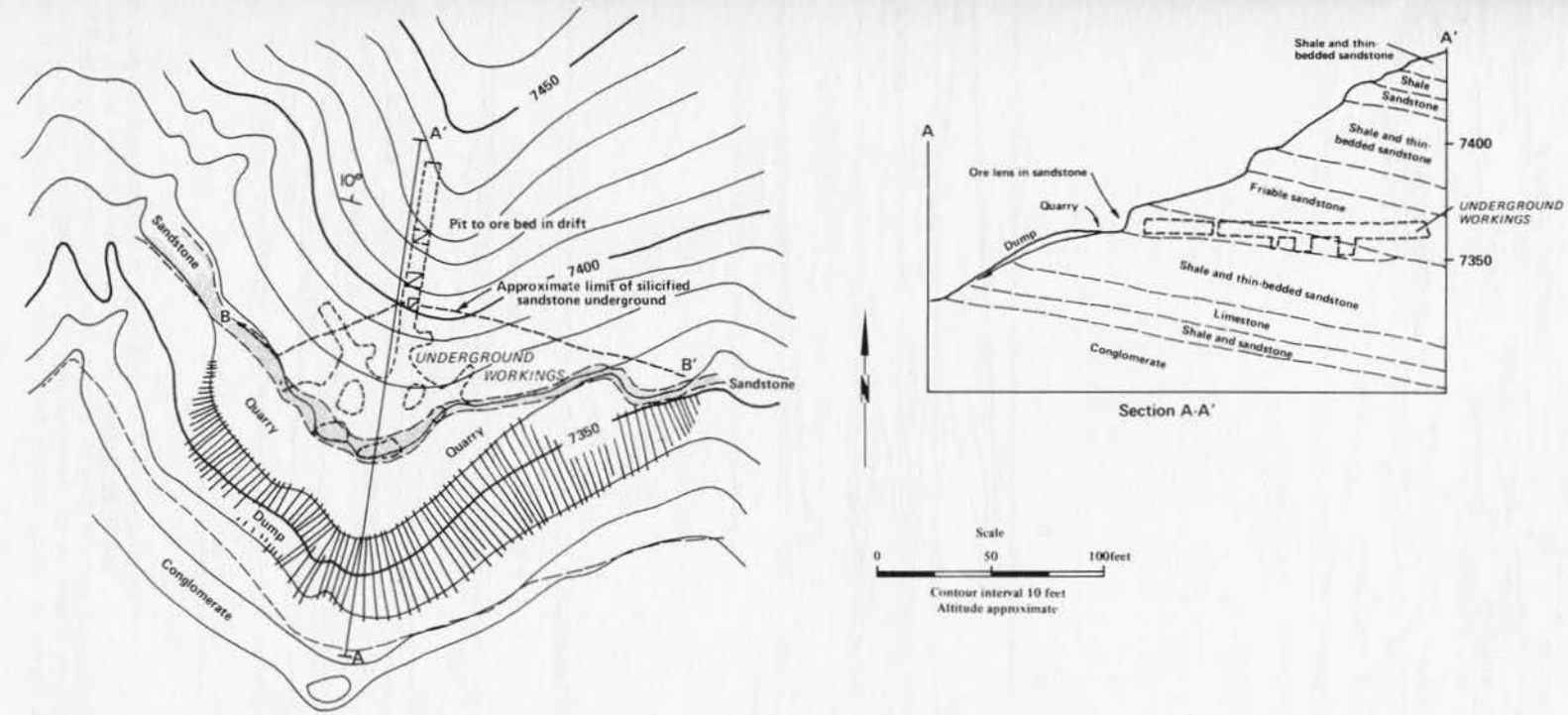
Butler (Butler and others, 1920, p. 560-62) comments on the geology:

> The valley of Coyote Creek is occupied by a variable succession of strata. At the base of the section is 150 feet of a gray conglomerate composed of a sandy matrix containing rounded quartz and quartzite pebbles whose maximum diameter is 6 inches. This conglomerate is overlain by a great mass of fine-textured buff and reddish sandstone and subordinate drab and red sandy and clayey shale and thin-bedded limestone, amounting in all to several hundred feet. No fossils have been found in these rocks, but they are provisionally referred to the Eocene because of their lithologic resemblance to other Eocene strata in the Plateau region. They are overlain by about 1,000 feet of andesitic tuff and lava, which caps the surrounding plateaus. The rocks are approximately flat, having only a general low northeastward dip. At the mouth of Coyote Canyon a fault causes the strata to dip steeply westward.

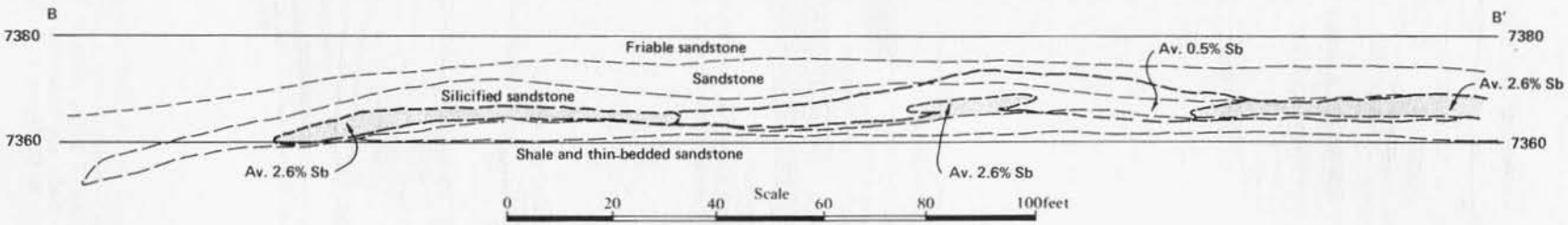
The writer has not visited the area.

The base of the formation, in fault contact with beds identified as Navajo Sandstone and Carmel Formation, is not exposed in the bottoms of any of the canyons. Smith (1957) assumes the sediments rest on a normal succession of Cretaceous rocks. From regional geology and well section data, it seems probable that the sediments rest on pre-Cretaceous rocks and that the Cretaceous is absent.

The overlying material is almost wholly landslide debris from the great cliffs of volcanic rock making up the steep west front of the Awapa Plateau (plate 9). It is assumed, however, that the volcanics directly overlie the sediments and are about 2,200 feet thick. The base undoubtedly is irregular, but appears at an altitude of 8,200 feet north of Antimony Canyon or some 1,300 feet above the canyon floor. South of the Antimony Canyon the volcanics are tilted westward and probably reach a lower elevation. In the upper reaches of the canyon, the contact may be at an altitude of 7,800 feet as both the volcanics and the sediments dip eastward. The dips in the sediments in Antimony Canyon recorded by Smith (1957) are north northeast from 3° to 8°. In Dry Canyon a closely spaced anticline and syncline appear with dips 10° or less. Williams and Hackman (1971) divide the volcanics into andesite breccias, which are equivalent to the Bullion Canyon Volcanics. They lie directly on the sediments, but appear to thin south around the head of Antimony



Geologic map of Mammoth Mine



Enlarged section along face of antimony ore in quarry; assay data from U.S. Bureau of Mines

Figure 37. Plan and sections of Mammoth antimony mine (modified from map and sections by F. M. Byers, D. C. Duncan and W. H. Myers, U. S. Geological Survey; surveyed 1941).

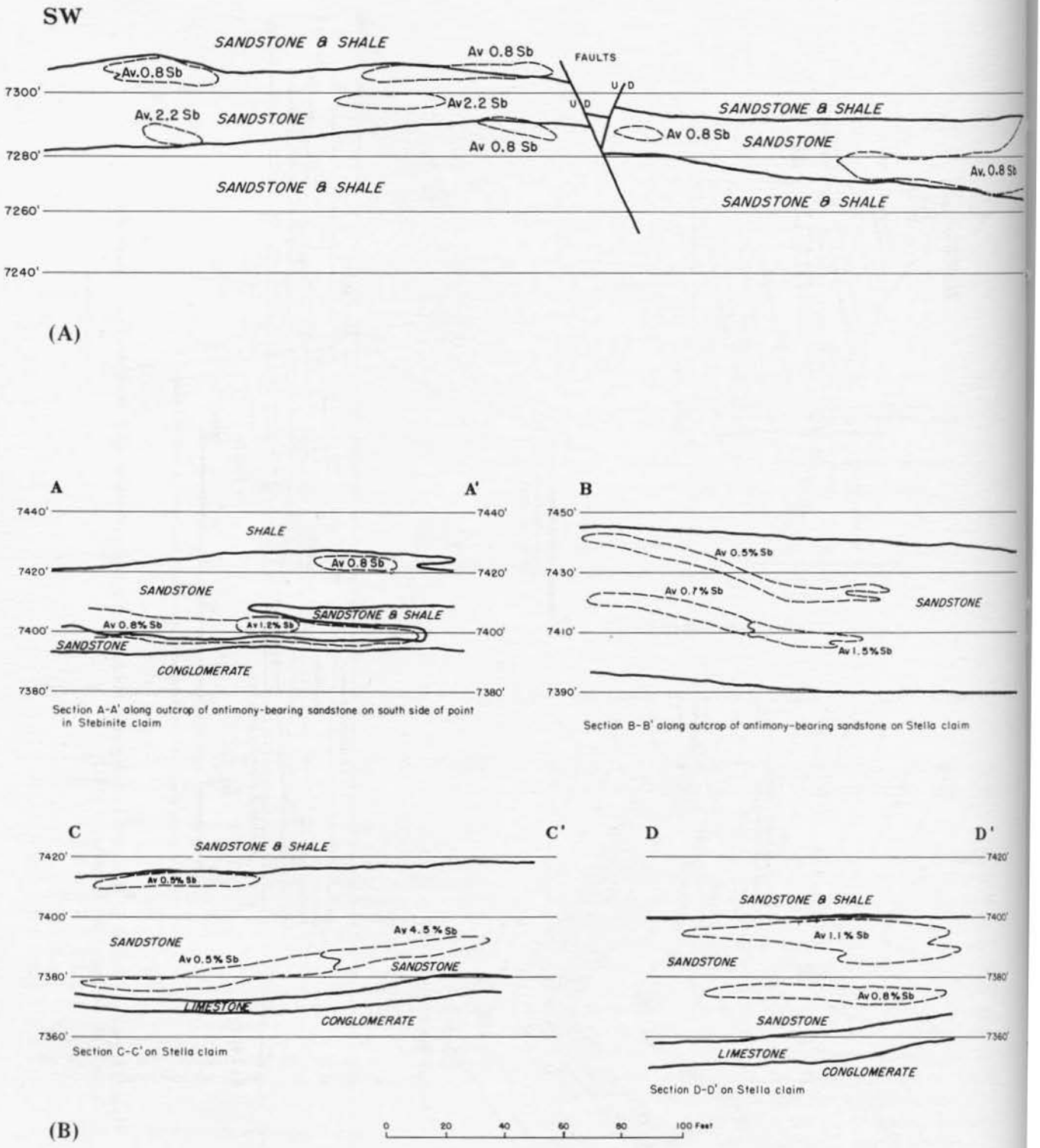
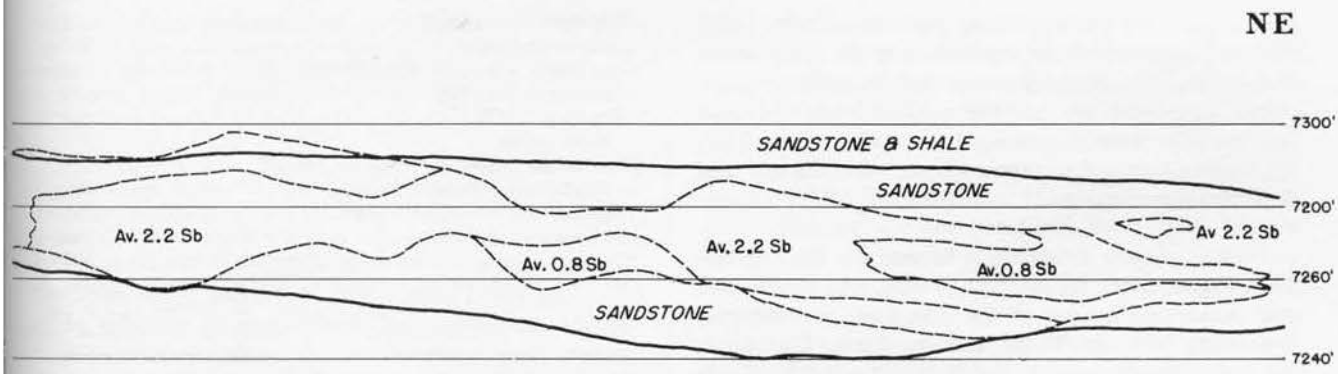
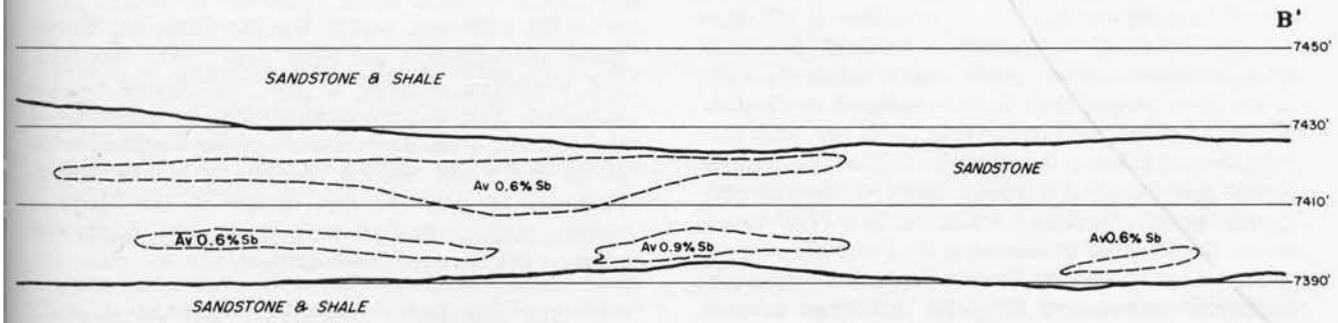
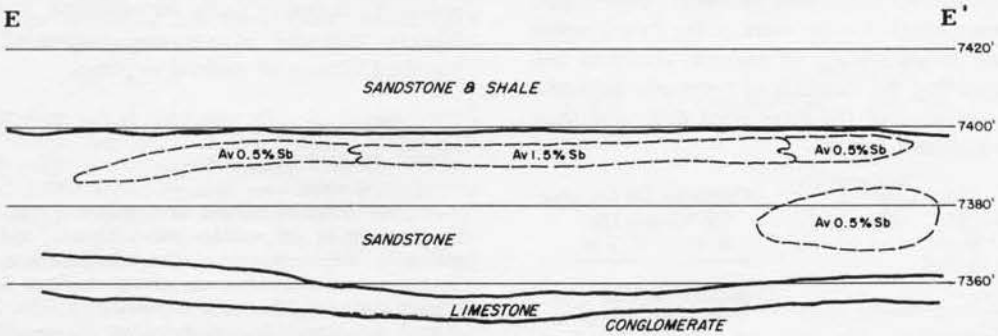


Figure 38. (A) Enlarged section along outcrop of antimony-bearing sandstone bed at south slope in northeast end of Emma (Little Emma) claim (modified from section prepared by D. C. Duncan and W. H. Myers, U. S. Geological Survey from sample and assay data of U. S. Bureau of Mines; surveyed 1941). (B) Enlarged sections along outcrops of antimony-bearing sandstone showing ore concentrations in Stella and Mammoth claims. Positions of sections are shown on plate 11 (modified from sections prepared by D. C. Duncan and W. H. Myers, U. S. Geological Survey. Antimony content from samples taken by U. S. Bureau of Mines; surveyed 1941).







Section E–E' along outcrop of antimony-bearing sandstone on west end of Mammoth claim

Figure 38. (continued)

Canyon. They are succeeded by basaltic andesite, Osiris tuff and latite which are equivalent to the Dry Hollow Formation. The group is succeeded by volcanic sediments equivalent to the Sevier River Formation and last by Quaternary olivine basalt. Eruptive cones of the Quaternary unit are preserved on the Awapa and Aquarius plateaus.

The plateau structure is broken by the regional Paunsaugunt fault system which separates the Awapa and Aquarius plateaus to the east from the elongate depression of Grass Valley and the Sevier Plateau to the west. The position of the fault is marked by slivers of Jurassic sedimentary rocks at the mouth of Antimony Canyon and to a lesser extent at the mouth of Dry Wash. The Flagstaff Formation is exposed along the fault for 6½ miles. The volcanics are downthrown to the west and dip westward 5° to 7° except near the fault where they may dip sharply eastward as much as 20°. The Flagstaff Formation is disturbed near the fault and may dip as much as 40° E. Within a distance of ¼ mile from the fault, the dip changes to 10° E. or NE and becomes less farther east. Smith (1957, p. 20-22) noted minor subparallel faults within 1½ miles of the Paunsaugunt fault with downthrow to the west. The fault slivers within the fault zone are judged to include rocks from the Triassic Chinle and Jurassic Navajo and Carmel formations. Dips are steep or overturned within the older rocks. Smith's (1957) map shows the Flagstaff as overlying the fault sliver at the south side of Antimony Canyon suggesting that a part of the disturbance on the fault took place prior to Paleocene time. Nevertheless the movement that defines the present geomorphologic configuration took place after the volcanic units were emplaced.

The logs of two petroleum test wells, drilled into the downthrown block 5 miles west of the Paunsaugunt fault, facilitate interpretation of regional structure and aid in understanding the location of antimony deposits. Altitudes of the tops of the recognized units and their thicknesses are shown below:

Tenneco Oil Co. No. 1 Unit NE SE NE sec. 30, T. 30 S., R. 2 W. (Ritzma, 1972, p. 80)	California Oil Co. Unit NE NE sec. 16, T. 31 S., R. 2 W.
Surface (6,263)	Surface (6,350)
Volcanics (670)	Volcanics (1,148)
Top Flagstaff (5,693)	Top Flagstaff (5,202)
Flagstaff (590)	Flagstaff (1,206)
Top Moenkopi (5,103)	Top Moenkopi (3,996)
Moenkopi (930)	Moenkopi including Sinbad (640)
Top Kaibab (4,173)	Top Kaibab (3,355)
Kaibab and Toroweap (760)	Bottom hole (3,206)
Top Cedar Mesa or Queantoweap (3,413)	
Cedar Mesa (1,056)	
Top Redwall (2,357)	
Redwall (854)	
Top Devonian (1,503)	
Devonian (560)	
Top Limestone above Mauv (943)	
Limestone (1,170)	
Top Mauv (227)	
Mauv (630)	
Top Bright Angel (857)	
Bright Angel (560)	
Top Tapeats Sandstone (1,417)	
Bottom hole (1,562)	

As the Tenneco well is 4 miles north northwest of the California well, comparison of altitudes of the sedimentary units shows that the structure slopes gently southward and that the axis of the Beaver uplift or arch described earlier is near or north of the Tenneco well. Both the volcanics and the Flagstaff are thicker to the south so that the top of the Moenkopi is 1,100 feet lower to the south. The indicated slope is 275 feet per mile or 3°. Both Cretaceous and Jurassic are absent in the wells although the Jurassic appears in the fault slivers.

The California well is opposite Antimony Canyon where the volcanics are more than 2,000 feet thick, and a marked thinning in the downthrown block is indicated. This is even more striking in the record of the Tenneco well. The thinning of the Flagstaff to the north under the Bullion Canyon Volcanics and its thickness of only 50 feet or less in the Marysvale vicinity suggests marked erosion over the Beaver arch prior to extrusion of the volcanics.

The analysis of stratigraphy and structure suggests the antimony mineralization was centered at or near the crest of the broad east extension of the Beaver uplift or arch which trends easterly or southeasterly into the Kingston Canyon and Antimony areas. No intrusive rocks are reported. Stibnite mineralization generally is on the outermost rim of the standard zoning of mineral deposits.

The low-grade stibnite ore is described by Traver (1949, p. 7-8) as follows:

> The deposits consist of veinlets, lenses, and irregularly shaped blobs of nearly pure stibnite and its alteration products, antimony oxides. The veinlets are scattered through sandstone and shale but are largely confined to fractured and jointed zones in the massive sandstones. The distribution and size of the veinlets is very irregular, consequently the grade of the bulk rock containing the antimony veinlets is highly variable from place to place in each individual deposit.

Butler (Butler and others, 1920, p. 562-63) comments on the deposits (*circa* 1911) as follows:

> The occurrence and character of the deposits differ in the different prospects. A common occurrence is in layer-like bodies of irregular thickness but averaging only a few inches. The "layers" are not continuous and are only approximately parallel to the bedding. Many of them are undulatory and

thicken and thin out irregularly. In a number of places thin bodies of ore cut across the bedding of the sandstone and connect the more nearly horizontal deposits. The ore also commonly occurs disseminated in the sandstone in irregular segregations.

A characteristic feature of the antimony deposits of Coyote Creek is that the ore consists only of stibnite and its oxidation products, gangue minerals being almost completely absent. Only one exception was observed, at the Emily claim, on the south side of the creek, where in a small gash vein only a few inches wide stibnite and pyrite are associated with calcite. A thin section cut along the contact of the stibnite with the country rock shows an uneven junction, the stibnite extending very irregularly into the sandstone. Locally stibnite, with well-defined crystal faces, penetrates and is partly embedded in adjacent quartz grains of the sandstone.

The stibnite occurs in several forms. In the larger ore bodies it commonly forms aggregates of prismatic crystals arranged radially or in columnar masses. In one group crystals 6 inches long were observed. It also forms indiscriminately mixed groups of acicular crystals. Adjacent to the outcrop it is almost universally oxidized, the steel-gray sulphide giving place to the lighter brown, yellow, and white oxidation products. W. T. Schaller, of the United States Geological Survey, who examined a number of oxidized-ore specimens, reports that they are anhydrous and easily fusible and that they are either valentinite or senarmontite–probably the former . . . In many places the valentinite occurs in acicular crystals as a pseudomorph after stibnite. Locally associated with the ore and forming efflorescences on the walls of the country rock are epsomite; a hydrous aluminum sulphate, probably alunogen; a hydrous ferrous sulphate; and gypsum.

Small quantities of arsenic minerals have been found in the valley of Coyote Creek contiguous to the antimony deposits, but so far as known not immediately associated with them. On the north side of the creek, about 100 feet southeast of the stibnite prospect known as "Black Jack No. 2," there is a small deposit of the sulphides of arsenic in shales of Eocene age. Realgar and orpiment in irregular seams ranging in thickness from a fraction of an inch to about 6 inches and only a few inches in length occur in a blue-drab clay shale. No other vein minerals are present, and the realgar and orpiment, in small crystals, are intimately associated. Other similar small deposits of arsenic are reported from the valley of Coyote Creek.

The antimony ore is epigenetic–that is, it was formed subsequently to the deposition of the rocks in which it is found, and its origin is probably connected with the adjacent igneous rocks . . . The antimony may have been derived from these rocks either during their intrusion through the sediments or less probably after their eruption on the surface, the stibnite being deposited from percolating solutions in part filling existing spaces and in part by metasomatic replacement. The bed of shale which in many places immediately underlies the ore apparently arrested the solutions and determined the local concentration of the stibnite. In such places the solutions were evidently not directly ascending but were moving either laterally or downward.

That Smith found the same bedding units in the Flagstaff lying on Jurassic rocks near the Paunsaugunt fault as occur up the canyon suggests that the alluvial cover in the canyon bottom at an altitude ranging from 6,800 to 7,200 feet is near the base of the Flagstaff Formation. Smith's (1957) section shows about 300 feet of siltstone and 100 feet of conglomerate underlying the main mineral zone that occurs on the Albion, Nevada and Emma group of claims. Duncan and Myers (USGS, open-file, 1942) found a thicker section with the lower unit ranging up to 400 feet and the conglomerate ranging up to 200 feet. The topography of the Emma (figure 35) suggests a thickness of some 400 feet for the combined lower units. Duncan and Myers' section of the Emma shows 20 feet of sandstone and shale overlying the conglomerate. The ore horizon, ranging from 5 to 15 feet thick, is contained in a massive sandstone bed 20 feet thick overlying the sandstone and shale. Another ore horizon, which was prospected on the Pluto and Emily claims, occurs about 300 feet higher stratigraphically. Some antimony minerals were noted in Dry Wash drainage area as well.

Duncan and Myers' sample sections at the northeast part of the Emma show a lens 400 feet long and ranging up to 35 feet thick (figure 38a). Part of the material averages 2.2 percent antimony for a length of 320 feet, but the remainder averages 0.8 percent. No mineralization is associated with a fault cutting the same bed, but some small lenses occur on the side opposite the main lens. The lenses exposed on the Stella, Mammoth and Stebinite claims are mostly 5 to 10 feet thick (figure 38b). The antimony content varied widely. A part of a lens on the Stella claim 50 feet long averaged 4.5 percent. Two other lenses–one above the other–on the Stella and separated by 10 feet of sandstone average 1.1 percent for the upper lens and 0.8 percent for the lower. The grades of antimony do not follow details of layering in the sandstone, but may cut across from bottom to top of the containing layer. Traver (1949, p. 9) reports an assay of a 500-pound dump sample as follows:

			Percent						
Sb	Bi	As	Insoluble	SiO_2	CaO	Fe	Al_2O_3	MgO	S
3.7	no	0.07	87.8	79.2	1.6	2.5	3.3	0.14	0.9

Ounces per ton			
Pb	Zn	Ag	Au
no	no	0.12	trace

The content of even small amounts of precious metal links the antimony deposits with the precious/base metal deposits to the west.

Evaluation: Traver (1949) did not publish an estimate of antimony available in the Coyote mining district and no drilling was done to determine the extent of the ore behind the outcrop. Mining to the present has been from open faces on the outcrop and from small underground workings. The steep slopes favor hand mining, but would make open-pit mining

difficult. Drilling might disclose hidden bodies of minable grade, but the small size of the lenses known thus far does not encourage prospecting at present prices. The peace-time availability of antimony from other countries makes the mining of small, low-grade deposits in this country unattractive.

Alunite

The mineral alunite in pure form contains 11.37 percent potassium oxide, 36.92 percent alumina, 38.66 percent sulfur trioxide, and 13.05 percent water (aluminum metal 19.53 percent and sulfur 15.48 percent). At Tolfa in central Italy, alunite was mined, heated and the resulting calcine leached to produce alum in the Middle Ages. At Goldfield, Nevada, alunite, recognized as an associated mineral in rich gold veins, was sought after widely as a pathfinder mineral for gold.

Alunite was recognized in the Marysvale area in 1910, but not until the supply from Germany, then the only major source of potash, was cut off in 1914 was actual development and production stimulated. The price of potash rose to $440 per ton in 1916. In World War II, the shortage of bauxite, the ore of aluminum, again stimulated interest in exploration and development of alunite resources at Marysvale. Presently, a shortage of bauxite in the Soviet Union has stimulated a thorough search and study of alunite resources and at least one open-pit mine is operating to recover alumina.

The lack of bauxite supplies in Mexico stimulated a resource study on alunite and experimentation with recovery methods. In Utah an exploration group has been drilling altered volcanic rock in Beaver County west of Milford and is said to have demonstrated a multimillion-ton resource of alunitic material, ranging between 35 and 65 percent alunite. In the Soviet Union rock containing 50 percent alunite is considered normal ore; rock containing less than 50 percent is regarded as low grade.

Kashkai (1970) of the Soviet Union published a two-volume work which covers the mineralogy and geochemistry of alunite and 28 minerals in the alunite group and structural analogues. He presents a classification and genesis of alunite deposits and discusses alunite deposits and occurrences throughout the world; eight pages of discussion are devoted to Utah. The treatment of alunite and utilization of accompanying products also are treated. The map showing the worldwide distribution of alunite deposits and occurrences known to Kashkai is reproduced as figure 39. It shows the concentration of occurrences in east Siberia, Kamchatka, Kurile Islands, Korea, Japan and east China, and other centers in Kazakhstan in central Asia, the Urals, the Transcaucasus, in east Europe extending into Italy and across to Spain, and Morocco. The southwest United States has a high concentration which extends into central Mexico. More deposits undoubtedly will be located in the Andean chain. Australia has several deposits including a bed of alunite as sediment or precipitate in a dry lake (Lake Campion).

Rovirosa (1965, p. 41-71) briefly discusses the geology of Mexico's deposits and indicates that most of them are in rhyolite tuff. Tables of calculated reserves in grade classifications are summarized to show 5 million tons of material of more than 50 percent alunite content and a total reserve of 116 million tons, 104 million tons of which have a grade of less than 25 percent alunite.

The principal published descriptions of the alunite at Marysvale are those by Butler and Gale (1912b), Loughlin (1915, p. 237-270), Butler (Butler and others, 1920, p. 546-550), Callaghan (1938, p. 91-134), Thoenen (1941, p. 20-34), Willard and Proctor (1946, p. 619-643), Hild (1946, 17 p.), Callaghan and Parker (1961a and b; 1962a), and Willard and Callaghan (1962). The material presented below is taken to a large extent from the files and in part from the publications of the U. S. Geological Survey which were loaned to the Utah Geological and Mineralogical Survey. The field work of 1936 and 1938 and the wartime drilling and exploration in 1942 to 1946 are included in the file material. Maps made during the earlier period were modified as a result of trenching and drilling. The White Horse deposit was modified in 1943 when 12,000 tons were removed and shipped to the plant in Salt Lake City (Hild, 1946, p. 3). The mining records of the World War I operations kept by the Mineral Products Company were destroyed by fire in 1931.

Mt. Baldy Mining District

The vein deposits of alunite in the Mt. Baldy mining district are restricted to secs. 8, 16 and 17, T. 28 S., R. 4 W. in the drainage area of Cottonwood Creek. Most of the veins are on the summit and on the east slope of Alunite Ridge (figure 40) between the drainage of North Fork and the main branch of Cottonwood Creek, but a second vein system lying 3,000 feet west of the first reaches the L&N saddle between the Cottonwood Creek and Pine Creek drainages. Both systems trend about N. 40° W., but individual veins in the Alunite Ridge system may deviate as much as 90° from the general trend. Both

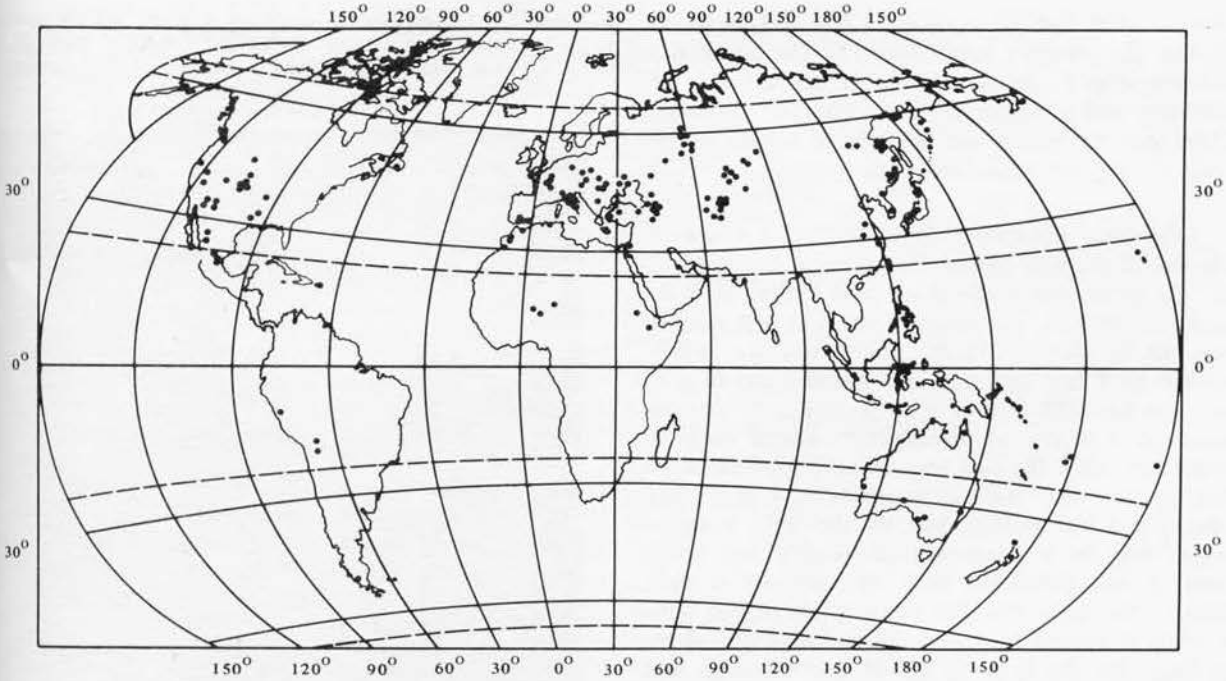


Figure 39. Worldwide distribution of alunite deposits and occurrences (Kashkai, 1970, v. 1, p. 295).

vein systems are in the lower part of the Bullion Canyon Volcanics between the Navajo Sandstone (quartzite) at the base and the Delano Peak Latite Member of the Bullion Canyon Volcanics. The lower part is an estimated 1,500 to 2,000 feet thick, and alunite veins are distributed through the full thickness although it is not known if veins in the summit area reach all the way to the quartzite. This part of the Bullion Canyon Volcanics consists mainly of tuff and breccia beds which mostly dip about 10° NW so the strike is roughly normal to the trend of the vein systems. South from the portals of the Mineral Products mine, however, the volcanics dip about 20° S. The quartzite contact also appears to dip southward here. Faults probably are more numerous than represented on the map because the thick mantle of broken rock on the steep slopes in the alpine environment (9,750 to 11,750 feet) limits outcrops to ridge crests. The L&N vein system is in a fault zone which displaces the Delano Peak Latite Member about 200 feet down to the east. Apparently partly as a result of the southerly dip of the volcanic tuffs and breccias in the south part of Alunite Ridge, a large landslide pulled away from the vicinity of the portals of the Mineral Products mine exposing the south part of the vein. The Cottonwood Creek drainage area west of Alunite Ridge was occupied by a glacier whose terminus was near the mouth of North Fork. The lateral moraine is about 400 feet above the valley bottom at the southwest side of Alunite Ridge and appears to have been overridden by the landslide.

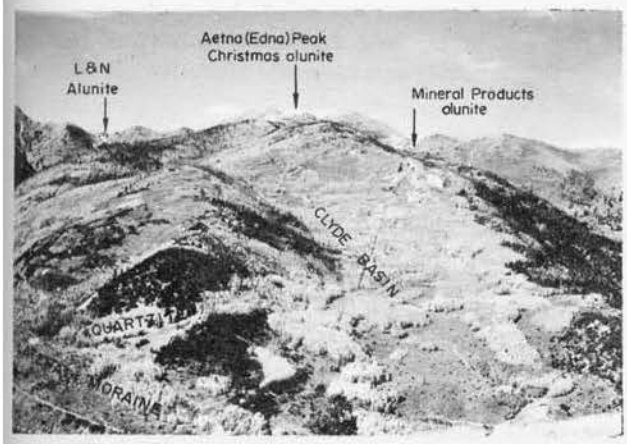


Figure 40. Alunite Ridge from south Mineral Products alunite mine at right center; Aetna (Edna) Peak on skyline in center; L&N alunite mine at left on skyline. Quartzite (Navajo Sandstone) in foreground at left and right; Clyde Basin (landslide scar) in center. Lateral moraine above road at lower left.

Mineral Products and Bradburn Mines. The Mineral Products mine was operated from 1915 through 1920 and produced an estimated 250,000 tons of alunite. The upper adit, at an altitude of 10,118 feet in the SE¼ sec. 16, T. 28 S., R. 4 W., was the working level of the mine. An aerial tramway carried the ore down the slope to the mouth of North Fork whence it was transported in wagons 3½ miles to the mill at the former town of Alunite. The main adit

included 3,600 feet of workings, 1,680 feet of which followed the principal vein (plate 12). Ore above this level was stoped out to the surface for a length of 1,080 feet and a height of 10 to 280 feet, although 24,000 tons of broken ore are said to remain in the stopes. No ore was stoped below the level.

The main adit (plate 13) was started in a 65-foot wide ore lens which curved sharply west and pinched out. The south end of the main vein, located after an interval of 70 feet, was followed for 800 feet ranging from 10 to 40 feet wide. Thereafter, the width declined to 4 feet and less, and pinched out in 400 feet. The last 240 feet of drift showed only narrow veinlets in a variety of directions in altered rock. A branch vein called the East vein diverged southeastward from the main vein, and was stoped as much as 15 feet wide toward the surface, but on the level is represented only by a stockwork of veinlets and short lenses. A vein called the West vein diverged at right angles to the main vein, but pinched out in 320 feet. However, it opened to 9 or more feet in width above the level. The dip is nearly 50° N. and the slope was followed by a raise 360 feet to the surface.

The lower adit (figure 41) was driven north as a crosscut to intercept the large lens at the portal of the upper adit. Both soft and firm altered rock was penetrated, but a drift to the northwest followed a succession of lenses for 160 feet. The drift was continued through silicified rock and some alunite veinlets as much as 15 inches thick to the south end of the main vein. The main vein was followed for 350 feet. A raise, which followed the steeply westward dipping vein, connected the two levels with an intervening space of 208 feet. The south end of the main vein is 50 feet north of the projected position on the upper level. The main vein is mostly less than 5 feet thick on this level in contrast to 10 feet or more in the upper level. No crosscuts were driven to test the possibilities of parallel or branching veins, and the full length of the ore shoot on the upper level was not tested.

The country rock of the alunite veins is an envelope of altered volcanic breccia. Crosscuts were insufficient to show accurately the relation of altered to unaltered rock, although only slightly altered rock appears in some places in the workings. The unaltered breccia west of the portals was analyzed and the results shown in table 11. The fragments in the breccia are porphyritic with white feldspar phenocrysts, but some are dense without conspicuous phenocrysts. The matrix contains abundant feldspar phenocrysts and less conspicuous pyroxene. Some units in this portion of the Bullion Canyon Volcanics have equivalent soda and potash compared to the low ratio of potash in the analyzed sample. The groundmass or matrix is mostly devitrified glass and microcrystals. The rock is purplish gray; some fragments are more definitely red. Calcite forms readily in these rocks, presumably as part of regional carbonate-quartz-sericite alteration.

Table 11. Comparison of unaltered volcanic breccia, altered equivalent and alunite at Mineral Products mine (R. E. Stevens and W. T. Schaller, analysts, U. S. Geological Survey).

	1	2	3	4	5	6
SiO_2	57.83	60.15	+ 2.32	5.28	0.22	
Al_2O_3	13.34	12.82	- .52	34.40	37.18	36.92
Fe_2O_3	7.21	.07	- 7.14	trace	trace	
FeO	.87	.43	- .44			
MgO	1.10	trace	- 1.10			
CaO	5.60	.13	- 5.47			
Na_2O	5.76	.50	- 5.26	0.56	0.33	
K_2O	1.08	3.75	+ 2.67	9.71	10.46	11.37
H_2O^-	.24	.14	- 0.10	.11	.09	
H_2O^+	.95	4.93	+ 3.98	13.08	12.90	13.05
TiO_2	.96	.62	- 0.34	–		
ZrO_2	.01	trace	- 0.01			
CO_2	4.73	trace	- 4.73			
P_2O_5	.38	.19	- 0.19	0.50	0.58	
SO_3	–	12.75	+12.75	36.54	38.34	38.66
S	.07	–	- 0.07			
Cr_2O_3	none	none	–			
MnO	.06	none	- 0.06			
BaO	.10	.03	- 0.07			
FeS_2	–	3.19	+ 3.19			
	100.29	99.70		100.18	100.10	100.00

1. Volcanic breccia 1,200 feet west of portal of Mineral Products main adit.
2. Altered volcanic breccia in main adit of Mineral Products mine.
3. Gain or loss of constituents in altered equivalent.
4. Light pink finely granular alunite, Mineral Products mine (Butler and Gale, 1912).
5. Coarsely crystalline alunite, Mineral Products mine (Butler and Gale (1912).
6. Theoretical composition of potash alunite.

The composition of the altered rock is shown in column 2 and the gain or loss in column 3 of table 11; analyses of the two types of alunite in the veins and theoretical composition also are included. The analysis indicates that the rock consists of quartz, alunite (33 percent) and pyrite (3.19 percent). The alunite tends to replace feldspar selectively and to be concentrated in the phenocrysts, whereas the groundmass tends to be replaced by silica. Pyrite is inconspicuous as it occurs as tiny grains less than 1 mm scattered through the dense silica. The altered rock is light gray where unaffected by weathering, but readily absorbs iron stain with release of iron as sulfate to the percolating groundwater. Not all altered rock is the hard material mostly associated with the veins; some is relatively soft. The silicified rock does not change to soil in

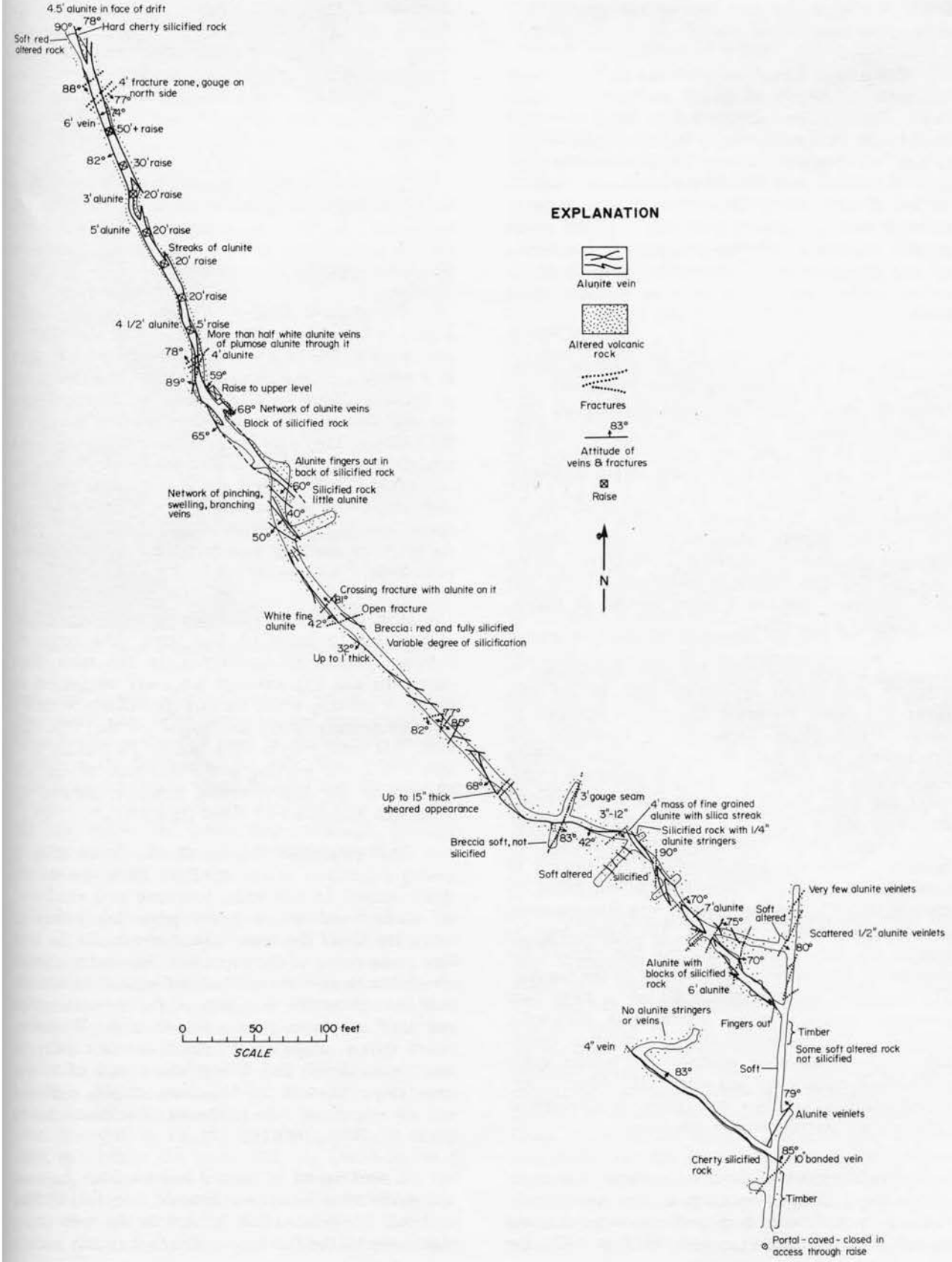


Figure 41. Geologic map of lower level of Mineral Products alunite mine (surveyed by E. Callaghan and G. F. Seager, 1936).

readily, but breaks up with freezing and thawing, and creeps down steep slopes.

Contacts of altered and unaltered rock are almost impossible to locate accurately on rubble covered slopes. Caved stopes at the surface show the solid altered rock changing to highly fractured material and, in turn, the fragments leaning and flowing down the slope. Trenching with a bulldozer showed as much as 30 feet of this material. Thus extensive areas shown as silicified rock in plate 12 actually may be much smaller. The vein alunite resists weathering, but breaks up into fragments which become incorporated in the surface rubble and may travel long distances down slopes.

The altered rock commonly contains quartz veins, some of which may be several inches wide and persist for several feet. The quartz crystals have their long axes normal to vein walls or to cavities and the veins tend to be open and vuggy. Quartz may be coated with alunite and quartz veins are cut by alunite veins. The soft altered rock was not analyzed at the Mineral Products, but a sample of soft altered rock at the L&N vein deposit contained 10.4 percent alunite, although the alumina content is 21.40 percent in the rock and the silica content is 65.80 percent. The soft rock, therefore, contains a lesser amount of alunite, but kaolinite is abundant.

The alunite occupying the veins is complex in structure and crystal appearance. Part of the vein filling is a dense, extremely fine-grained aggregate of minute crystal plates. Commonly it is massive and structureless, but in parts of the veins appears to have been sheared to a schistose aggregate which has a silky luster and splits readily into thin plates. Color ranges from gray with a slight pink tinge to pink or salmon. Some banding results from changes in color, but some banding parallels vein walls, inclusions and partings of dense alunite. Analyses of both types of vein filling are given in table 11. The more typical vein filling material is a banded, plumose aggregate. The bands tend to parallel the walls of the veins and the axes of the plumose or feather-like groups normal to the banding. The individual plumose groups are not a single long prismatic crystal, but an aggregate of differently oriented crystal grains radiating out along a central axis; thus even where the aggregates line cavities, single well-formed crystals do not occur. The color is prevailingly pink with salmon and yellow. At a locality in California the plumose alunite was green.

Crystal cavities in the drusy surfaces of plumose alunite lining elongate openings in the vein were as much as a half inch deep and square to diamond shaped in cross section (Loughlin, 1915, p. 243). The cavities are lined with tiny platy alunite crystals showing that the mineral formed as a vein mineral, but was dissolved out prior to the end of alunite mineralization. Loughlin suggests that the mineral was diaspore, but the writer is inclined to believe that they represent another sulfate, probably anhydrite or gypsum.

The plumose alunite is cut by bluish white veinlets of the clay mineral dickite which appears to be the last mineral in the primary sequence. Weathering has released hydrous iron oxide which may coat and stain the altered rock and vein material.

The plumose banded veins cut across the dense alunite and replace it. Both varieties cut the siliceous altered rock. The plumose veins cut across each other in a highly complex succession. Slabs and thin plates of siliceous altered rock commonly are detached from the vein walls and lie in the veins oriented parallel to the banding. They may be more than a foot wide and several feet long, or only a few millimeters. Plumose or even dense veins cut across the inclusions. As the inclusions could not be separated readily from the alunite, many were included in the mill feed, which reduced the grade of the mill feed below the actual composition of the alunite.

The size of the veins ranges from hairline fillings of fractures to lenses 65 feet thick. The extremely complex pattern is represented on the mine maps (plates 12 and 13), although not every veinlet can be shown at the map scale. The size may change vertically and horizontally along the course of the vein. The veins that were stoped were mainly 10 feet or more wide above the working level. That part of the vein exposed in the lower tunnel, however, showed the width had diminished to 5 feet (figure 41).

The structural features in the veins affected mining procedures and costs. Plate 13 shows the ore shoot, stoped 15 feet wide, bottomed in a stockwork of veinlets and a few lenses projecting downward below the level. The lower adit, driven under the large lens at the portal of the upper adit, exposed a network of veinlets in altered rock with a few small lenses. The map also shows the tendency of the veins to branch and send apophyses into walls. Even the West vein, which differs so greatly in dip and strike from the Main vein, curved into it and was a part of it. The open stopes showed the Main vein dipping northeast and the connecting raise southwest. The West vein dips about 50° N. (figure 42).

A striking set of vertical joints crosses the veins and projects an unknown distance into the silicified wallrock. The joints could be seen in the open stopes continuing to the full height. They are usually a single

Figure 42. Open stope in Mineral Products alunite mine.

joint, but groups of closely spaced joints also occur. They were clay filled, but plumose vein alunite was noted on the surfaces of some of the fractures crossing at 90° to the banding in the vein. The crossing fractures failed to appear where the vein and the enclosing envelope of altered rock are thin, and they apparently did not reach the lower level, although fractures dipping steeply southeastward were mapped as were fractures in other directions.

Exploration by the U. S. Bureau of Mines and the U. S. Geological Survey in 1942 and 1943 uncovered several veins not known previously and showed horizontal and vertical variations in structure of veins and altered rock (plate 12 and figure 43). A group of mainly narrow veins overlies the West vein. The Gar vein was opened for a length of 200 feet; it continued downward for 350 feet. The Bradburn vein, which is 20 feet wide in the adit (figure 44), was found to maintain its width 350 feet below the outcrop. The drilling did not test the continuity of the Main vein below the lower adit, but Drill-hole No. 6 reached the level and showed a branch vein 50 feet east of the level. No additional work was done on the group of small veins 1,200 feet northeast of the portal of the Mineral Products mine. The Crowfoot adit explores a curving vein one-half to 3½ feet wide dipping 20° to 32° S. and W. The Discovery tunnel shows a fault contact of volcanic tuff against quartzite dipping 74° N. Tuff near the fault dips 27° N. The Lucy B. tunnel is wholly in quartzite. The normal contact of tuff and quartzite is not exposed, but is believed a few feet above the Lucy B. or about 9,500 feet. Quartzite appears on the west side of Alunite Ridge at an altitude of 9,800 feet. Drilling failed to reach the quartzite floor under the Mineral Products mine, but the floor could be at 9,500 feet or higher, which would place the quartzite as close as 400 feet below the Mineral Products lower adit.

Because of its relation to the Mineral Products group of veins, the Bradburn vein is described and mapped (plate 12 and figure 44) with the Mineral Products, although only a small part of the Bradburn vein is within the Custer patented claims. A geologic map of the Main adit made by the writer in 1937 is included as figure 44. The vein, about 1,400 feet long on the surface, strikes N. 25° E. on the average and dips 70° to 85° SE. The vein is on the steep east slope of Alunite Ridge so the difference in altitude of the two ends is about 600 feet. A diamond drill hole penetrated the vein about 350 feet below the outcrop. The vein is almost entirely obscured by talus and rock debris on the steep slope. Some ore was mined by Swift and Co. from an open cut and from the drift shown in figure 44. The vein, exposed for 240 feet in the drift, is mostly 20 feet wide and measured 27 feet across the face. The drift was backfilled at the northeast end. A branch breaks away from the west side of the vein in a southwesterly direction. Throughout the width of the vein, alunite is banded parallel to the walls, but contains partings of dense alunite and slabs of silicified wall rock. A mass of white, dense alunite near the east end of the drift contains veinlets of plumose alunite. All the wallrock is altered but differs in degree of silicification; some is firm and pyritic, some is porous and iron stained.

Considering the part of the deposits with that remaining, more than 2 million tons of alunite must have formed or more than 200,000 tons of potash added to a relatively small block of ground. Exploration was not extensive enough to show the continuation of alunite veins in the sedimentary rocks. The writer, however, found a small dense alunite vein in quartzite south of the Mineral Products mine and a prospector, Joe Burns, reported he had driven a short drift on an alunite vein in red shale near Cottonwood Creek south of the Mineral Products. The writer is convinced that the eroded surface of the quartzite under the volcanics is only a few hundred feet beneath the exposed veins and that all the constituents of the alunite came up through a sedimentary column of unknown thickness from a wholly concealed igneous

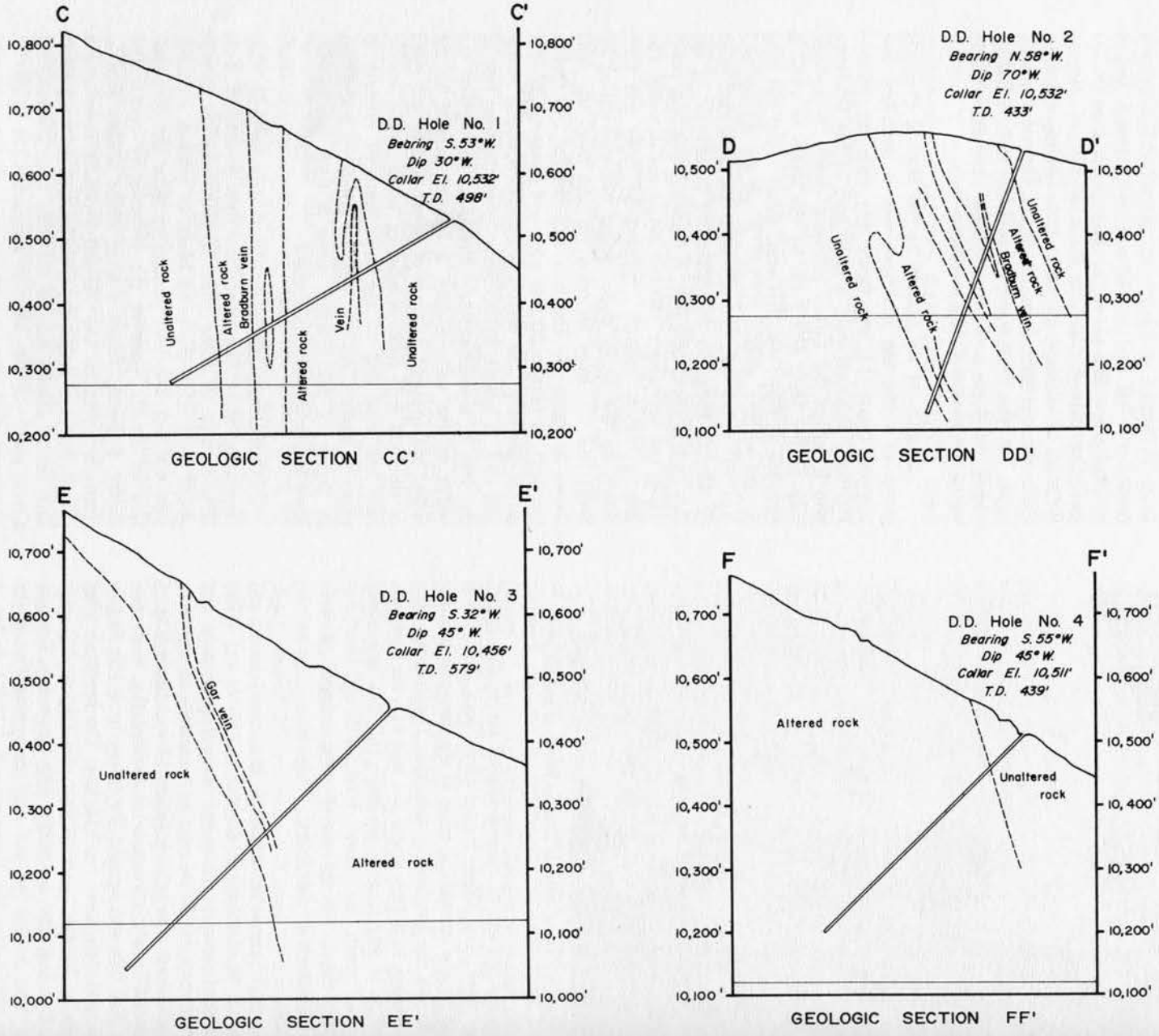
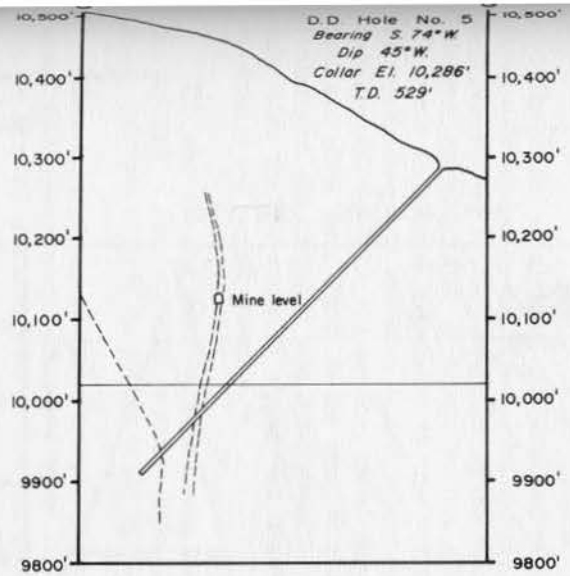
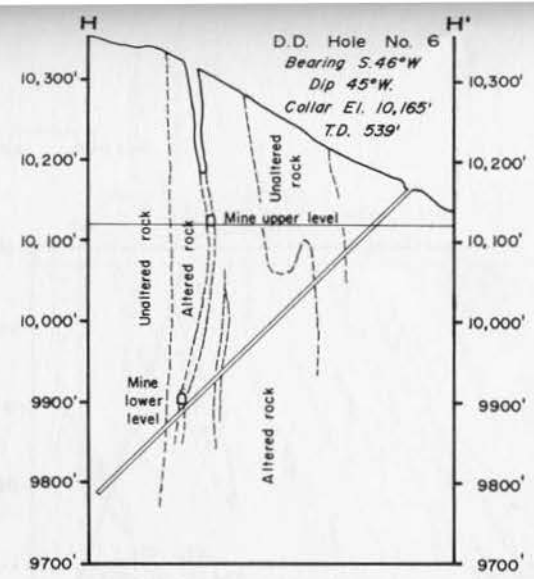


Figure 43. Geologic sections of drill holes on Bradburn and Mineral Products alunite vein system (modified from Hild, 1964. Original interpretations by M. E. Willard, 1942 and G. L. Bell, 1943).



GEOLOGIC SECTION GG'



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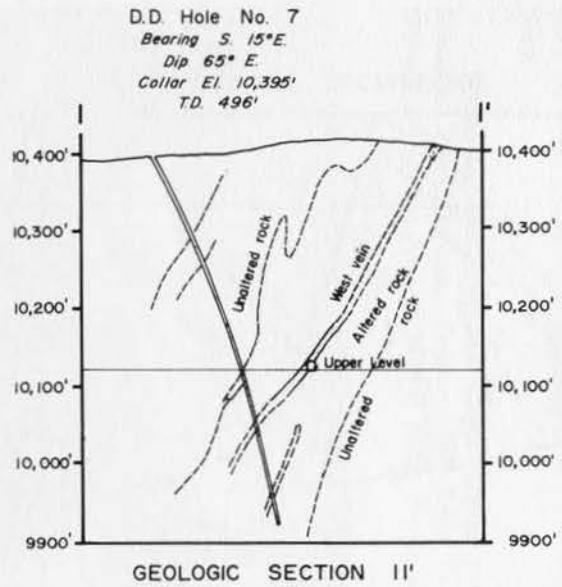
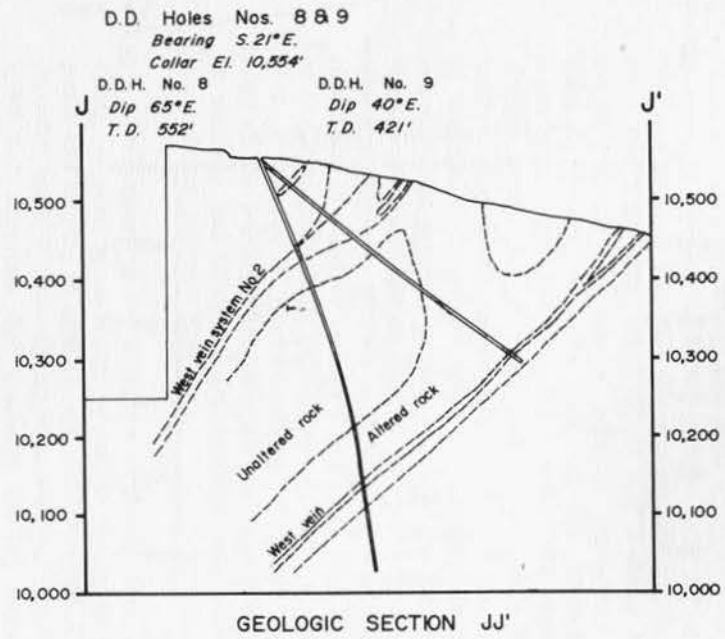


GEOLOGIC SECTION II'



GEOLOGIC SECTION JJ'

Figure 43. (continued)

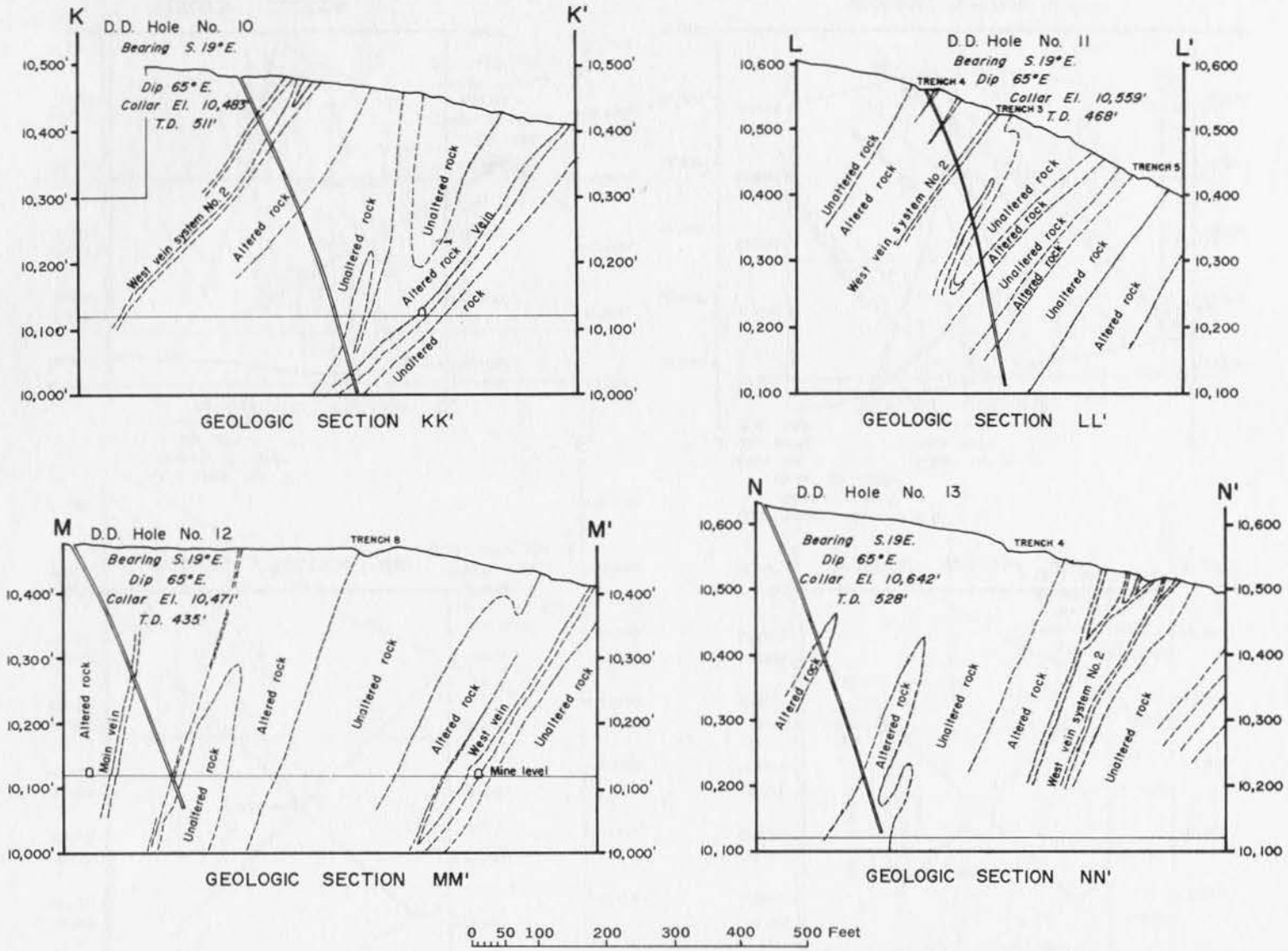


Figure 43. (continued)

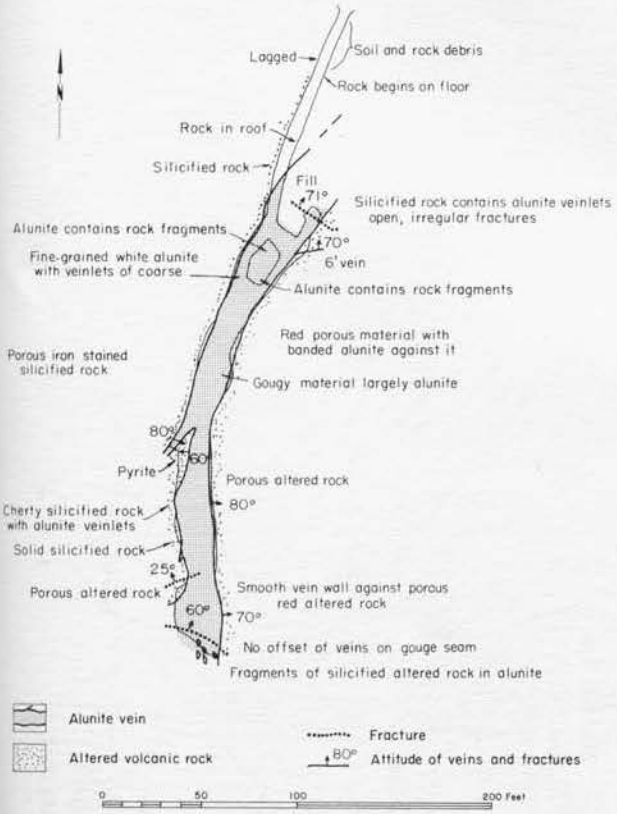


Figure 44. Geologic map of Bradburn alunite mine (map by E. Callaghan; surveyed 1938).

source. The only known evaporite in the geologic section is gypsum.

The masses of silicified, alunitized and pyritized altered rock formed by hot waters emerging from fractures beneath the volcanics and soaking out into the volcanics, probably from an initial fracture system. This event is believed subsequent to the carbonate-sericite-chlorite-quartz alteration that is related to the formation of the base and precious metal deposits. Gold and silver were absent in the assay of alunite. Furthermore, the carbonate and other alteration minerals, with the exception of quartz, are absent or destroyed in the alunitic altered rock.

The silicified and alunitized rock masses became firm so that a resolution of tectonic forces could shatter and open them in the pattern of the veins.

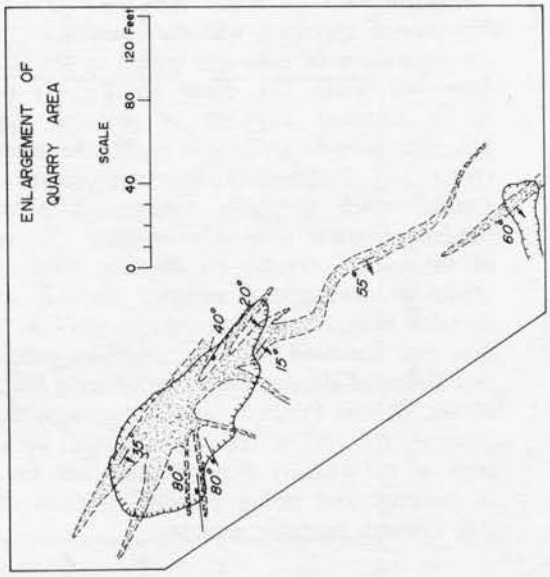
As a consequence of such a tectonic event, the altered rock masses were broken and many fractures and the lines of weakness were created and occupied by the two sets of veins seen today, one at right angles to the other. The unaltered volcanic breccia, not as firm, did not open freely so the veins do not project appreciably into it or did not open widely when the unaltered rock was nearby.

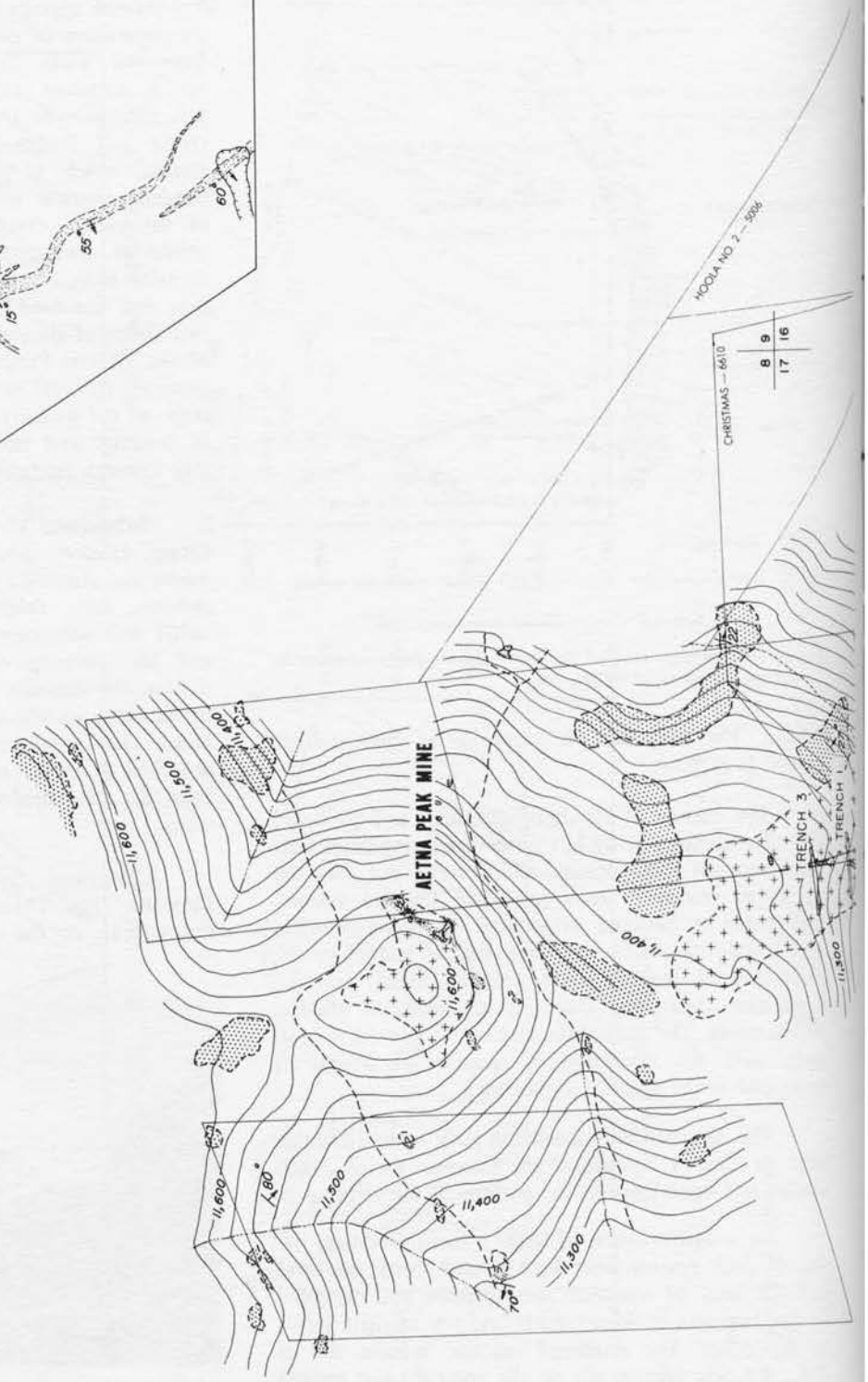
Following the opening of the vein fracture system, the veins were filled–a long and complex chemical procedure. The initial stage was possibly the formation of a gel which may have crystallized as a fine-grained aggregate with the opening of the vein and the separation of slabs and plates of the silicified rock from the walls. The dense alunite was replaced by much coarser crystals in plumose aggregates, a pulsating growth from vein walls, the sides of inclusions and longitudinal fractures within the dense alunite, which, in places, remained as partings in the banded, plumose mineral assemblage. Toward the end of the epoch, crystals of another mineral, probably anhydrite or gypsum, possibly formed, but became unstable with a change in the composition of the solution and dissolved out. The openings were lined with tiny flakes of alunite. Fractures crossing the thick parts of the Mineral Products vein system also were opened close to the end of the mineralization epoch. A final stage of the primary mineralization was the deposition of coatings and filling of tiny fractures with a blue clay mineral, probably dickite.

Subsequent to the formation of alunite, faulting, tilting, erosion, groundwater movement, oxidation of pyrite and staining of minerals and rocks occurred. The deposits were subject to tectonic activity, regional uplift and volcanism that produced the Dry Hollow and Mt. Belknap volcanics and later basalts. Nevertheless, the deposits were not dislocated or interrupted by faulting to any appreciable extent. Although older than the uranium mineralization, they have not absorbed it as far as the writer is aware. Erosion has been the most profound in removing large parts of the veins.

Christmas, Sunshine and Aetna (Edna) Peak Deposits. The Christmas, Sunshine and Edna Peak deposits are on the crest of Alunite Ridge (figure 45)

Figure 45. North portion of Alunite Ridge in center from L&N mine. Christmas mine is center at ridge crest. Aquarius Plateau (Boulder Mountain) in extreme distance.


ENLARGEMENT OF
QUARRY AREA
SCALE
0
40
80
120 Feet
35°
80°
80°
40°
20°
15°
55°
60°


AETNA PEAK MINE
11,600
11,500
11,400
11,300
80°
70°
TRENCH 3
TRENCH 1
CHRISTMAS — 6610
HOOLA NO. 2 — 5006
8
9
17
16
22

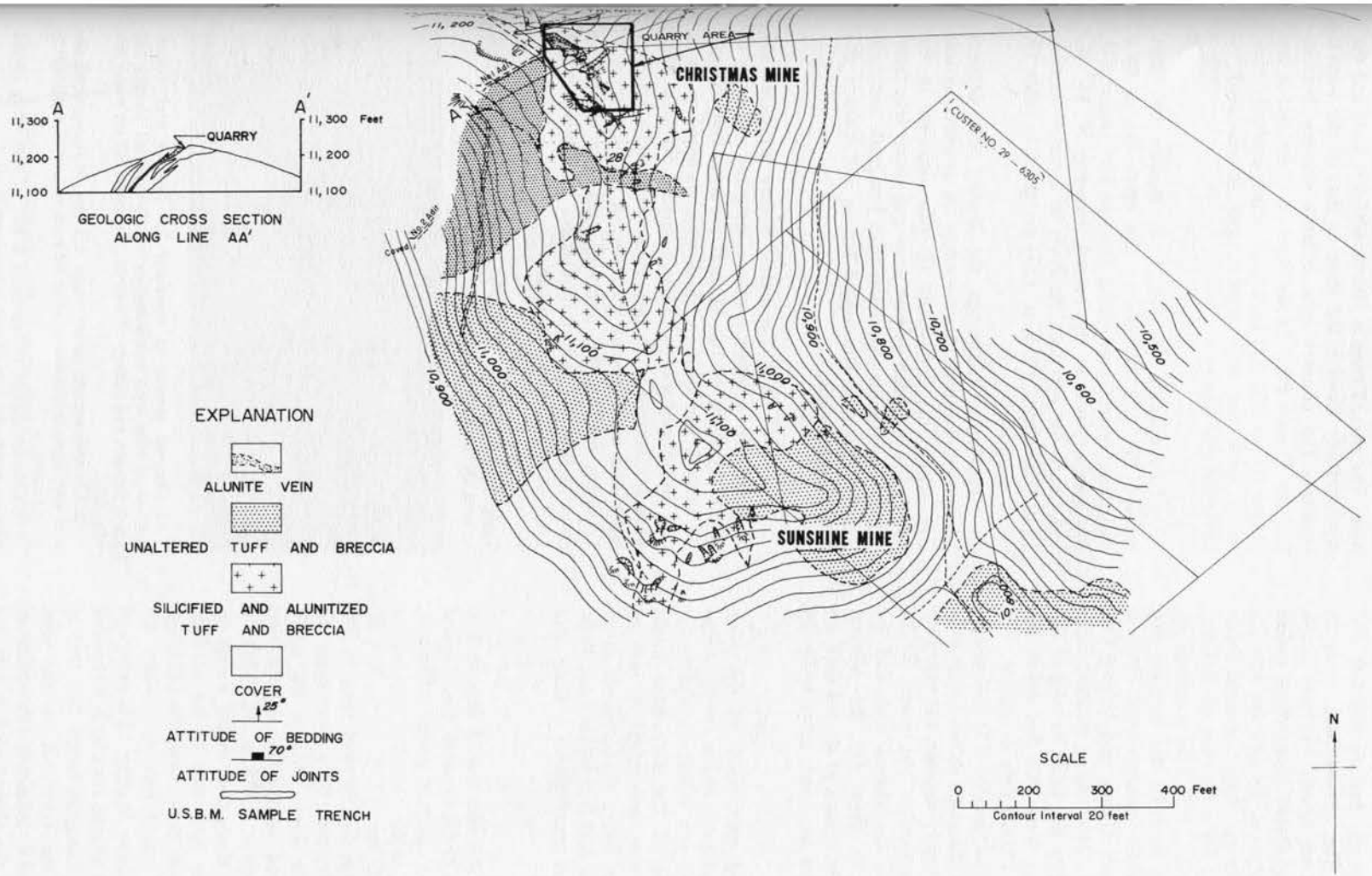


Figure 46. Geologic map of Aetna (Edna) Peak, Christmas and Sunshine alunite deposits (modified from maps by E. Callaghan and G. F. Seager, surveyed 1936; M. E. Willard and P. D. Proctor, surveyed 1942; G. L. Bell, surveyed 1943).

between the altitudes of 10,900 and 11,600 feet in secs. 8 and 17, T. 28 S., R. 4 W. Figure 46 shows the distribution of altered volcanic breccia and tuff and areas of unaltered rock. The altered rock tends to break into fragments that are heaved by frost action and to flow down over unaltered rock which makes smooth slopes. A long open cut follows the vein for 120 feet and a drift was driven from a crosscut about 80 feet below the outcrop for a distance of 360 feet (figure 47). The crosscut and drift were reopened by the U. S. Bureau of Mines in 1943 and mapped. No drilling was done, but sample trenches were cut and samples taken. The Florence Mining and Milling Co., which Loughlin (1915, p. 240) shows as claiming a large area in 1914, including the L&N, developed the property, erected a furnace some 700 feet below the deposit and mined about 12,000 tons of alunite. The vein was followed on the surface for 270 feet and in the drift for 340 feet. The thickness shown in the map of the drift (figure 47) is highly variable, but mainly 5 feet or less. The dip also is variable, but mostly 50° or less. The characteristics of the altered rock and the vein filling are similar to those for the Mineral Products and Bradburn. The masses of altered rock are much smaller and the veins are much more restricted in all dimensions.

Some cuts in altered rock south of the mine show small veins in altered rock, and a cut on Aetna (Edna) Peak shows a small vein which was traced for about 200 feet. Trenching of the deep talus might show other small veins now concealed. A belt of altered rock not shown in figure 46 continues down the slope to the east about 600 feet below Edna Peak. At least one cut on this zone shows a little vein alunite.

L&N Deposit. The L&N vein alunite deposit is in the saddle on the drainage divide between Cottonwood Creek and Pine Creek. The common corner of secs. 7, 8, 17 and 18 is on the saddle, but the exploration workings on the vein are in sec. 17, T. 28 S., R. 4 W. The altitude in the saddle is slightly more than 11,200 feet. The vein zone was explored by a short open cut and an adit on the south slope. Cuts on the north slope showed only altered rock. The deposit was mapped in 1936 by Callaghan (1938, p. 122-123). In 1943 the U. S. Bureau of Mines constructed a road up into the saddle and made four cuts in the zone of altered rock. No drilling was done. Loughlin (1915, p. 240) shows a group of cuts a half mile down the glaciated slope as being alunite bearing. Cuts examined by the writer showed soft altered rock with a network of bluish dickite veinlets. Loughlin noted 20½ feet of plumose-type alunite in the open cut on the vein. Some silicified altered rock occurs in the belts of altered rock, but most of the altered rock is soft and argillic. Thus it makes a hollow in the erosion surface rather than bold outcrops characteristic of the silicified rock. The altered zone is 300 to 400 feet wide and the northwesterly trend is the same as that of the veins it encloses. The country rock is latite volcanic breccia, but the Delano Peak Latite flow or ignimbrite is displaced 150 to 200 feet by a fault which probably coincides with the vein system, but is obscured by alteration and cover.

Exploration by the U. S. Bureau of Mines showed the vein exposed in the open cut to be a branching system continuing for 400 feet (figure 48); the vein exposed in the tunnel, trending N. 55° W., was traced for 200 feet. Analyses of samples taken in 1936 (Callaghan, 1938, p. 123) are given in table 12.

Evaluation: Although the alunite vein deposits are spectacular and prime sources of alumina, potash and sulfur, the economics of vein deposits in the 1970's are regarded as high cost and much less favorable for profitable operation than low-grade multimillion-ton deposits. The rugged terrain and altitude also deter development.

In 1945 U. S. Geological Survey geologists and U. S. Bureau of Mines engineers prepared estimates of alunite available in the Mineral Products vein system. All veins 2 feet or more thick were included as ore as well as stockworks of closely spaced veinlets. Data were synthesized from measurements in trenches, drill holes and underground workings. A volume factor of 12 cubic feet to the ton was used. The results are given in table 13. The estimates for the Christmas and L&N were added by the writer.

Table 12. Analyses of alunite and wall rock from the L&N area (R. K. Bailey, analyst).

	1	2	3
Al_2O_3	38.50	28.70	21.40
K_2O	7.90	6.75	1.11
Na_2O	.26	.38	.16
SO_3	29.30	26.20	4.02
H_2O^+	13.33	9.50	7.33
H_2O^-	0.10	0.10	0.20
SiO_2	10.85	27.10	65.80
	100.24	98.73	100.02

1. Channel sample to represent 9.4 feet of pink coarse-grained alunite with small masses of fine-grained alunite and small veinlets and fillings of dickite. T-shaped cut on south side of saddle.

2. Channel sample to represent 4.3 feet of fine-grained alunite with some fragments of silicified rock at face of west drift in main tunnel.

3. Channel sample to represent 8 feet of soft white altered rock on southwest side of vein in same cut as no. 1.

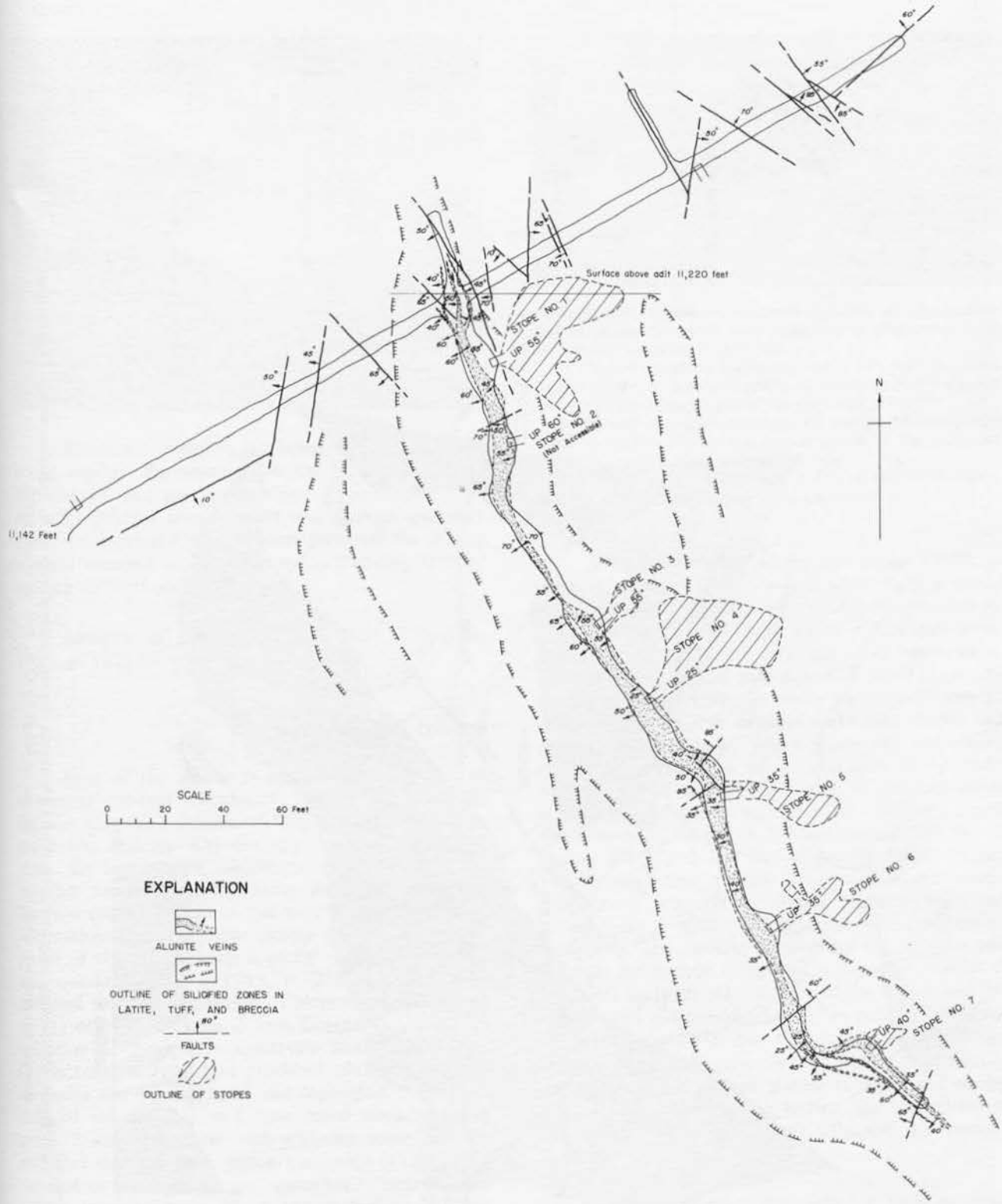


Figure 47. Geologic map of upper level (No. 1), Christmas (and Sunshine) mine (map by G. L. Bell, surveyed 1943).

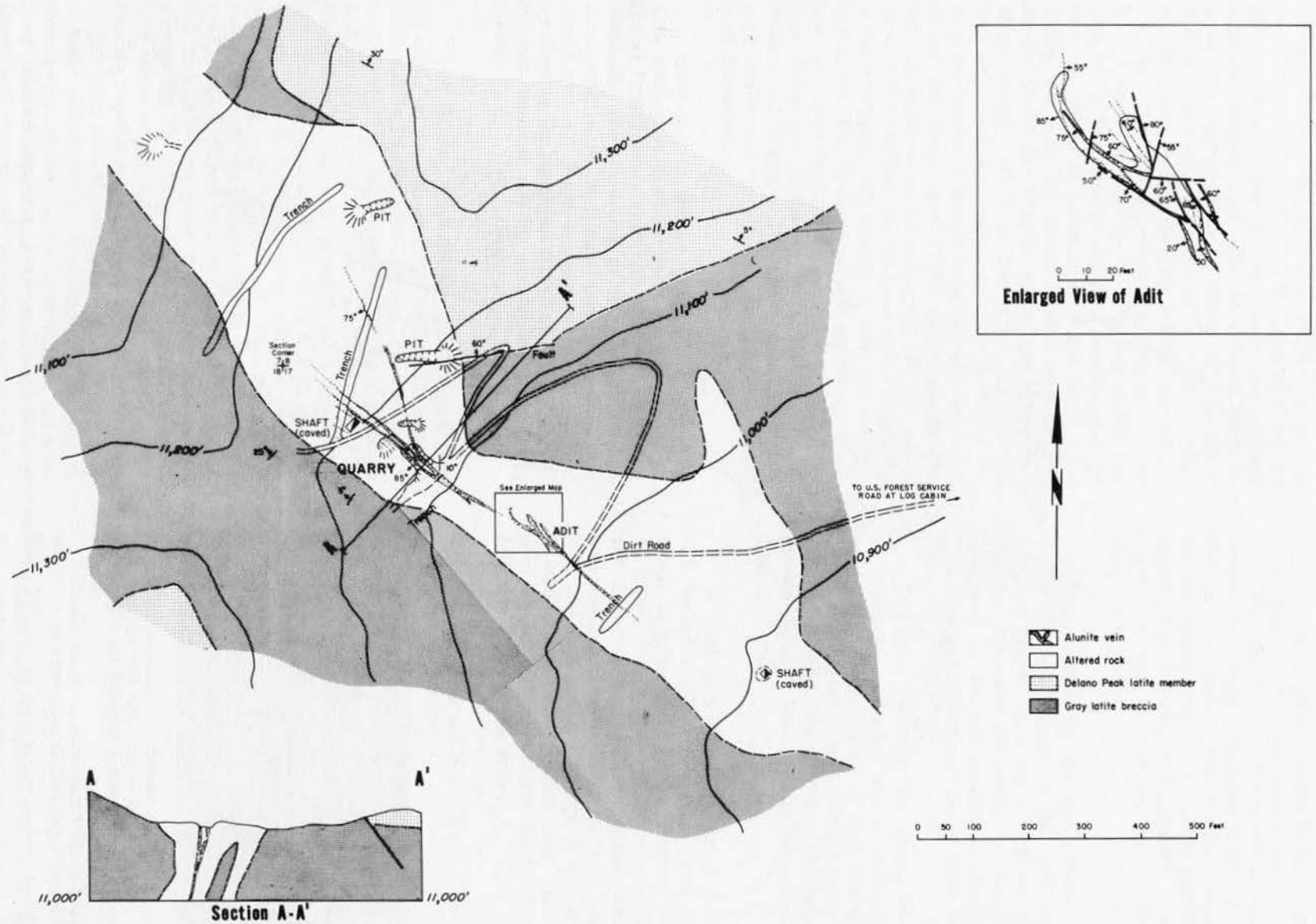


Figure 48. Geologic map and section of L&N alunite deposit (original map by E. Callaghan and G. F. Seager, surveyed 1936. Map showing exploratory work by U. S. Bureau of Mines by G. L. Bell, surveyed 1943).

Table 13. Estimated alunite in the Mineral Products vein system.

Area	Measured ore (tons)	Indicated ore (tons)	Inferred ore (tons)
Mineral Products			
Main Vein	459,900	86,300	
West Vein	160,450	11,300	21,000
West Vein No. 2	101,250	36,000	
Gar Vein		10,000	
Northeast Veins		20,000	40,000
Bradburn		44,000	300,000
Christmas (5 x 100 x 340)		14,000	
L & N (5 x 100 x 400)		16,000	
	721,600	237,000	361,000
Wall rock, estimate, not included in inferred ore			100,000

Alunitized wallrock included in the estimates could modify the resource picture markedly. If vein material of any size were added to alunitized rock, even 33 percent alunite grade, the tonnage probably could be expanded to 2 million tons and the mining method changed to open pit or block caving, thereby making the cost competitive.

Analyses of samples taken in 1936 (Callaghan, 1938, p. 122) are reproduced in table 14.

Table 14. Analyses of alunite from the Sunshine area (R. K. Bailey, analyst).

	1	2	3	4
Al_2O_3	39.45	35.35	37.70	30.70
K_2O	7.67	7.00	8.25	6.51
Na_2O	.68	.67	1.12	.42
SO_3	36.10	31.50	34.00	25.20
H_2O^+	13.33	12.50	13.00	11.50
H_2O^-	0.15	0.15	0.10	0.30
SiO_2	2.20	10.95	4.65	21.00
Fe_2O_3				5.30
	99.58	98.12	98.82	100.93

1. Channel sample to represent 4.2 feet of pink coarse-grained alunite containing some fragments of altered rock, from pit 140 feet southeast of glory hole.
2. Channel sample to represent 6 feet of soft platy, very fine-grained alunite on the south side of the coarse-grained portion of the vein at the southeast end of the glory hole.
3. Channel sample to represent 4.2 feet of extremely hard white or slightly pinkish fine-grained alunite at the northwest end of the glory hole on south side of raise.
4. Channel sample to represent 5 feet of reddish alunitized rock containing some coarse-grained alunite veinlets. Adjoins no. 3 on the north.

Alunite Replacement Deposits

Most of the alunite in the Marysvale region is an alteration product of various volcanic rocks of the Bullion Canyon Volcanics of Oligocene age. The overlying Mt. Belknap Rhyolite apparently was extruded after the termination of alunitic alteration with the possible exception of the Sheep Rock deposit in the Newton mining district at the west base of the Tushar Mountains. Here a rhyolite closely resembling the gray phase of the Mt. Belknap is partly replaced by alunite and quartz (Loughlin, 1915, p. 258-264). It can be assumed that the deposition of alunite was subsequent to (1) deposition of the Bullion Canyon Volcanics, (2) intrusion of the quartz monzonite and related rocks, (3) tectonic activity that produced relative movement on faults and regional uplift and depression, (4) deposition of the precious and base metal veins, and (5) some further tectonism and probably some erosion, and that the Marysvale region assumedly (6) became a thermal or geothermal area. According to isotopic ages of the intrusive rocks (2, above) of 23.6 to 26.0 my and of the Mt. Belknap rocks of 13.7 to 20.0 my, there is a minimum interval of 3.6 my and a maximum of 10.1 my for the events (3) to (6) to occur.

A study made by Austin and Pringle (1970, p. 1-40) of the Coso thermal area at China Lake in southeast California reveals the variety of geochemical situations in a single area under which alunite may form. The Coso thermal area is estimated at 80 square miles; the Marysvale thermal area may have been about 250 square miles. At Coso the rocks are surface cover or debris of granite and volcanic rocks over diorite and granite. Thermal leaks, where steam and hot waters reach the surface and where alteration of the rocks with deposition and reconstruction of dissolved solids is active, were studied in detail. At one leak, a well was drilled to a depth of 375 feet through 210 feet of surface debris and 165 feet of granite. Tables 15 and 16 compare the content of the dissolved solids, temperature and pH in surface shallow wells and springs with a water sample taken under controlled conditions. The striking features are the strongly acid water at the surface compared to the alkaline water at 375 feet, the high SO_4 content of the surface and the high sodium and considerably higher potassium content of the water at 375 feet. Chlorine is correspondingly high in the deep sample. Alunite, not soda alunite, is prominent in the altered granite at depth and among the minerals formed at the surface. The gas emitted at the surface was 98.1 percent CO_2 and 1.9 percent N_2 + A.

Minerals formed at the surface at Coso are significant. Except for residual quartz the minerals of the volcanic and granite rock fragments in the alluvium are destroyed. Quartz crystals 1.0 mm in diameter formed

Table 15. Recent analysis of waters at Coso thermal area (Austin and Pringle, 1970, p. 4, table 4).

Analysis	Location and date				
	22/39-7J1 Spring, 1960	22/39-4K5 Well, 1961	22/39-4K4 Well, 1961	22/39-4K3 Condensed steam from well, 1960	22/39-4K2 Spring, 1960
Constituent, ppm:					
SiO_2	326	306	326	203	202
Fe	28	9.0	5.5	0.06	0.09
Al	44	3.8	2.3	0.11	1.4
Ca	18	44	28	17	98
Mg	81	19	12	6.2	25
Na	14	36	30	25	81
K	28	9.2	8.8	8.6	23
HCO_3	–	–	–	–	–
CO_3	–	–	–	–	–
SO_4	1,450	1,270	947	133	528
Cl	–	375	275	1	6.5
F	0.9	0.6	0.4	0.2	0.8
NO_3	3.0	0.6	0.5	0.1	8.1
B	0.6	–	0.11	–	–
Mn	1.7	–	0.8	–	–
Li	0.1	–	0	–	–
PO_4	–	0	0.10	–	–
Br	–	1.8	3.4	–	–
As	–	0	0	–	–
Mo	–	0.004	0.004	–	–
I	–	0.003	0.006	–	–
Cu	–	–	–	–	–
Total dissolved solids, ppm	2,260	2,060	1,070	443	1,030
pH	2.2	1.2	2.1	4.5	4.0
Temperature, °F	206	115	173	201	78

in the alteration aggregate. Opal, some of it clear hyalite, is the most abundant new mineral. Sulfur is abundant, bringing gas and steam vents or disseminated in openings in porous rock in areas no longer hydrothermally active. Cinnabar occurs as streaks in opal and was mined, but now is undetectable in the water. Pyrite as brassy crystals up to 0.13 mm in places makes up 25 percent of the altered material. Sooty covellite coats pyrite in some places. A variety of sulfates occurs in the surface material. At the Devils Kitchen locality, alunite occurs (1) as a massive, plastic, clay-like material, (2) as granular masses mixed with residual quartz, and (3) as "columnar coatings from ½ to ¾ inch thick growing over compacted alteration products following periods of high rainfall" (Austin and Pringle, 1970, p. 13). The rocks in the alluvium being altered are low in potash so that the increment in potash must be added from the solutions. Several iron sulfates are recognized: copiapite butlerite, halotrichite and voltaite. Chalcanthite is present and gypsum surprisingly is minor. Hematite occurs as stains and coatings.

In the drill hole, the various kinds of rocks in the alluvium as described in the log appear little altered although the temperature rose to 203° F and steam began venting at 120 feet. At 170 feet, temperature increased to 220° F and pH from 6 to 11. Calcite, pyrite and hematite stains appeared. At 210 feet the cuttings were gray granite interpreted as solid rock which contains pyrite, calcite and iron oxide. At 235 feet with temperature at 235° F and pH 11, alunite is abundant, but occurs with calcite and hematite. The mineral grouping continues to the bottom of the hole, temperature 240° F and pH 11, which was completed June 1967. The hole was cleaned out March 1968 and sampled. The temperature had increased to 287° F and the pH was 8.5. Tests showed the well could not maintain itself as a live steam well.

At Coso the occurrence of two fluids with such different dissolved solids distributions and pH at the surface and at relatively shallow depth, and the occurrence of alunite in the environment of each is significant in considering the origin of alunite. Anderson (1935, p. 240-252) found alunite as a mineral formed at the surface in acid hot spring waters at Mt. Lassen. Kerr (1957, p. 79-81) discussed alunitic alteration and noted its limitation with depth. Willard and Proctor

Table 16. Water analysis of samples of Coso No. 1 drill hole taken at depth of 375 feet (Austin and Pringle, 1970, p. 36, table 12).

	1	2	3
Data:			
Sample taken	6-27-67	3-68	3-68
Analysis	7-12-67 to 8-3-67	4-16-68	4-16-68
Temperature, °F	240	287	287
Constituent, ppm:			
Ca	72.8	359.0	74.4
Mg	0.5	0.6	1.0
Na	1,764	2,808.0	1,632.0
K	154	172.0	244.0
CO_3	84	50.4	77.4
HCO_3	134.2	0.0	0.0
SO_4	38	216.0	52.8
Cl	2,790	3,681.0	3,042.0
NO_3	7.1	trace	trace
NO_2	–	negative	negative
SiO_2	50	27.0	154.0
F	3.70	1.60	2.20
B	48	57.42	71.60
Fe	0.15	–	–
Mn	0.0	–	–
PO_4	0.4[1]	0.23	0.88
Cu	0.0	–	–
OH	–	76.2	1.7
Br	–	4.67	2.55
As	–	0.94	7.50
NH_4	–	trace	trace
Hg	–	1.4	0.0
Synthetic detergents, apparent ABS	0.290	–	–
Total dissolved solids, ppm	5,744	6,894.0	5,228.0
pH	8.9	9.8	8.5
Analytical laboratory	Navy	Hornkohl	Hornkohl

[1]Ortho.

Sample 1 was taken from the well discharge (clear water) at completion of drilling after blowing the well with compressed air for over 1 hour. Samples 2 and 3 were taken after the well was idle for 7 months. Sample 2 is from the first and third bailers, and sample 3 from the 13th and 14th bailers.

(1946, p. 632) described the Kaolin aureoles around alunite and concluded that the White Horse deposit was formed by selective replacement of the synclinal parts of flow-folded latite by sulfate-bearing solutions produced at depth. Callaghan (1938, p. 115-117) reviewed earlier theories of the origin of alunite and concluded that ascending sulfate-bearing solutions were responsible, but that supergene solutions derived from the oxidation of pyrite could have modified alunite grade and distribution. The absence of calcite is significant in indicating the formation of alunite in an acid environment. Its presence in association with alunite in the deeper part of the well at Coso suggests that this geochemical limitation is not necessary in all situations.

Gold Mountain Mining District

Winkelman. The Winkelman, also known as Copper Butte, was a deposit developed in the later stages of World War I. An aerial tramway connecting the quarry at the deposit on Deer Creek with the railroad at the mouth of Deer Creek, in sec. 3, T. 27 S., R. 4 W. at 6,900 feet altitude, was never completed. Some 30 carloads or 1,500 tons of material supposedly were taken from the property.

The property is covered by six patented claims. The deposit was mapped in 1938 and again in 1942 by Max Willard (figure 49) when 2,995 feet of diamond drilling was completed by the U. S. Bureau of Mines (Hild, 1946, p. 10-11). Analyses were quoted by Callaghan (1938, p. 125-126), and the deposit was studied by Kerr (1957, p. 166-168) during the uranium investigation. The map prepared by Willard shows the location of the Bureau of Mines drilling and the assays are listed by Hild (1946, p. 34-40).

The Winkelman area is in a small window of Bullion Canyon Volcanics which, except on the north side, is surrounded by the Red Rhyolite (ignimbrite) phase of the Mt. Belknap Rhyolite. The Mt. Belknap Rhyolite is unaffected by alunitic alteration. The locality is in line with the Tushar fault which apparently died out south of the property. The drilling indicates that the alunitic alteration is confined to a bed of latite tuff which dips 20° on the average to the east or southeast. The contact with underlying latite is essentially parallel, but is marked by a bedding plane fault. Many other small faults of variable dip and strike transect the tuff and are post-mineral, as are sets of closely spaced joints in the alunitized areas. Parts of the tuff, however, were brecciated prior to mineralization because alunite fills spaces between the blocks and outlines of blocks are seen faintly where replacement was complete. These areas controlled the paths of alteration and mineralization, and tuff between them is only slightly if at all altered. Abundant talus from the canyon walls covers much of the Winkelman area and obscures relationships. The altered rock, however, tends to stand out as outcrops from less altered material.

The highest grade alunite is an extremely dense, semitranslucent, waxy material which breaks with a conchoidal fracture and ranges in color from white through pink to yellowish green and usually is mottled with black. Analyses indicate that it contains some silica. Although the rock is hard, it may be cut by a knife. Less altered tuff is mostly covered by talus, but is shown bleached in a tunnel. Some layers are chalky white whereas others are gray. The shapes of the bodies are not clearly shown, but drilling indicates

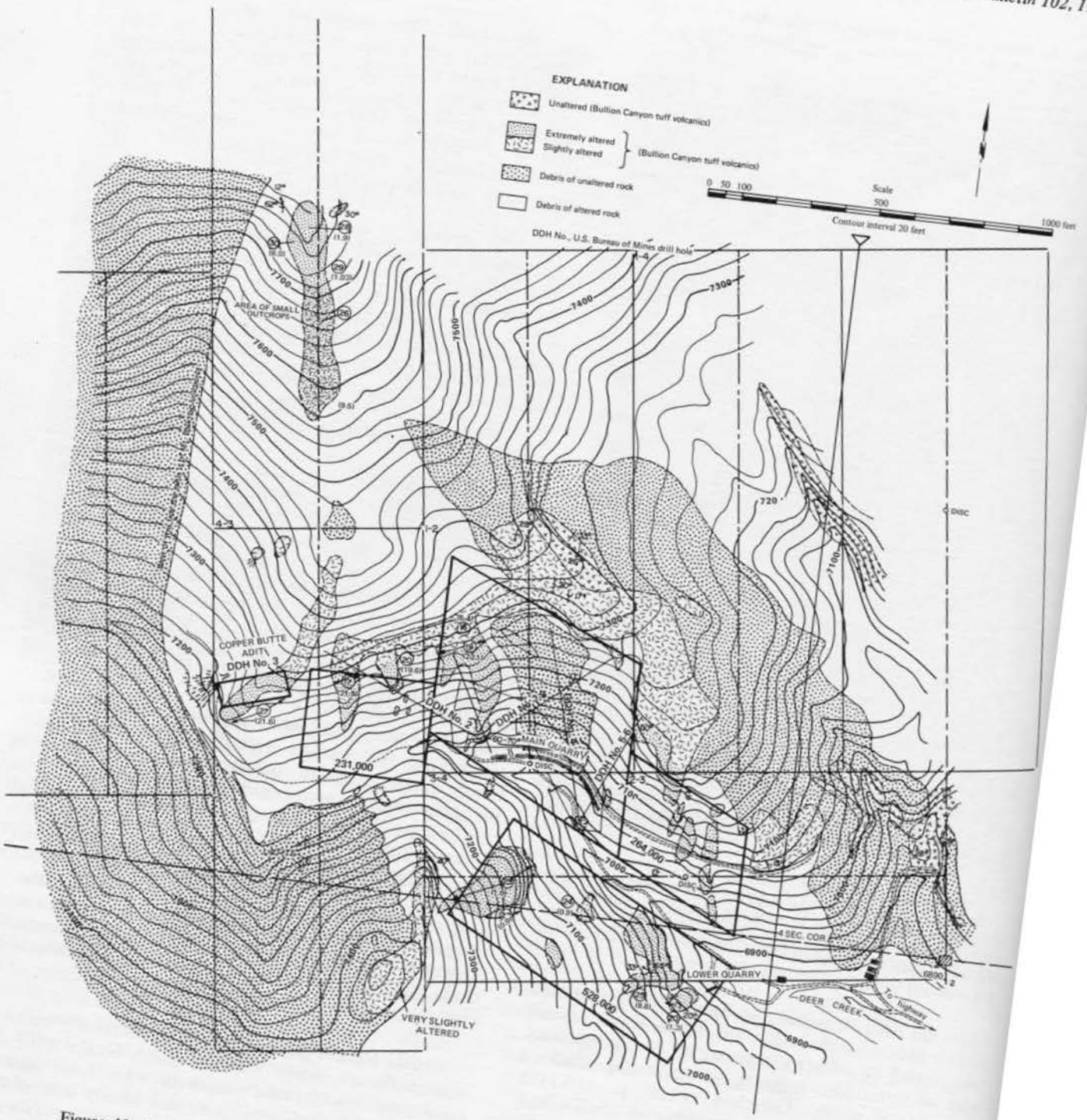


Figure 49. Geologic map of Winkelman alunite deposit (topography and geology by M. E. Willard, surveyed 1942).

they are vertical plugs with flat bases against the tuff-latite contact. In places the mineralization apparently follows a layer outward from the plug-like body. Alunitic rock on the ridge above the main quarry does not have a downward projection and its source connection undoubtedly was removed by erosion.

The drilling was designed to test the ore's extent rather than to block it out. Nevertheless, the geologist who observed the drilling estimated three blocks contained about 1 million tons averaging 50 percent alunite.

Analyses of samples from various sources are listed in table 17.

An adit and pit, known as the Copper Butte, on the west side of the altered area was investigated for uranium. Kerr and others (1957, p. 166-168) located autunite, torbernite, uranophane and radon in the adit which was excavated years before to test a show of copper carbonate minerals. He indicates that the uranium mineralization is surely later than the alunite, and the copper also may be later, although, it could be earlier.

Pittsburgh. The Pittsburgh property of 16 patented claims and a millsite in secs. 29 and 30, T. 26 S., R. 4 W. on Deer Creek Canyon begins 300 feet west of U. S. Highway 89 in Marysvale Canyon and continues 7,000 feet west along the steep north slope of Deer Creek Canyon. Only the east end of the property is shown in plate 14. The slope to the north and east of the north side of the property is the bright yellow Big Rock Candy Mountain. The property was prospected for alunite during World War I. Several cuts and short adits were made on the Ironside No. 1 and Pay Ledge No. 2 claims facing Marysvale Canyon, and several cuts and two adits were excavated on the Potash King claims at the west end of the property. The samples for the analyses in table 18 were taken from both areas. The south side of the area included in the claims closely follows a prominent westerly trending fault which drops some complex rhyolite rocks, representing the basal part of the Mt. Belknap Rhyolite southward, against variably altered rocks of the Bullion Canyon Volcanics.

Plate 14 was made by V. C. Kelley in 1938 and the whole area is represented on the map of the Sevier quadrangle (Callaghan and Parker, 1962b). The Pittsburgh area also was included in the geologic and alteration maps made by Kerr and others (1957, pls. 12 and 13); they discussed the Big Rock Candy area in a special section of their report (1957, p. 152-161). Kerr divided the Bullion Canyon Volcanics into a Rock Candy agglomerate, making up most of the face of Big Rock Candy Mountain, and Rock Candy Latite and Tuff, making the crest of the mountain (6,500 contour

Table 17. Analyses of alunite from the Winkelman deposit.

	1	2	3	4	5	6	7
Al_2O_3		32.36	29.94	36.50	24.50	30.14	31.31
K_2O	7.76	5.12	8.58	8.86	5.90	4.60	5.20
Na_2O	.66	1.80	1.36	1.31	1.12	3.60	1.73
SO_3	28.55	30.04	27.00	36.50	23.40	30.24	30.07
H_2O^+	–	–	7.71	12.91	8.64	11.32	11.26
H_2O^-	–	–	–	–	–	.11	.09
SiO_2	–	20.96	24.40	3.72	35.20	19.74	18.32
Fe_2O_3	–	.14	.74	.20	.71	1.17	2.74
TiO_2	–	trace	–	–	.22	–	–
P_2O_5	–	–	–	–	.56	–	–
Ignition loss[1]	–	39.60	–	–	–	–	–
CaO	–	trace	–	–	–	–	–
MgO	–	trace	–	–	–	–	–
	–	–	99.73	100.00	100.25	100.92	100.72

[1] Includes both SO_3 and H_2O.

1. Partial analysis of yellowish flinty, very fine-grained sample submitted by Dr. Fleischer. R. K. Bailey, analyst.
2. Sample of hard semitranslucent material from quarry. Pittsburgh Testing Laboratory, analyst. From copy of report of 1920 by R. L. Smith to Pittsburgh-Utah Potash Co.; loaned by Dr. Fleischer.
3. Sample to represent 25 feet of light-gray dense material in face of quarry. From copy of report by Smith Emery Co. to Aluminum Potash Co. of America; loaned by Dr. Fleischer.
4. Sample to represent best grade of material; same locality and same reference as no. 3.
5. Average sample to represent one carload from quarry. Kalunite Co., analyst.
6. "Massive white alunite" (Knickerbocker and Koster, 1936).
7. "Massive white alunite" (Knickerbocker and Koster, 1936).

Table 18. Analyses of alunite from the Pittsburgh property.

	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	24.26	33.02	21.68	36.46	19.41	25.00	17.59	37.80	32.78	18.50	36.68
K_2O	3.90	4.85	3.79	4.91	.71	3.12	2.37	4.85	1.78	2.09	8.47
Na_2O	.92	1.12	.56	2.90	1.10	.78	.23	3.13	1.74	.85	.47
SO_3	19.84	29.40	19.58	34.00	10.98	21.96	13.98	34.60	23.12	8.50	27.23
H_2O^+	–	–	–	–	–	–	–	–	–	–	11.84
H_2O^-	–	–	–	–	–	–	–	–	–	–	.19
SiO_2	43.60	18.90	47.20	8.24	56.70	36.60	59.30	5.86	29.50	57.86	12.74
Fe_2O_3	.14	.28	.14	1.14	2.43	1.00	.71	1.00	.42	1.00	1.91
TiO_2	.60	.60	.60	1.20	1.20	1.20	1.20	trace	.80	1.00	–
Ignition loss[1]	26.85	40.30	25.75	44.30	17.95	31.30	18.05	47.24	33.10	12.90	–
CaO	trace	trace	trace	trace	trace	trace	trace	trace	trace	5.52	–
MgO	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	–
	120.11	.128.47	119.30	133.15	110.48	120.96	113.43	134.48	123.24	108.22	99.53

[1] Includes both SO_3 and H_2O, accounting for the high totals.

1. Sample to represent altered rock from bed overlying pyritic rock in Alum Peak or Big Rock Candy Mountain, American Flag No. 1 claim. (Samples 1-10 from report of R. L. Smith, 1920. Pittsburgh Testing Laboratory, analyst.)
2. Sample to represent same outcrop as no. 1, but 750 feet distant. American Flag No. 1 claim.
3. Sample to represent white flinty rock from shallow open tunnel about 200 feet east of west end of Potash King No. 2 claim.
4. Sample to represent 6 feet of soft yellow fine-grained material in open cut on Potash King No. 8 claim.
5. Sample to represent powdered rock from tunnel 40 feet long near east end of Potash King No. 8 claim.
6. Sample to represent white powder with angular fragments of harder material from tunnel 63 feet long about 200 feet from east end of Potash King No. 2 claim.
7. Sample to represent soft white material from open cut 60 feet long on crest of ridge about 175 feet from east end of Potash King No. 8 claim.
8. Sample to represent white material from a vein 12 feet wide trending S. 20° E. on Ironside No. 1 claim.
9. Sample to represent soft white material from sample taken across 40 feet of material on Pay Ledge No. 1 claim.
10. Sample to represent soft brown material that bleaches white on drying, about halfway up face of Alum Peak.
11. "Pink to yellow fine powder" (Knickerbocker and Koster, 1936).

in plate 14). He shows pyroxene andesite and two other varieties of tuff dipping southward toward the bounding fault. All the units are involved in alteration, but the much younger Mt. Belknap rocks south of the fault are not altered. Kerr drew additional faults which provided some radioactive anomalies, but no recognized uranium minerals. His alteration maps show the front of Big Rock Candy Mountain as argillized (illite-montmorillonite) and abundantly pyritized. The pyrite weathers readily and the resulting sulfuric acid produces gypsum and jarosite which accounts for the bright color. The rock is represented in column 10, table 18. Gypsum and jarosite are suggested by the analysis. Some unaltered remnants are preserved. Rock Candy Latite is changed to montmorillonite. Tuff units tend to alter to alunite-kaolinite-silica which makes bold outcrops at the top of Rock Candy Mountain. As indicated in column 1, table 18, it is about 50 percent alunite. On the slope, facing Marysvale Canyon on the Iron Side No. 1 and Pay Ledge No. 2 (plate 14), however, soft, pink, fine-grained material is represented in column 8, table 18, as nearly pure natroalunite. Soft material on the Potash King No. 8 claim in the west area is mainly natroalunite. The soft material represented in column 11, however, is mainly potash alunite.

Evaluation: The distribution of alunite alteration is spotty and the rock masses are small. Some high-grade natroalunite and alunite is restricted to vein-like lenses 10 feet or less in width and of limited continuity.

Mt. Baldy Mining District

Close In. The Close In alunite property was an early discovery, possibly because it is ¾ mile northeast of the Deer Trail mine and beneath the powerline. It is located in S½ sec. 1, T. 28 S., R. 4 W. on a dissected boulder slope, an unknown distance, but probably about ½ mile, to the east of the Tushar fault which may have a throw of 3,500 feet. In any event, the deposit consists mostly of a rubble of tightly packed boulders of latite, some alunitized and containing dense alunite veinlets, others slightly if at all altered, and all lying on Sevier River Formation which dips 10° to 25° SW. The surface is covered with boulders of quartzite eroded from the high face of Deer Trail Mountain. The altitude is between 6,700 and 6,900 feet.

According to the late owner, Max Krotki, the deposit was mined during World War I and 1,600 tons

of selected material from a quarry and from some of the tunnels were shipped to Los Angeles. The early prospectors were puzzled by the geology and one explained to the writer that the deposit slid off the top of Deer Trail Mountain. Before movement started on the Tushar fault, the alunite could have been considerably above the top of the mountain. Some 3,600 feet of adits were driven, part in Sevier River Formation and part in the rubble of alunitized latite. The deposit was trenched, sampled and mapped by the U. S. Bureau of Mines and U. S. Geological Survey in 1942 to 1944. Some 5,800 feet of trenching and nine pits were completed and 493 samples taken and reported by Hild (1946, p. 13-14 and 57-61). Table 19 gives analyses of alunite from various localities in the area. The deposit was mapped by Callaghan in 1937 (Callaghan, 1938, p. 123-124; figure 50).

Adits, which remained dry and open in spite of the rubbly nature of the material they penetrated, show the geology of the deposit. Adits were driven into the slopes of each of the three gullies that cross the area. The sections are based on the information derived from the adits. The main mass of shattered alunitized latite is on the south side of the northwest gully. A quarry was opened there and all the adits penetrate alunitic material. A short adit above the quarry shows typical open accumulation of angular blocks of reddish, hard, silicified and alunitized latite. The porphyritic texture of the original rock is preserved in the altered rock. The Burt adit shows 40 feet of soft, altered breccia at the portal, boulders of unaltered latite for 70 feet and an irregular contact with 80 feet of rubble of alunitized latite and gougy, sheared rubble at the face. The Shelton No. 1 adit is about 45 feet below the other workings and shows Sevier River Formation throughout dipping 12° to 23° SW. The Shelton No. 2 adit, about 20 feet higher, shows the contact of Sevier River Formation below with weathered, slightly altered latite blocks. Within the Shelton No. 2 are 25 feet of hard, alunitized and silicified latite blocks which contain veinlets of coarse pink, plumose alunite and dense, white fine-grained alunite. The Gillen adit, presumably the discovery adit of alunite prospector Tom Gillen, shows streaks of soft, crushed material coursing through an open breccia of hard silicified and alunitized blocks. The adits on the north side show mainly Sevier River Formation containing blocks of alunitized rock, but a northwesterly trending fault in the north drift of the Hanson adit brings breccia of altered rock against Sevier River Formation which dips 20° SW. The south drift shows a block of bluish latite.

The main adit in the north slope of the middle gully shows Sevier River Formation dipping 19° to 25° SW for 200 feet. The contact with overlying alunitized breccia is a fault with 1 to 5 feet of gouge dipping 20° SW or parallel to the bedding. The bedded Sevier River Formation contains angular to subangular latite fragments and a few fragments of quartzite and limestone. The remainder of the adit shows altered and unaltered latite except the crowfoot at the innermost face where the Sevier River Formation emerges from below.

Table 19. Analyses of alunite from the Close In property.

	1	2	3	4	5	6	7	8
Al_2O_3	19.46	21.82	21.30	23.05	35.38	20.00	29.8	38.10
K_2O	5.33	5.93	5.39	1.91	9.80	4.83	5.91	9.38
Na_2O	.37	.37	.23	.55	.55	.52	1.05	1.01
SO_3	19.82	22.65	20.70	9.15	36.82	19.10	25.00	35.8
H_2O^+	7.10	8.37	9.55	9.55	15.37	8.84		
H_2O^-	.00	.00	.09	.36	.06			
SiO_2	43.78	38.18	39.90	54.82	1.48	44.30		
Fe_2O_3	3.45	2.73	3.77	1.23	.54	3.00	2.20	.05
TiO_2	.74	.60				.27		
Insoluble						.42	27.1	1.40
P_2O_5								
	100.05	100.65	100.93	100.62	100.00	101.28		
Percent alunite	51.4	58.7	53.7	23.8	95.5	49.4	64.8	90.7

1. From 19 feet in first drift in main tunnel across 10 feet of rubble (sample taken by Callaghan, USGS).
2. First drift to south in main tunnel across 6 feet (sample taken by Callaghan, USGS).
3. "Massive white alunite" (Knickerbocker and Koster, 1936).
4. "Small sample of soft pink deposit 300 feet in south tunnel " (Knickerbocker and Koster, 1936).
5. "Pink alunite in pockets adjoining massive white alunite " (Knickerbocker and Koster, 1936).
6. Sample to represent one carload of alunite from quarry, Kalunite Co.
7. Sample of alunite bagged for shipment and left exposed for 20 years (Thoenen, 1941).
8. Sample of high-grade pink coarsely crystalline alunite exposed for 20 years (Thoenen, 1941).

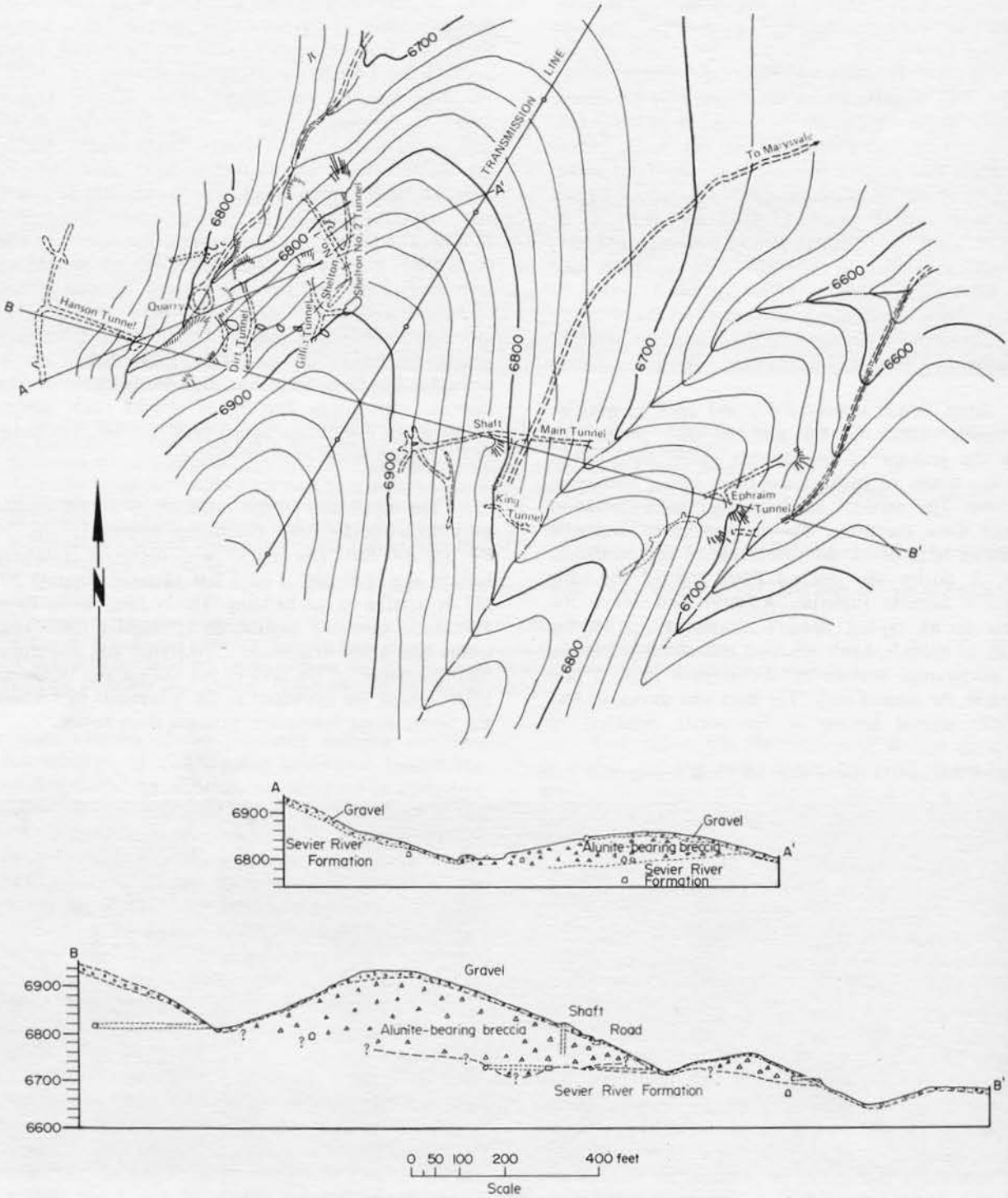


Figure 50. Map and sections of Close In alunite deposit (topography and geology by E. Callaghan, surveyed 1938).

In the southeast gully the low adits show only Sevier River Formation, but the higher adits are in the blocks of altered latite.

The thickness of the underlying Sevier River Formation is unknown in the downthrown rock mass at the east side of the Tushar fault. A body of altered latite probably was involved in the Tushar fault zone and, during the relative depression of the valley, tipped over and flowed as a landslide over the surface of the Sevier River Formation as it then existed. The Sevier River Formation was not overlying the breccia, but it could be incorporated in the Sevier River. The southwestward tilting could be considered a later feature.

The grade of the rubble accumulation is highly variable–samples range from nearly pure alunite to material only slightly alunitized. The carload sample from the quarry showing about 50 percent alunite appears a fair sample. The assays recorded by Hild (1946, p. 57-61) show a range of 20 to 50 percent alunite. Iron as Fe_2O_3 ranges from 1 to 6 percent for the most part. Silica where determined ranged from 30 to 60 percent.

An early consultant's report showed the percentages of alunite in the samples taken in the adits as follows:

Shelton No. 1	35.6
Ephraim	52.0
Gillan	36.8
King	35.4
Shaft dump	57.3
Main	49.0

Evaluation: In 1945 the project geologist, G. L. Bell, estimated 2 million tons of the highly variable material in the categories of measured, indicated and inferred ore. The mining situation is favorable and trenching above the 6,700 contour over a larger area might add to the total of available material.

Henry Mining District

White Horse. The White Horse alunite deposit in the S½ sec. 10, T. 27 S., R. 3 W., 3 miles northeast of Marysvale at an altitude of 6,400 feet, supplied the Kalunite, Inc., plant at Salt Lake City which recovered alumina from alunite during World War II. Quarries were opened on the north and south sides of a gully bisecting the deposit. A truck road was built from the deposit to the top of the terrace at the railroad station at Marysvale; a crushing plant was installed and the ore moved to the treatment plant by rail. Some 12,000 tons were reported treated. The deposit was recognized as alunitic during World War I and was explored by pits and adits. It was mapped by the writer in 1938 (Callaghan, 1938, p. 130). In addition to the work done by Kalunite, Inc., the U. S. Bureau of Mines drilled and sampled the deposit. Fourteen holes were drilled in 1943 totalling 3,522 feet and 578 core samples taken (Hild, 1946, p. 12-13). The geology was mapped thoroughly by Willard and Proctor and laboratory work done (Willard and Proctor, 1946, p. 619-643). The outcrop map of the quarry benches is reproduced as figure 51. The regional geology is covered by the Marysvale quadrangle (Willard and Callaghan, 1962). The White Horse deposit was included in the geologic map of the uranium area made by Kerr (Kerr and others, 1957, pl. 12) and the geology and alteration discussed (1957, p. 81 and 191-193).

The alunite deposits and associated kaolinite consist of a series of lenses demonstrated by drilling to narrow and die out in depth. The controls for this configuration of rock alteration required an unusual geologic situation; Willard and Proctor (1946) showed that flowage folds in a single porphyritic calcic latite flow directed the alteration. The thickness of the flow exceeds the 300 feet reached during exploration. The flowage folds as well as lava cemented or even porous flow breccia can be detected in unaltered latite. The flow structures are preserved sufficiently in the altered equivalent to show their relationship to the highly altered lenses. One float block of quartzite is shown on figure 51. Kerr and others (1957, pl. 12) show that the latite flow covers an area of about 4 square miles, including the White Hills alunite, and contains many float blocks of quartzite and small quartz monzonite intrusions. Willard and Proctor (1946) explain that as this thick flow moved along, the top congealed and was infolded; crustal material was broken producing a flow breccia. Thus was provided a downward converging sheeted structure with the axis normal to the direction of flow. It undoubtedly was covered by other material, since removed; when the area became thermal, the rising steam readily entered the sheeted synclines and eventually replaced the cores.

Kaolinite and alunite were produced by the replacement process with the alunite concentrated in the cores of the syncline and kaolinite forming an envelope around alunite. Surrounding the core areas the porphyritic latite is altered partly with the phenocrysts changing to soft white clay, and the dense groundmass remaining firm and dark. Chemical analyses of the various stages are given in table 20.

Willard and Proctor (1946) describe the mineralogic changes as follows (p. 628-630):

> In the outer parts of the kaolinized envelopes that surrounded the alunite bodies the andesine phenocrysts of the latite are completely changed to a mixture of clay and sericite; but the groundmass and other mineral grains are unaffected.

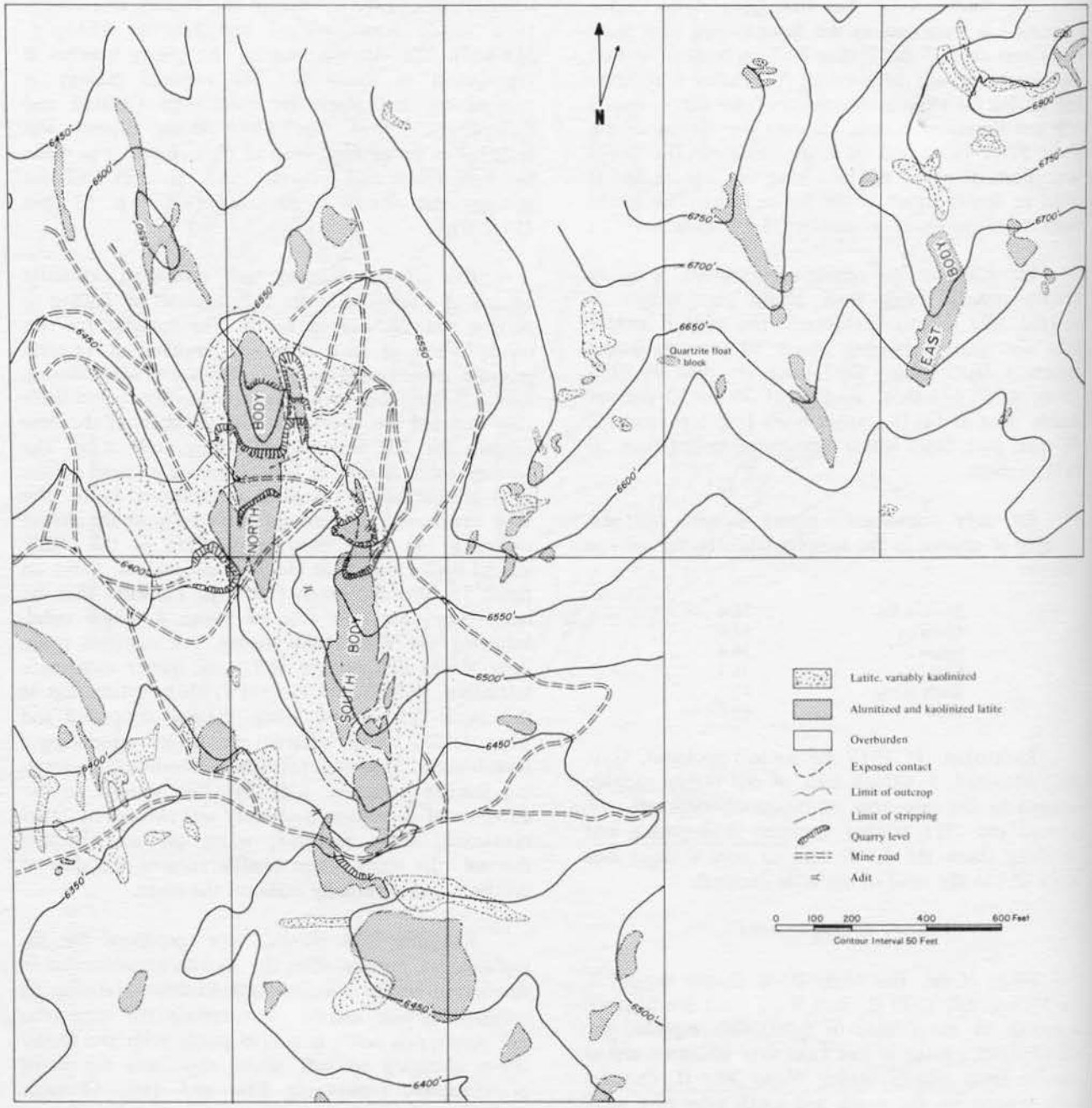


Figure 51. Outcrop map of North, South and East ore bodies, White Horse alunite deposit (from Willard and Proctor, 1946, p. 627).

Table 20. Chemical analyses of various alteration stages, White Horse deposit (Cyrus Feldman, analyst; Willard and Proctor, 1946, p. 626, table II).

	1	2	3	4
SiO_2	60.47	64.72	47.88	13.40
Al_2O_3	19.29	17.59	20.33	31.55
Fe_2O_3	1.27	1.70	.97	.56
FeO	3.93			
MgO	1.54			
CaO	2.28			
Na_2O	3.24	3.43	.10	.79
K_2O	5.11	5.89	4.59	8.64
H_2O^-	.44	.94	.10	.08
H_2O^+	.61	4.67	6.82	10.54
TiO_2	.56	1.34	.62	.77
CO_2	.49			
P_2O_5	.02			
SO_3	none	.37	19.60	33.80
MnO	.38			
Total	99.63	100.65	101.01	100.13

1. Fresh latite–On "old road" at south end of White Horse deposit.
2. Kaolinized latite between alunite lenses on east side of North ore body.
3. Highly alunitized latite near south end of North ore body.
4. Vein material–East side of Main quarry in North ore body.

The kaolinized latite in these outer parts of the envelope retains its original textures and structures. It also retains its dark color or is slightly bleached to a purplish-gray, and when exposed to surface weathering has a tendency to crumble. The inner parts of these envelopes of kaolinized latite are highly bleached, the biotite flakes are light colored or are completely absent, and the andesine phenocrysts are altered to light-green clay masses that after exposure dry out and turn white. Clarence S. Ross of the United States Geological Survey has identified the greenish clay of these altered phenocrysts as largely kaolinite. The altered phenocrysts commonly contain a very few small, delicate, needle-like crystals of alunite. In the most highly kaolinized rock the identifiable minerals of the groundmass are kaolin, microscopic grains of quartz, a fine dust of mixed hematite and leucoxene, and scattered grains of fresh albite.

The mineral composition of the kaolinized latite as calculated from the ultimate analysis . . .

Quartz	17.34	
Orthoclase	34.46	
Albite	27.77	
Kaolinite	14.02	
Limonite	1.76	
TiO_2	1.36	(leucoxene)
Alunite	.72	
	97.43	
	3.53	(residual H_2O)
	100.96	

The change from dominantly kaolinized to dominantly alunitized rock is abrupt, commonly occurring within a few inches; but within the zone of change the rock is noticeably more siliceous, and alunite and kaolinite may be present in nearly equal amounts. Typically there is within this zone a marked increase in the amount of hematite. From the zone of change to the center of an altered body the percentage of alunite increases. Assays show a maximum of between 55 and 60 per cent alunite in the central parts.

The highly alunitized latite consists mainly of small needle- or plate-like crystals of alunite, seldom more than a few microns long, disseminated in a groundmass of extremely fine-grained quartz and clay. Commonly there is also present a rather uniformly distributed dust of hematite and small lathlike grains of leucoxene . . . The highly alunitized rock is mostly chalky white, and noticeably heavier than the less altered rock; the porphyritic texture of the original latite is only faintly evident. Many of the relict phenocrysts, even in this highly alunitized rock, are predominantly clay. The flow structure in the highly alunitized latite is clearly evident on weathered surfaces but otherwise may not be apparent . . . Where alteration has been less severe the alunitized latite may range from pink to lavendar depending on the amount of iron remaining, and, as would be expected, the original textures and structures of the latite are quite apparent. Locally this less altered rock is porous, as though the vesicular nature of the original latite had somehow remained.

There are, within the alunitized masses, small veinlets or pods of an extremely soft white powdery material that is predominantly alunite and quartz . . . The small amount of Na_2O in this material . . . is probably present as natroalunite in an isomorphous mixture with the alunite. A part of the Na_2O in the replacement ore may also have the same occurrence. Natroalunite was not identified in any of the ore from the White Horse, but it is conspicuous at the Yellow Jacket where it occurs mainly in veinlets that cut the replacement ore. Natroalunite has also been reported . . .in other deposits of the Marysvale region.

They further comment on the chemical changes and conclude (1946, p. 631-632):

The average specific gravity of both the latite and the alteration products is 2.62; therefore, assuming no change in volume during alunitization, the changes in percentages of the various oxides can be considered as the relative weight changes per unit volume of rock replaced.

During kaolinization the SiO_2 content of the latite is not appreciably changed. There is a small loss in Al_2O_3, and a part of the total Al_2O_3 is released from the silicates and combined in a form that is subject to leaching with dilute sulphuric acid. A small amount of SO_3 is added, as indicated by the tiny crystals of alunite previously mentioned. Apparently there is a slight loss of K_2O and Na_2O, and all of the CaO is removed. A large part of the iron is also removed, but some of it remains as hematite or in residual silicate minerals.

During alunitization the latite loses from 10 to 15 per cent silica, and gains 15 to 23 per cent SO_3. The K_2O content remains constant, but most of the sodium and iron that it originally contained are lost. It should be noted that all of the iron that remains in the alunitized rock occurs as hematite; no pyrite was seen.

Conclusions.–The alteration to alunite was produced by a sulphate-bearing solution that reacted with the original constituents of the latite, taking into solution, in addition to potash and alumina, all the sodium together with a part of the iron and silica. A large part of the released potash and alumina was immediately deposited as alunite but some remained in solution. It seems likely that the veinlets or pods of chalky

alunite represent the filling of open spaces by this enriched solution. Most of the dissolved silica and iron were carried beyond the present areas of alunitization before they were deposited. The sodium that went into solution was also removed unless the potash originally present in the latite was not sufficient to exhaust the solution by combination with the SO_3. If, on the other hand, the available SO_3 was in excess of that necessary to combine with the potash present in the rock, natroalunite was formed.

The intimate mixing of the kaolin and alunite and the distribution of the kaolin as an envelope about the alunitized masses strongly suggest that the two are genetically related. The small euhedral crystals of alunite in the kaolinized phenocrysts of the latite and growing inward from the outer edges of these phenocrysts suggest that the kaolin developed first. The writers are of the opinion that the advancing sulphate-bearing solution partly kaolinized the latite, thus preparing it for later alunitization.

The evidence at the White Horse deposit does not definitely establish the origin of the mineralizing solution. Most of the observed chemical and mineralogic characteristics could have been produced by a sulphate-bearing solution of either deep-seated or surface origin. The lack of pyrite in all the rocks of the deposit, without evidence of it ever having existed in quantity, makes it doubtful that the mineralizing solution developed from the oxidation of that mineral. Nonselective replacement of the minerals of the latite and replacement in large part independent of evident fractures suggest that the solution was hydrothermal. The regional distribution of the replacement alunite in an aureole about an exposed stock of quartz-monzonite . . . strongly suggests that it overlies the source of at least a part of the mineralizing solution. Therefore, the writers are of the opinion that the alunite at the White Horse deposit was formed by a sulphate-bearing solution that was largely produced at depth possibly from the oxidation of hydrogen sulphide of magmatic origin.

Three bodies of alunitic altered rock containing 50 percent alunite, the North, South and East, have been explored (figures 52 to 54 and table 21). The North ore body consists of two coalescing lenses with a length of 740 feet, maximum width of 160 feet and depth of more than 100 feet (figure 54). At the south end at the west side of the North ore body is a lens 260 feet long and 90 feet maximum width. Another lens 20 feet east of the North ore body is 260 feet long and 35 feet wide. It pinches out 30 feet below the lowest exposure. The central parts of the lenses are porous, perhaps as much as 15 percent. The trend of the North ore body is N. 10° W.; it dips steeply east and plunges south. The kaolinite envelope ranges from a few feet to more than 100 feet in width. The South ore body is offset *en echelon* to the east of the North ore body and also consists of coalescing lenses. It is 670 feet long and has a maximum width of 180 feet and a depth of about 100 feet at the north end. The East ore body is 400 feet long and 100 feet wide maximum.

In all the lenses the greatest depth of mineralization is in the fold troughs and the highest grade or highest proportion of alunite is in the axial plane of the trough. Joints in kaolinized latite are abundant next to the alunitized lenses.

Table 21. Analyses of alunite from the White Horse deposit (from R. E. Stevens, analyst, letter of June 11, 1938).

	1	2	3	4	5
Al_2O_3	23.66	18.67	20.59	24.40	20.34
K_2O	5.88	4.81	5.40	6.49	5.39
Na_2O	.50	.73	.66	.67	.63
SO_3	21.95	17.76	19.80	23.41	19.42
H_2O^+	9.42	6.80	7.32	8.28	7.00
H_2O^-		.28	.14	.16	.08
SiO_2	38.50	48.15	44.01	34.80	44.38
Fe_2O_3	.81	1.01	.95	.24	1.35
TiO_2	.05	.54	.46	.35	.45
P_2O_5	.38				
CaO	trace				
MgO	.01				
Insoluble					
	101.16	98.75	99.33	98.80	99.04
Percent alunite	56.9	46.1	51.3	60.7	50.4

1. Average sample from a carload from the North ore body, made by Kalunite, Inc.
2. Channel sample taken horizontally across 10.5 feet to represent moderately hard somewhat porous white, best-appearing material. Sample taken from the north wall of upper tunnel on west side of ridge 120 feet from entrance.
3. Channel sample taken horizontally across 6.7 feet of very hard white material. Sample taken on north wall of tunnel 113 feet from entrance.
4. Channel sample taken horizontally across 11.5 feet to represent greenish to pinkish material. Sample taken in upper part of main quarry. This represents the zone from which most of the material has been quarried.
5. Channel sample taken horizontally across 5 feet to represent white porous siliceous material that makes prominent outcrops. Sample taken at north end of quarry.

Evaluation: The amount of 50 percent alunitized rock in the three ore bodies is not known to the writer. The abrupt boundaries of alunitic rock eliminate large areas in projected mining operations. The ore seemed more favorable than any to test the Kalunite process for alumina recovery.

White Hills. The White Hills alunite deposit was owned by the late Max Krotki who explored the deposit by means of six adits aggregating 1,630 feet of underground work. Some 600 tons of alunitic rock were mined from the quarry and shipped during World War I. The common corner of secs. 1, 2, 11 and 12, T. 27 S., R. 3 W. is on the west side of the property. To the north the slope into a deep ravine is steep, but the other slopes are rounded and moderate (figure 55). The altitude is between 7,000 and 7,850 feet. The country rock is porphyritic latite and is included by Kerr and others (1957, pl. 12) in the same flow unit in which the White Horse deposit occurs. Folded flow structure and flow breccia also occur. Surface rock

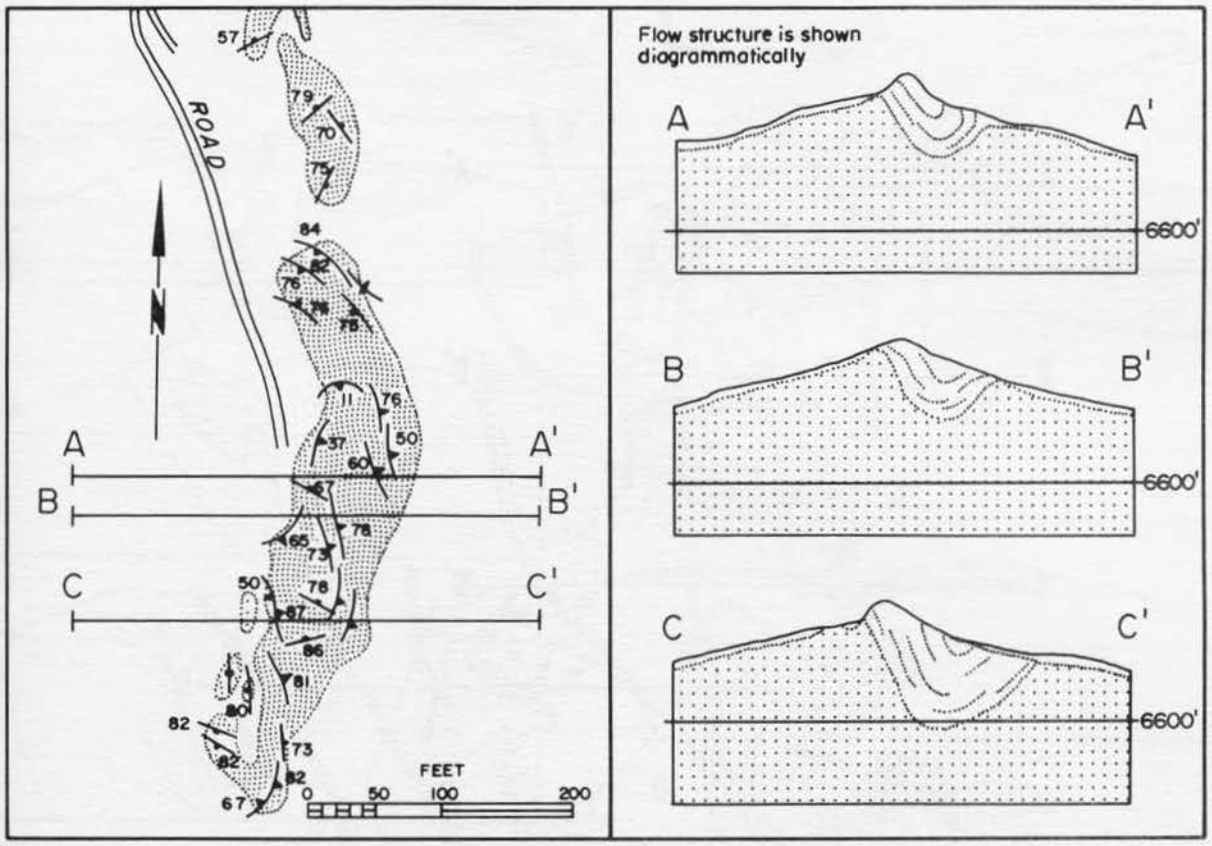


Figure 52. Geologic map and sections of East ore body, White Horse alunite deposit (from Willard and Proctor, 1946, p. 638).

debris and soil conceal the bedrock and scattered small outcrops show altered rock. The deposit is about 4,000 feet west of the Sevier fault, but relatively few faults were recognized. Bell interpreted material in the most thoroughly alunitized portions as tuff and breccia. In 1944 the U. S. Bureau of Mines explored the deposit with 8,200 feet of trenches and seven vertical diamond drill holes totalling 1,501 feet (Hild, 1946, p. 16-17). Adits were cleaned out bringing the total to 2,340 feet. Some 1,706 samples were taken. Figure 55 was made in 1938 by V. C. Kelley under the writer's direction and the adits (figure 56) mapped and sampled. G. L. Bell, project geologist during the drilling, prepared a draft report.

The structure of the volcanic assemblage is not clearly revealed by the adits. From the drilling and trenching, Bell interprets the rocks near the summit and those most thoroughly alunitized to be tuffs; the adits seemed to be in porphyritic biotite latite throughout. He interprets the regional dip in the area as 20° to 30° SE, and also noted fault or fracture systems with minimal throw striking N. 15° W. and N. 65° W. and dips steeply southwest.

The samples taken in the North adit (1, 2 and 3, table 22) indicate material that is as much as 59 percent alunite, but samples taken by Bell (8 and 9, table 22) indicate a content of 38 percent alunite. The samples from the trenches taken by the U. S. Bureau of Mines (Hild, 1946, p. 66-74), however, show few running even 27 percent alunite and not many as much as 50 percent. Drill-hole samples assayed mainly less than 40 percent alunite. Some silicified rock shows as ribs on the surface as well as in the adits. The Bureau assays commonly show that alumina remains much the same although SO_3 content drops in 2 percent indicating that throughout much of the altered rock the alteration mineral is mainly kaolinite with silica. Bell noted that bedding structures were continuous through highly altered, lightly altered and unaltered zones indicating the replacement nature of the deposit. The main altered area is 1,400 feet long in a north-northwest direction and 1,110 feet wide. Drilling showed variations in the altered rock and indicated the area extended as much as 250 feet below the summit of the hill, although most is much shallower. The core in DDH-4 at 89 feet showed highly silicified rock with some disseminated alunite cut by pink fine-grained alunite veinlets. Jarosite veinlets cross the alunite. In DDH-6 at the base of the highly altered material, the rock is silicified and contains tiny pyrite cubes partly changed to iron oxide or iron sulfate. It is cut by

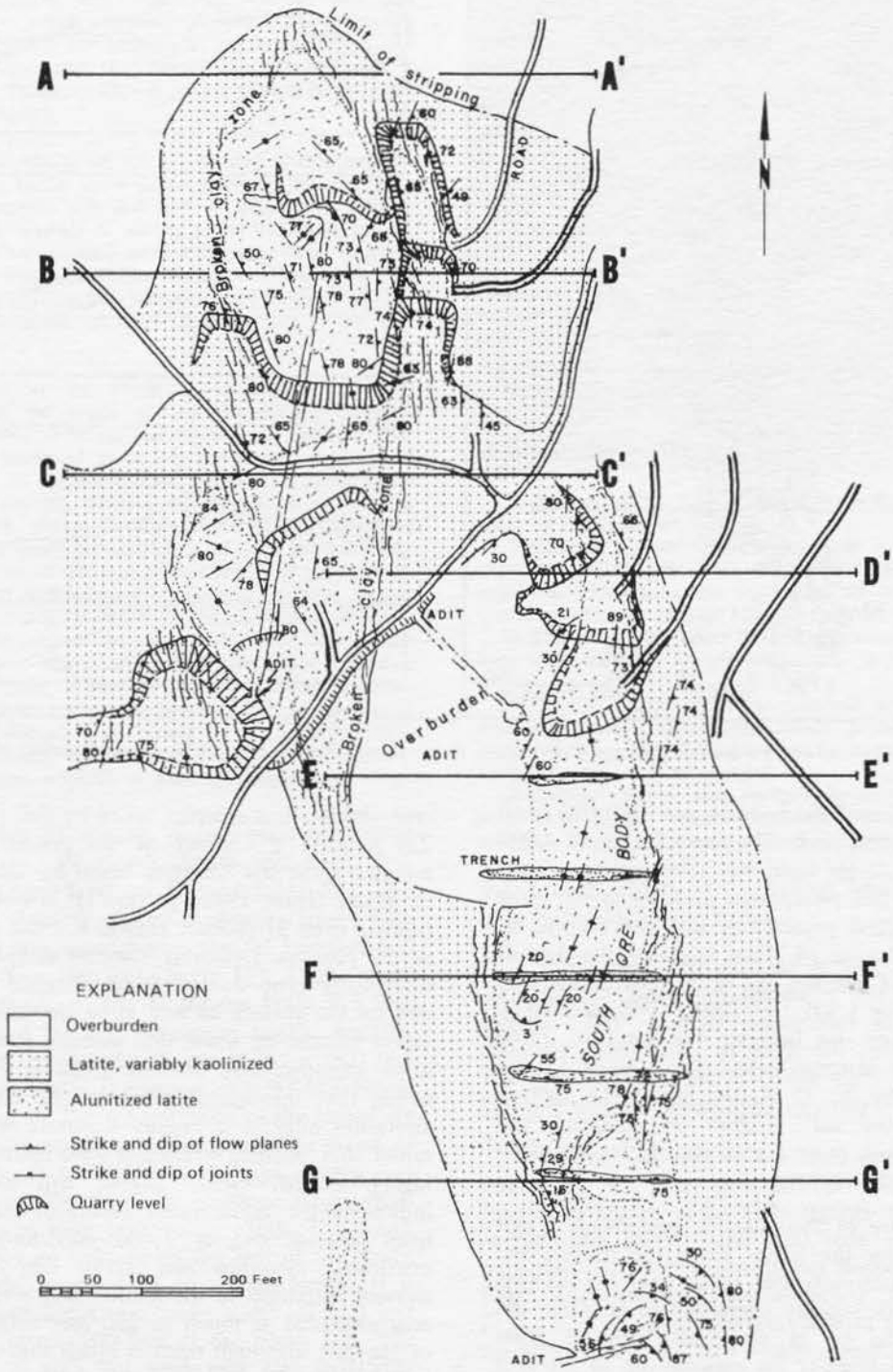


Figure 53. Geologic map and sections, North and South ore bodies, White Horse alunite deposit (from Willard and Proctor, 1946, p. 634, 635 and 637).

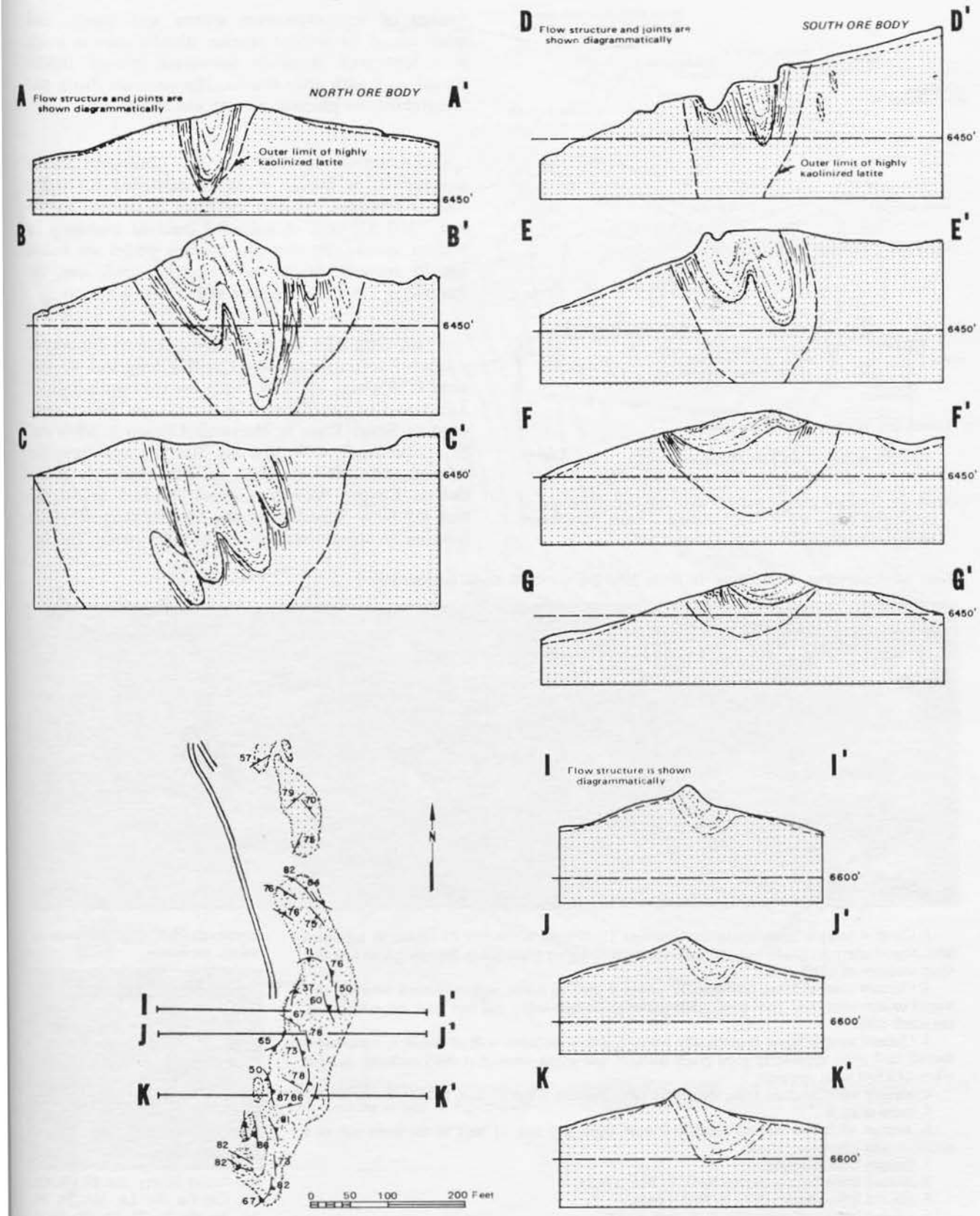


Figure 53. (continued)

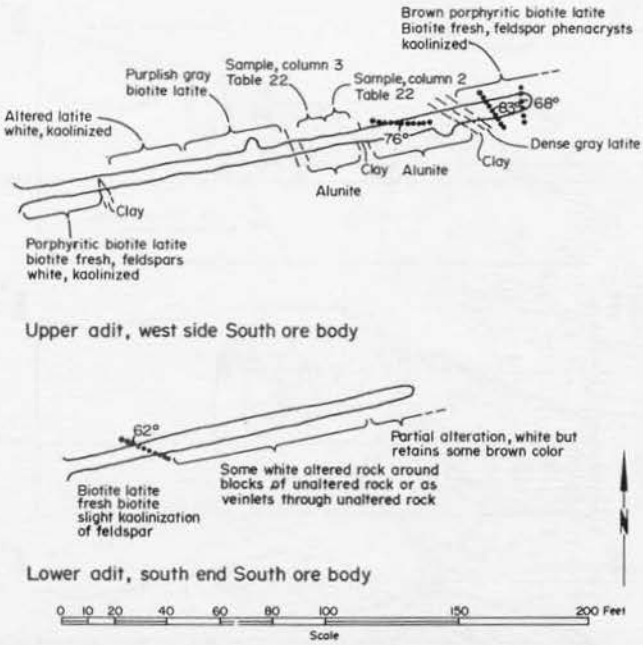


Figure 54. Geologic map of adits at west side and south end of South ore body, White Horse alunite deposit (from maps by E. Callaghan, 1938, and R. Parker, 1951).

veinlets of microcrystalline alunite and quartz, and assays about 24 percent alunite. Alunite veins as much as a foot wide continue downward through lightly altered rock with little alunite. The veins are dense and fine-grained; no plumose alunite was noted.

Evaluation: In 1945 the U. S. Geological Survey and the U. S. Bureau of Mines estimated 3,170,000 tons of measured material averaging 24 percent alunite and 2,100,000 tons of indicated material averaging 16 percent alunite. Because the average grades are below the 35 percent alunite considered low-grade ore, the material is a possible resource rather than a reserve.

Big Star. The Big Star alunite deposit consists of a lens of soft natroalunite 120 feet long and 40 feet wide (Callaghan, 1938, p. 127) on the north side of Antelope Canyon (figure 57); the canyon drains westward to Sevier River in Marysvale Canyon in SW¼ sec. 21, T. 26 S., R. 4 W. The Big Star is a mile from the railroad and 700 feet above it. The deposit is in the Bullion Canyon Volcanics about 30 feet below the base of Gray Rhyolite of the Mt. Belknap Rhyolite lying on an erosion surface on the older rocks. The Joe

Table 22. Analyses of alunite from the White Hills deposit (S. H. Cress, analyst, 1-3).

	1	2	3	4	5	6	7	8	9	10
Al_2O_3	20.11	20.33	23.40	22.11	25.39	19.00	–	24.76	0.67	19.36
K_2O	5.20	5.16	5.92	3.82	4.88	4.46	5.31	3.84	0.13	3.97
Na_2O	.81	.91	1.03	.92	.80	.92	.52	0.34	0.19	2.63
SO_3	20.29	19.94	23.00	22.13	22.14	17.2	18.50	14.84	1.03	14.67
H_2O^+	6.28	6.54	7.72	7.90	9.03					
H_2O^-	.20	.20	.18	.10	.12					
SiO_2	43.84	48.81	34.70	42.44	37.46			50.50	88.28	56.02
Fe_2O_3	1.46	1.50	1.90	1.16	.73	1.25		1.00	0.85	0.33
TiO_2	.30	.67	.69							
Insoluble						51.3				
	98.49	98.06	98.54	100.58	100.55	–	–			
Percent alunite	59.3	51.7	59.6	57.4	57.4	44.6	48.0	38.3	2.6	37.9

1. Channel sample taken horizontally across 10 feet on north side of tunnel to represent gray, apparently poor grade material with some white higher grade spots. Sample taken 278 feet from entrance of north adit.
2. Channel sample taken horizontally across 9 feet of south wall of tunnel between two stopes to represent hard gray good grade material. Sample taken 338 feet from the entrance of the north adit.
3. Channel sample taken horizontally across 6.2 feet on south wall of tunnel to represent 3 feet of hard gray, apparently good grade material and softer somewhat rusty material. Sample taken 455 feet from entrance.
4. Massive white material from the quarry (Knickerbocker and Koster, 1936).
5. Same as no 4.
6. Average of better part of alunitized zone from 270 feet of wall in the inner end of a 400-foot adit (Thoenen, 1941).
7. Sample from property.
8. Altered latite breccia (report by G. L. Bell, 1945).
9. Altered latite (report by G. L. Bell, 1945).
10. Altered latite tuff (report by G. L. Bell, 1945).

Spectrographic determination of minor elements.

	8	9	10
B_2O_3	.007	.02	.01
BaO	.04	.05	.05
BeO	.0002	–	–
Cr_2O_3	.02	.003	.004
MnO	.06	.1	.2
NiO	.0003	.001	.0008
SrO	.06	.02	.04
V_2O_5	.03	.004	.02
ZrO_2	.08	.2	.09

Not found in any: As, Bi, Cb, Cd, Co, Cu, Ge, In, La, Mo, Pt, Pd, Au, Ag, Re, Ta, Tl, Th, Sb, Sn, Y, Yb, W, Zn.

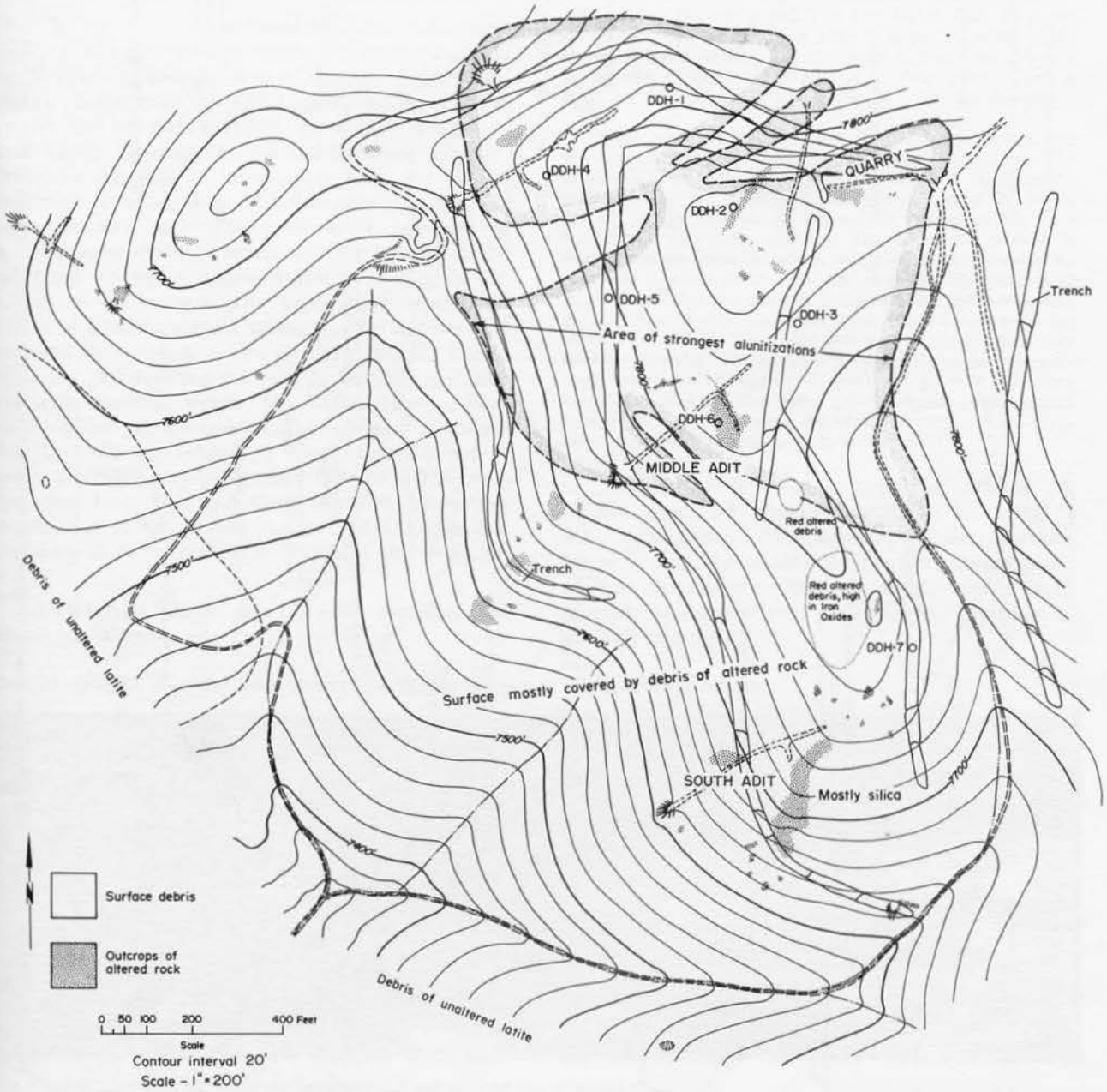


Figure 55. Geologic map of White Hills alunite deposit (topography and geology by V. C. Kelley, surveyed 1938. Trenches and drill holes added from map by G. L. Bell showing results of exploration by U. S. Bureau of Mines, prepared 1944).

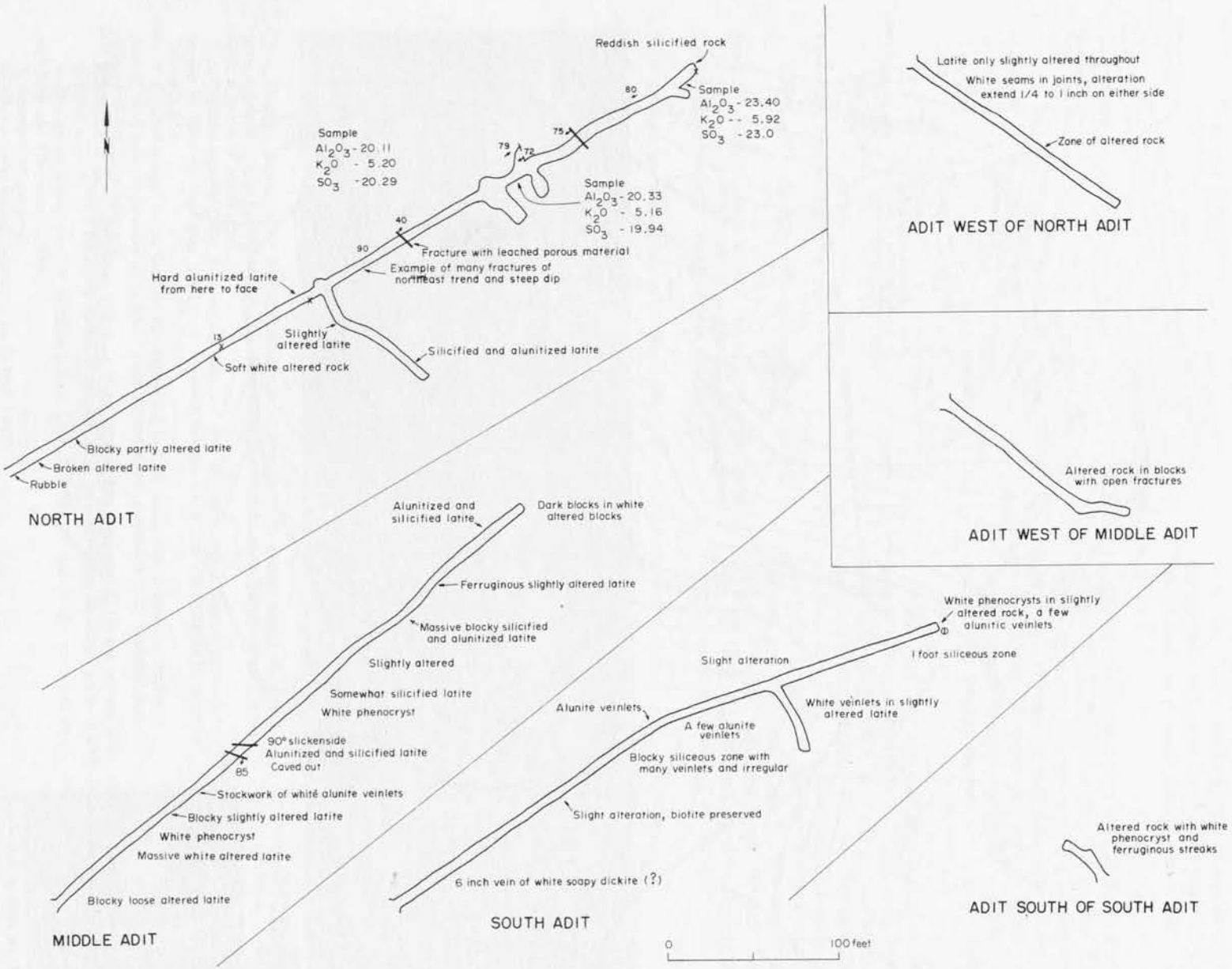


Figure 56. Maps of adits in White Hills alunite deposit (mapping by E. Callaghan and V. C. Kelley, surveyed 1938).

Lott Tuff of the Mt. Belknap Rhyolite Group appears east of the deposit and underlies the Gray Rhyolite (figure 57). Both units are broken by normal faults with throws of 20 and 40 feet.

The Big Star is included in Kerr and others (1957, p. 12) geologic map of the uranium area and in the Monroe quadrangle map (Callaghan and Parker, 1961a). Three units of Kerr's group in the Bullion Canyon Volcanics are included: green latite porphyry, Rock Candy agglomerate, tuff and pyroxene andesite. The rocks dip northeastward away from the quartz monzonite intrusive body and the associated zenolith of sedimentary rock. The green latite porphyry is hardened somewhat by contact with the intrusive body and tends to make rugged slopes; it occurs in the bottom of the canyon. The agglomerate or volcanic breccia is altered near the alunite or natroalunite and protrudes as a yellow to brown cliff. An adit driven below the cliff revealed the rock to be fairly soft and gray with abundant pyrite. The tuff is mainly a fine-grained phase of the volcanic breccia and is altered also. The andesite tended to resist alteration and is mostly a reddish gray fine-grained flow rock. The overlying Joe Lott Tuff and Gray Rhyolite follow the irregularities of an erosion surface and although not involved with the alteration are displaced on two faults.

Callaghan (1938, p. 127-128) describes the deposit as follows:

> The deposits, which are on a steep spur ridge, are prospected by two quarries and three tunnels, one of which is about 300 feet long. A steam shovel was operated at the quarries, but the amount of material shipped is unknown. The lower quarry at the end of the spur ridge is 80 feet long, 40 feet wide, and over 40 feet high at the face. The upper quarry, 700 feet to the north and 120 feet higher than the lower quarry, has been opened in a series of steps. The width of the upper quarry is 40 feet, and the length in a westerly direction is 140 feet, of which about 60 feet is in the alunitic zone. A short tunnel has been driven S. 85° W. under the deposit . . .
>
> The principal lens of alunite (natroalunite) is exposed in the upper quarry and extends southwestward for 120 feet. The maximum width is about 40 feet, but the limits of the better-grade material are gradational. The eastern part of the lens is cut off at the bottom by a flat fault and appears to have moved out over talus material. The best-grade material is slightly pinkish white, powdery, and flaky; harder material on each side contains more silica. The unusually high content of Na_2O shows that the sulphate is natroalunite. The best sample in the upper quarry represents a lens only 8 feet wide and about 20 feet long. The lower quarry evidently contains only siliceous material. The analyses show a wide range from relatively pure natroalunite to siliceous altered rock. The long tunnel southwest of the upper quarry exposes pyritic altered rock in the face, but nearer the portal a stockwork of fibrous halotrichite, an iron-bearing alum, is exposed.

The first three samples, represented in table 23, contain about 39 percent natroalunite according to SO_3 content but excess alumina indicates abundant kaolinite with the alunite. Sample 6 represents nearly pure natroalunite. The thoroughly altered rock generally contains varying proportions of natroalunite, kaolinite and silica.

Table 23. Analyses of alunite (natroalunite) from the Big Star deposit (R. E. Stevens, analyst).

	1	2	3	4	5	6	7	8	9
Al_2O_3	24.80	22.88	24.59	27.20	27.57	35.50	31.98	24.96	17.58
K_2O	1.04	.92	.91	4.74	3.01	4.60	4.11	3.65	.72
Na_2O	3.11	2.77	2.85	3.06	3.69	4.61	4.23	3.28	1.64
SO_3	16.86	15.13	14.19	27.42	27.50	37.77	33.85	26.89	9.01
H_2O^+	8.61	8.04	8.80	10.09	9.96	12.43	11.39	9.09	6.35
H_2O^-	.34	.25	.24	.46	.56	.12	.30	.49	.41
SiO_2	43.78	49.01	45.87	26.21	26.99	4.39	13.08	30.39	62.82
Fe_2O_3	.81	.88	1.74	.77	.49	.61	.70	.63	.83
TiO_2	.62	.62	.74	.28	.42	.29	.39	.37	.56
CaO	–	–	–	–	–	.05	–	–	–
MgO	–	–	–	–	–	.03	–	–	–
	99.97	100.50	99.93	100.23	100.19	100.40	100.03	99.75	99.92

1. Channel sample to represent southernmost 9.2 feet in lower part of upper quarry.
2. Channel sample to represent next 7.0 feet north of no. 1.
3. Channel sample to represent next 7.0 feet north of no. 2.
4. Channel sample to represent southernmost 11.5 feet in upper part of upper quarry. This line of samples is 31 feet on 38° slope west-southwest of the line from which preceding samples were taken.
5. Channel sample to represent next 6.9 feet north of no. 4.
6. Channel sample to represent next 8.0 feet north of no. 5. This is best grade of natroalunite; it exhibits faint veining and is pinkish and soft.
7. Channel sample to represent 6 feet of material north of no. 6 but separated from it by 2 feet of rubble.
8. Channel sample to represent 6 feet of best-appearing material in north center of open cut 60 feet southwest of top of upper quarry.
9. Channel sample to represent 6 feet of whitest, best-appearing part in lower quarry over short tunnel.

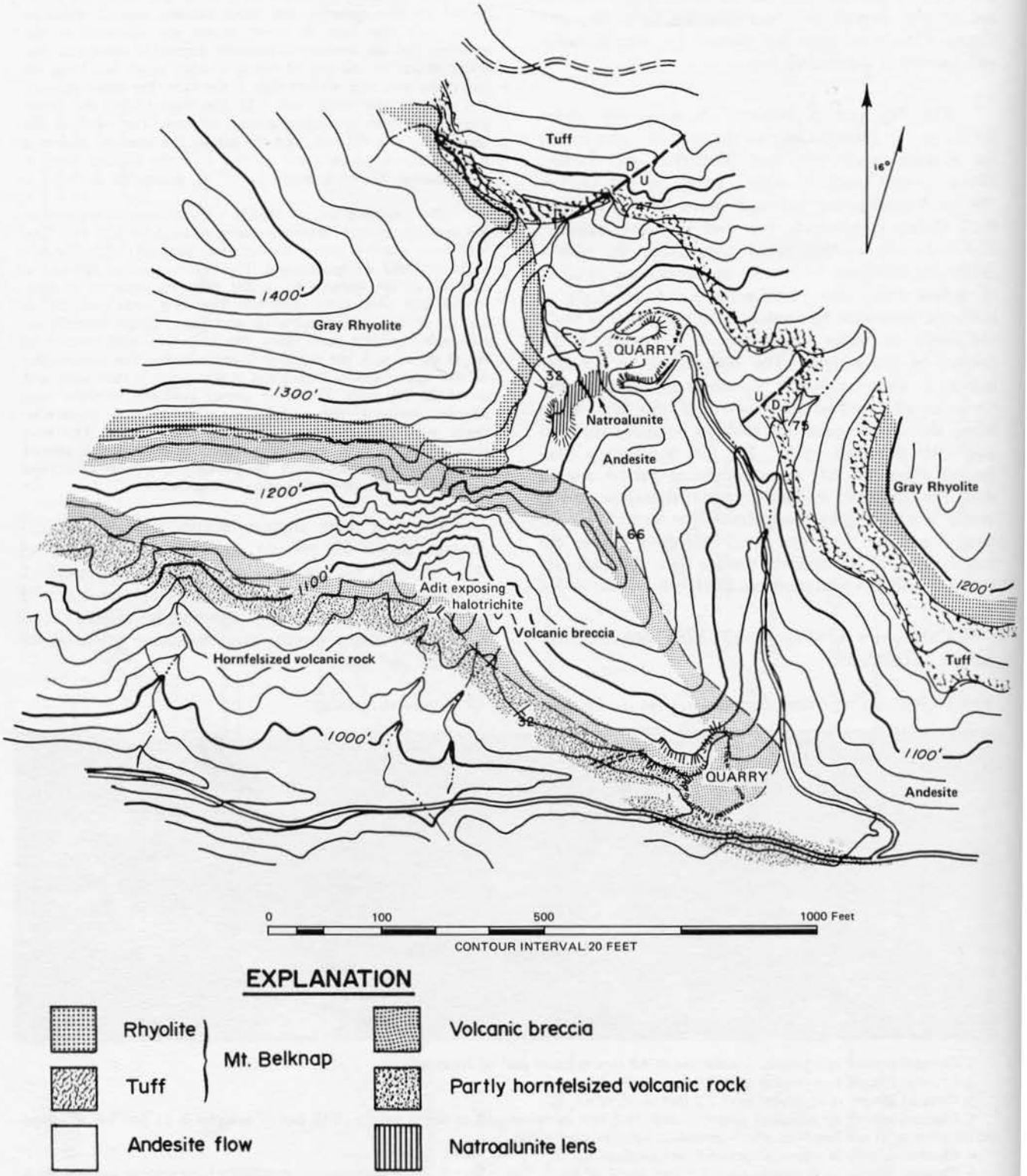


Figure 57. Geologic map of Big Star natroalunite deposit (adapted from topographic and geologic map by E. Callaghan and G. F. Seager, surveyed 1936).

Evaluation: A small quantity of high-grade natroalunite is limited to one lens. The main mass of altered volcanic breccia is argillic and pyritic rather than alunitic, closely resembling the altered rock at Big Rock Candy Mountain (Kerr and others, 1957, p. 159).

Big Chief. The Big Chief deposit of natroalunite is exposed in an adit beneath the Iron Cap iron and manganese mine on Twin Peaks in SE¼ sec. 15, T. 26 S., R. 4 W. The locality is called Iron Peaks on Kerr's map (Kerr and others, 1957, pl. 12) and is described under Iron Cap iron mine in this report (figure 34). The adit reveals varying degrees of alteration of volcanic breccia. Two samples taken by G. F. Loughlin in the adit 220 feet from the portal were analyzed (table 24).

Sample 1 consists of a small white streak of soft material picked as free as possible from brown coloring material and thought to represent the purest alunite obtainable in the tunnel. Sample 2 consists for the most part of white streaks 1 to 4 inches thick alternating with dark-colored streaks in which the structure of the original rock is partly preserved. The analyses show that the sulphate is natroalunite.

A sample of altered rock from an open cut on a spur ridge on the southeast side of the Twin Peaks proved to be mainly potash alunite (table 25).

Evaluation: The higher grade material represents a small part of the mass of variably altered rock. Extensive exploration probably would uncover a considerable quantity of low-grade alunitic altered rock.

Yellow Jacket. The Yellow Jacket alunite deposit (figure 58 and plate 15) is covered by eight patented claims held by American Smelting and Refining Company in the S¼ sec. 14, T. 26 S., R. 4 W. Some 500 tons reportedly were mined and shipped to an alum plant at Murray, Utah (Callaghan, 1938, p. 129). The U. S. Geological Survey and the U. S. Bureau of Mines explored the property in 1943 and the Bureau

Table 24. Analyses of alunite (natroalunite) from the Big Chief deposit (J. G. Fairchild, analyst).

	1	2
Al_2O_3	38.17	33.01
K_2O	2.04	3.29
Na_2O	4.72	3.40
SO_3	32.37	24.71
H_2O	14.80	12.21
SiO_2	5.13	7.86
Fe_2O_3	1.68	10.37
TiO_2	.35	3.80
	99.26	98.65

Table 25. Analysis of altered rock, Twin Peaks area (R. C. Wells, analyst).

	Percent
Al_2O_3	23.82
K_2O	5.41
Na_2O	1.26
SO_3	22.61
H_2O^+	7.64
H_2O^-	.12
SiO_2	38.37
Fe_2O_3	trace
TiO_2	–
	99.23
Percent alunite	53.6

diamond drilled three holes totalling 739 feet, dug 40 test pits, and completed 2,373 feet of hard trenches and 1,183 feet of bulldozer trenches (Hild, 1946, p. 11-12 and 41-51). Callaghan's geological mapping was expanded by Willard and later by Bell. G. L. Bell prepared a report in 1945. The area is included in Kerr's (Kerr and others, 1957, pl. 12) map and the Monroe quadrangle map (Callaghan and Parker, 1961a).

The Yellow Jacket deposit is in a saddle, on a low ridge trending northward that ends in the alluvium of Long Valley. It is a part of the approximately 4-square-mile area of variably altered rocks of the Bullion Canyon Volcanics lying north of the large mass of quartz monzonite in the Antelope Range. Kerr (Kerr and others, 1957, pl. 12) shows the Yellow Jacket as being in altered tuff and pyroxene andesite. Bell describes the rocks as (in ascending order): biotite quartz latite, tuff interbedded with latite, latite breccia and thin-bedded crystal tuff. In the least altered latite, Bell found andesine, augite, biotite and quartz. In the more altered portion he noted fresh orthoclase with altered andesine and pyrite. Thin-bedded tuff in the north ridge contains breccia fragments, is silicified and partly alunitized and contains blebs of iron oxide. Silicified breccia crops out in the deposit and is widespread to the south and west. Pyrite is disseminated as tiny grains in silicified rock. Bell noted dips of 20° to 50° NE in the altered volcanics and found several faults of small displacement. Table 26 gives analyses of several samples from the Yellow Jacket deposit.

Kerr (Kerr and others, 1957, pl. 13) also shows the large area of altered rock which includes the Yellow Jacket and other alunite deposits. Large areas of bleached tuff are shown on the maps as well as large areas dominated by argillic alteration in stages from moderate to complete destruction of igneous minerals and textures. In the moderate stage, plagioclase changes to kaolinite and montmorillonite, but other

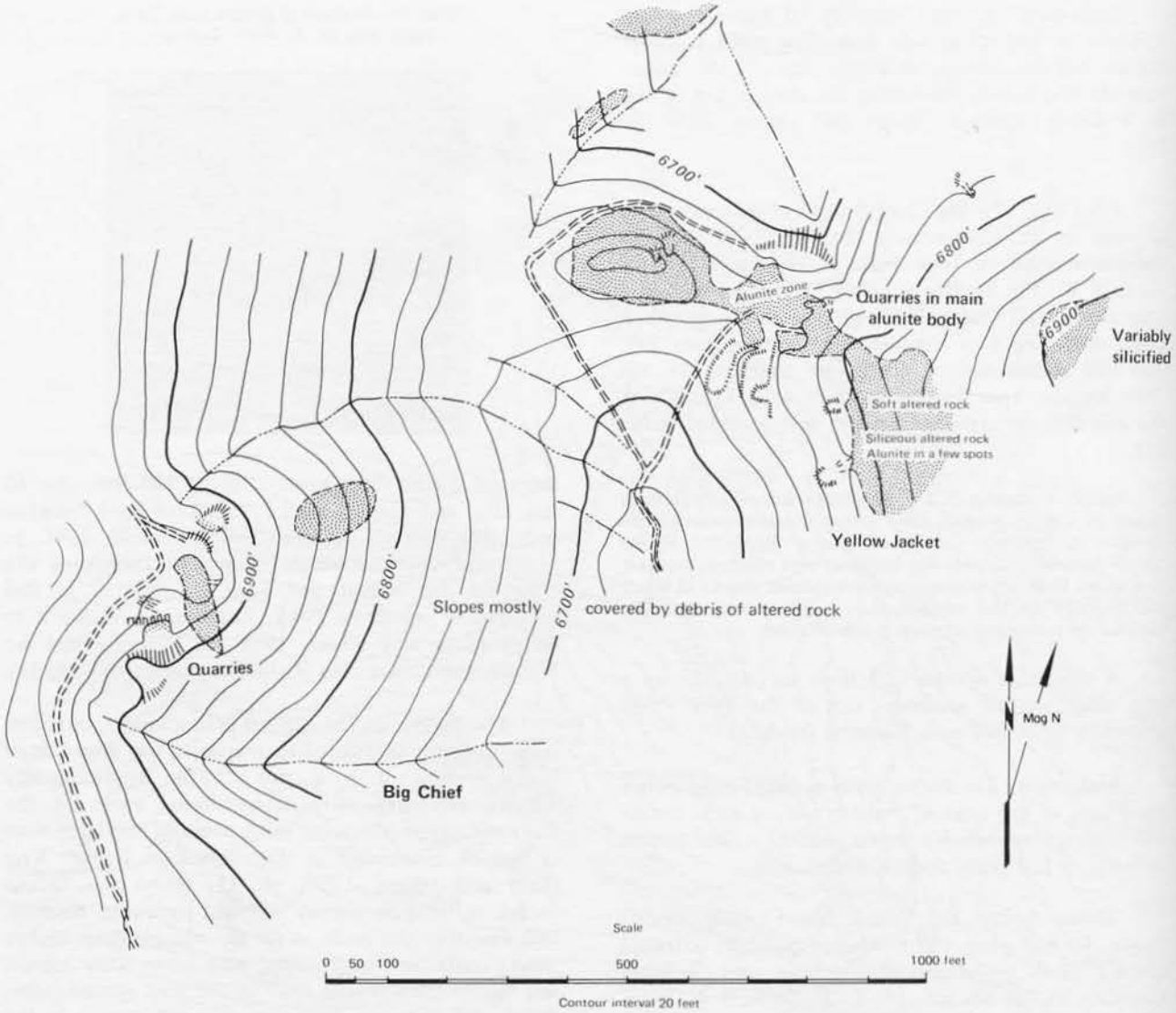


Figure 58. Geologic map of Big Chief alunite deposit and quarry area of Yellow Jacket deposit (topography and geology by E. Callaghan, surveyed 1938).

igneous minerals are preserved. In stage 3 the alteration of plagioclase to kaolinite is advanced to growth of illite flakes and in areas of most intense argillic alteration illite becomes the principal clay mineral. Areas of mixed alunitic and argillic alteration are much more restricted. That including the Yellow Jacket deposit is shown by Kerr as extending 2,500 feet to the northwest and has a width of 500 feet. Areas of dominant alunite alteration within the mixed argillic-alunitic alteration are mostly less than 500 feet in maximum dimension. Willard noted that maximum alunitization was in the tuff beds.

The sketch made by Bell (figure 59) of the Main quarry face shows a mass of gypsum formed by the weathering of anhydrite, a hypogene mineral. The gypsum is surrounded by a shell of gray quartz and alunite with some clay minerals. The material making up the remainder of the quarry face is mainly alunite with quartz and minor clay minerals. A sample representing two carloads from the quarry contained 58 percent alunite with an excess of alumina indicating associated clay. The altered rock contains disseminated fine-grained pyrite partly altered to limonite. Jarosite also formed through the oxidation of pyrite.

As shown by plate 15 the main quarry is in the saddle at the head of the northward-flowing gully. The U. S. Bureau of Mines trenched the ridge to the east for 2,200 feet from the hilltop east of the quarry and for 900 feet to the southeast. Variable but generally small amounts of alunite occur throughout the area.

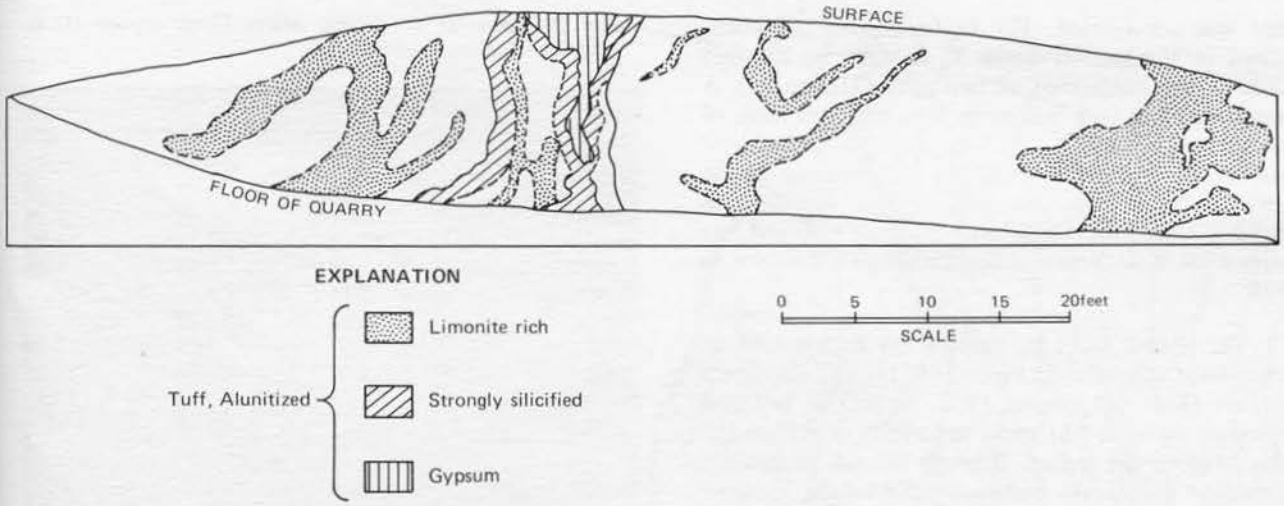


Figure 59. Sketch of face in main quarry of Yellow Jacket alunite deposit showing gypsum, silica and iron oxide in alunitized tuff (adapted from sketch by G. L. Bell, 1945).

Evaluation: As a result of exploration, the U. S. Bureau of Mines and the U. S. Geological Survey selected three areas for estimation: block A, a small area including the richest material in the main quarry; block B, a larger area including the main quarry and saddle, and block C, including a large area on the north ridge. On the basis of drilling, block A was estimated to contain 42,000 tons measured ore with 59 percent alunite, based on an average SO_3 content of 23.1 percent. Block B is shown as indicated ore with 420,000 tons averaging 52 percent alunite, based on an average SO_3 content of 20.4 percent. In block C, 3.7 million tons averaging 31 percent alunite, based on an average SO_3 content of 12.1 percent, is estimated together with 4.2 million tons averaging 23 percent alunite, based on an average SO_3 content of 9.1 percent. The averages fall below the 35 percent alunite, considered as the lower limit, and the 50 percent alunite regarded as reasonable in low-grade deposits. Blocks A and B are small, but average more than 50 percent alunite.

Table 26. Analyses of alunite, Yellow Jacket deposit (Kalunite, Inc., and J. G. Fairchild, analysts).

	1	2	3	4
Al_2O_3	26.90	23.98	25.14	19.60
K_2O	5.37	6.90	7.15	4.27
Na_2O	1.20	0.25	0.14	1.22
SO_3	22.80	23.67	24.62	17.60
SiO_2	31.00	30.04	31.72	–
Fe_2O_3	1.74	4.32	.57	1.64
TiO_2	0.20	0.78	.86	–
H_2O^+	9.51	9.11	9.91	–
H_2O^-		.22	9.81	–
P_2O_5	.71	–	–	–
CaO	.11	–	–	–
MgO	.15	–	–	–
	99.69	99.27	100.07	
Percent alunite	58	61	64	

1. Average sample representing two carloads from the quarry.
2. Sample to represent 4.8 feet at northeast corner of lower excavation in quarry.
3. Grab sample from best 2 feet in quarry.
4. "Across the two benches in the upper quarry" (Thoenen, 1941).

Potash Butte. The Potash Butte prospect is one-half mile south of Yellow Jacket in the general area of altered rock in secs. 22 and 23, T. 26 S., R. 4 W. Several pits and a large quarry expose light-colored altered volcanic rock (Callaghan, 1938, p. 129). Kerr's alteration map (Kerr and others, 1957, pl. 13) shows no alunitic alteration at this location. One sample from the quarry was analyzed with the results given below. The analysis indicated this rock is an excellent example of argillic alteration essentially free of alunite.

Al_2O_3	18.88
K_2O	.12
Na_2O	.78
SO_3	.67
H_2O^+	6.54
H_2O^-	.20
SiO_2	70.15
Fe_2O_3	.93
TiO_2	.61
	98.88

(Channel sample taken vertically across 6 feet to represent variable material; soft and powdery, hard and cherty, pinkish porous siliceous altered rock. Sample taken 20 feet northwest of center of quarry.)

Marys Lamb. The Marys Lamb deposit was prospected actively during World War I and a leaching

plant was constructed. The foundation of the plant, located in N½ sec. 23 T. 26 S., R. 4 W., is 200 feet north of the confluence of two gullies (figure 60). A quarry 120 feet long was opened on the east bank of the west gully and an adit was driven into the west bank of the east gully. Other pits were opened on the ridge between the two gullies. The deposit was described briefly by Callaghan (1938, p. 130) and was mapped by V. C. Kelley under the writer's direction in 1938.

The altered rocks are part of the Bullion Canyon Volcanics (Callaghan and Parker, 1961a) and are shown by Kerr (Kerr and others, 1957, pl. 12) as tuff and pyroxene andesite. The rock, apparently a tuff on the ridge between the gullies, although altered, preserves a lamination and breaks readily into thin slabs. Volcanic breccia and flows of andesite or latite also occur in the area, but are not altered and alunitized as completely as the laminated tuff. The dip of the structure in the tuff is westerly at 25° in the large quarry on the west side of the ridge, but swings northwest and eventually northeast on the east side. Samples from the adit and from the large quarry were analyzed (table 27).

Kerr (Kerr and others, 1957, p. 131) reported an alteration at the Marys Lamb deposit as follows:

> The deposit is quite large and consists of replaced tuff (Stage 2) and pyroxene andesite (Stage 2). Altered areas are bleached and have almost pure white alunite outcrops. At the adit the porphyry contains quartz geodes 3 inches long. Feldspars here are fresh and glassy, but the rock is slightly bleached. This zone passes abruptly into an argillic zone 1½ feet wide. Vesicles are filled with iridescent opal, but earlier texture is still discernible. Nearby in alunitized porphyry, all texture is obliterated. The narrow zone of Stage 3 consists of montmorillonite-illite which replaces sericitized feldspars. Early carbonate is replaced by quartz and kaolinite. Intensely altered pyroxene andesite (Stage 2) shows montmorillonite-illite being replaced by alunite, kaolinite, and quartz. The alteration channel within the porphyry is fracture-controlled and much more easily defined than that in the overlying and underlying tuffs.

Evaluation: The highest grade of the Marys Lamb deposit is below the minimum 35 percent alunite for possible commercial mining. More extensive exploration could show a considerable tonnage of altered rock, but the grade probably would be lower than shown by the analyses (table 27). The excess alumina shown in the analyses probably occurs as kaolinite.

Von Hindenberg. Several openings north of the Yellow Jacket in sec. 14, T. 26 S., R. 4 W. are known as the Von Hindenberg. Some dense, hard alunite, anhydrite and gypsum were reported, but production data were not secured.

Al Kee Mee. The Al Kee Mee deposit was opened as a quarry in altered Bullion Canyon Volcanics (figure 61) at the northeasternmost corner of the area of altered rock in the Antelope Range in NW¼ sec. 19, T. 26 S., R. 3 W. Although most of the slope is covered with debris, a few outcrops appear. The quarry (figure 61) shows an expanse of generally light gray porous altered rock. A sample was taken at an adit 33 feet long entering the base of the quarry and another, cut across a vein more than a foot wide and having a fibrous cross structure, proved to be nearly pure natroalunite with some alumina indicating the presence of as much as 10 percent kaolinite. The adit sample also showed excess alumina indicating kaolinite, but showed excess silica as well (table 28).

Table 27. Analyses of alunite, Marys Lamb deposit (U. S. Bureau of Mines, analyst).

	1	2	3
Al_2O_3	17.70	14.12	14.4
K_2O	3.00	1.70	2.59
Na_2O	.50	1.30	1.26
SO_3	12.27	13.72	12.9
H_2O^-	.26	.00	
H_2O^+	6.46	5.15	
SiO_2	58.30	60.28	
Fe_2O_3	.57	2.80	.29
TiO_2	1.00	.84	
Insoluble			64.1
	100.06	99.91	
Percent alunite	31	33	33

1. Sample taken to represent 5.7 feet altered rock in adit 149 feet from portal.
2. Sample from northwest part of main quarry across lamination.
3. Sample taken across quarry face (Thoenen, 1941).

The deposit is not considered commercial, but the large veins of natroalunite showing the cross fiber structure are unique in the Marysvale area.

J&L. The J&L alunite deposit near the south edge of sec. 28, T. 26 S., R. 4 W. is a small body of alunitized altered rock. It was drilled and sampled intensively by the U. S. Bureau of Mines and U. S. Geological Survey in 1943. The area was mapped by V. C. Kelley under the direction of the writer in 1938, and the mapping was extended in 1943 by Bell who prepared a manuscript report (plate 16 and figure 62). The deposit was explored by an adit 260 feet long in a north-northwest direction and by a quarry 20 feet wide and 50 feet long above the adit. Bell reports that nearly 5,000 tons were mined and treated at the local mill between 1937 and 1940. The Bureau diamond drilled six holes totalling 1,026 feet and dug 700 feet of trenching and several test pits (Hild, 1946, p. 14-15 and p. 62-65). Also in 1945, 150 tons were mined

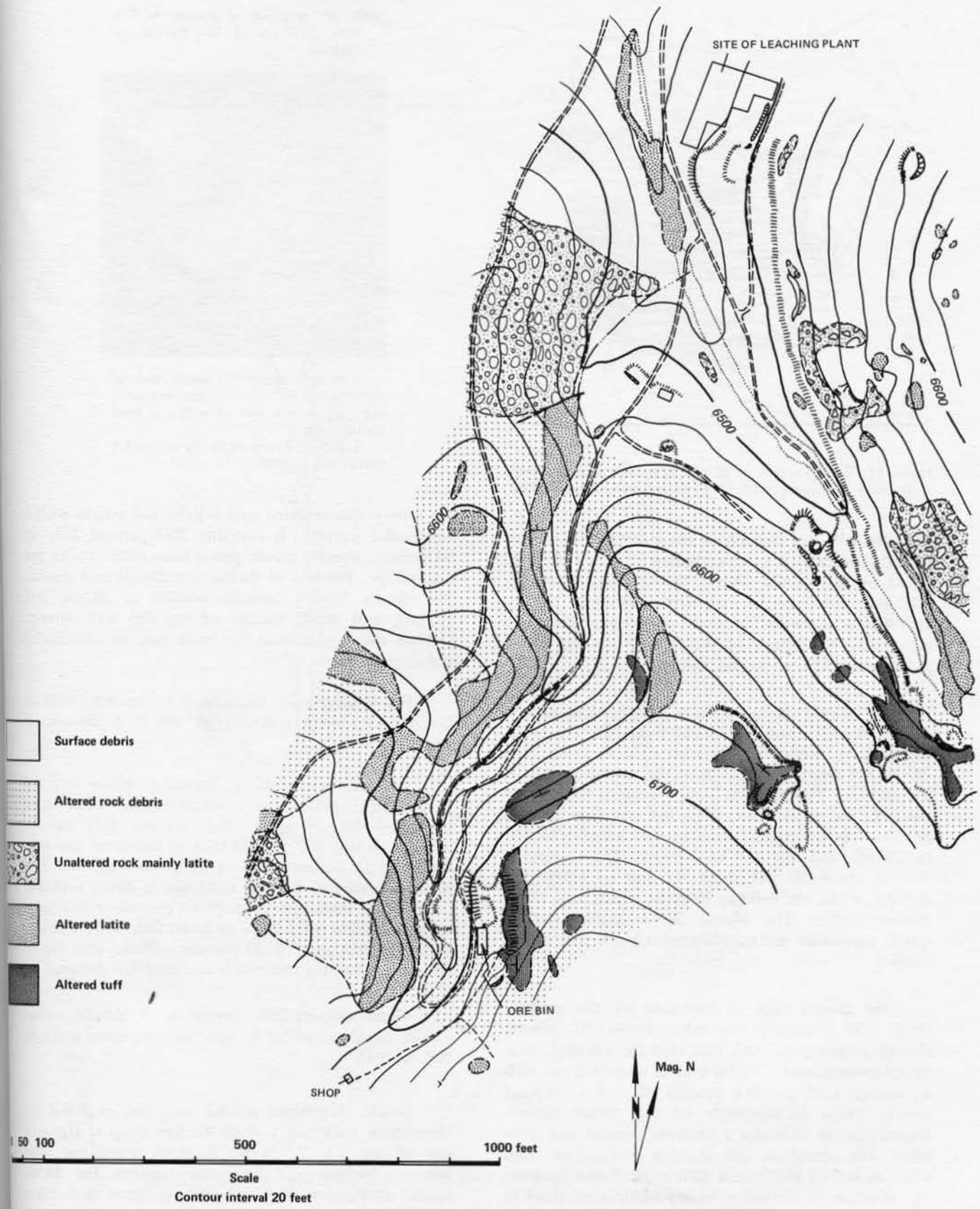


Figure 60. Geologic map of Marys Lamb alunite deposit (geology and topography by V. C. Kelley, surveyed 1938).

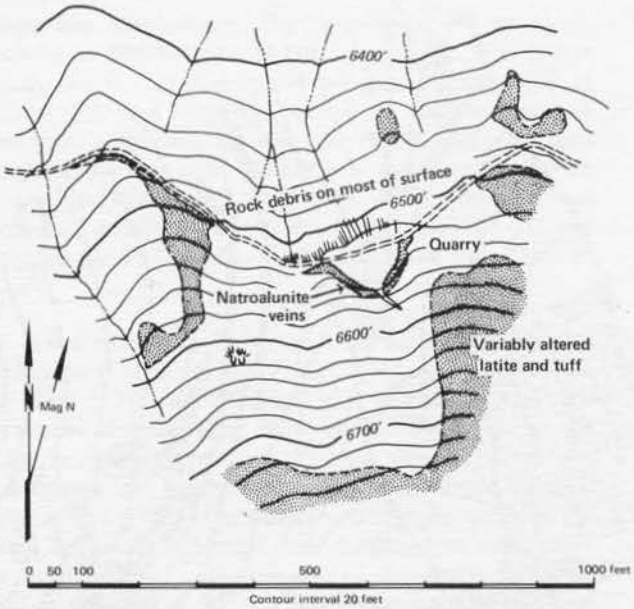


Figure 61. Geologic map of Al Kee Mee natroalunite deposit (geology and topography by E. Callaghan, surveyed 1938).

Table 28. Analyses of alunite, Al Kee Mee deposit (J. G. Fairchild, analyst).

	1	2
Al_2O_3	23.32	37.32
K_2O	2.54	4.46
Na_2O	1.30	3.77
SO_3	15.40	34.95
H_2O^+	8.76	13.77
H_2O^-	.92	.56
SiO_2	38.14	4.38
Fe_2O_3	7.32	.36
TiO_2	1.60	.10
	99.30	99.67
Percent alunite	39.9	90.5

1. Sample taken on south wall of short tunnel 33 feet from entrance vertically across 6.5 feet of soft and hard altered rock.
2. Sample taken vertically across 1.1 feet of alunite vein.

from the adit and shipped to Boulder City for experimental treatment. War Minerals Report 429, 1945, was issued on the results. During the uranium boom the adit was found to be radioactive although only a secondary uranium mineral, phosphuranylite, was associated with a fault at the face of the adit (Kerr and others, 1957, p. 76 and 164).

The alunite occurs as a lens 260 feet long in a N. 25° W. direction, and 160 to 260 feet wide. The depth indicated by drilling is 150 feet. A fault trending N. 28° E. and dipping 85° SE limits the northwest side of the deposit. The alunitized rock extends variably to the east. The deposit is in latite tuff and flow material of the Bullion Canyon Volcanics which strike N. 10° to 25° E. and dip 25° to 30° SE. The deposit is covered about 50 feet above the adit by nearly flat rhyolite of the Mt. Belknap Rhyolite which rests on an erosion surface. The deposit lies somewhat east of quartz monzonite and hornfelsized volcanic rock at the contact.

The altered rock as indicated by the analyses (table 29) is mostly somewhat above 50 percent alunite. Exploratory work indicated the ore body contained an estimated 270,000 tons of measured ore with an average grade of 16.8 percent SO_3 or 43 percent alunite which is essentially of the potash variety. Excess alumina indicates a kaolinite content and some silica. The alunitized and silicified tuff ranges from white to brown and breaks with a conchoidal fracture. The structure of the tuff is mostly obliterated. Rock in the quarry also is dense and brittle, and breaks with a conchoidal fracture. It contains 20.3 percent SO_3 or 54 percent alunite. Rutile grains were noted under the microscope. Veinlets of dickite cut alunite and quartz. The alunite border contains veinlets of dickite and gypsum and small masses of jarosite and quartz. Outside the border zone the latite may be chloritized and contain pyrite cubes.

The three samples taken from the material sent to Boulder City were analyzed by the U. S. Bureau of Mines (table 30).

Evaluation: The U. S. Bureau of Mines and the U. S. Geological Survey calculated 270,000 tons measured ore averaging 16.8 percent SO_3 or 43 percent alunite and 50,000 tons of indicated ore estimated at 10 percent SO_3 or 25 percent alunite. The samples contained alumina insoluble in dilute acid and the Bureau, therefore, developed a procedure to heat a weighed sample 600° C for an hour, followed by leaching with an excess of 20 percent sulfuric acid for an hour. The resulting solution is analyzed for alumina.

Small Occurrences. Several small alunite occurrences, mostly explored by pits, were reported to G. L. Bell in 1943.

Divide. Alunitized altered rock was explored by three open cuts and a shaft 40 feet deep at the east side of sec. 25, T. 26 S., R. 4 W. where the road between Monroe and Marysvale traverses the divide south of Poverty Flat. Alunite, kaolinite and silica

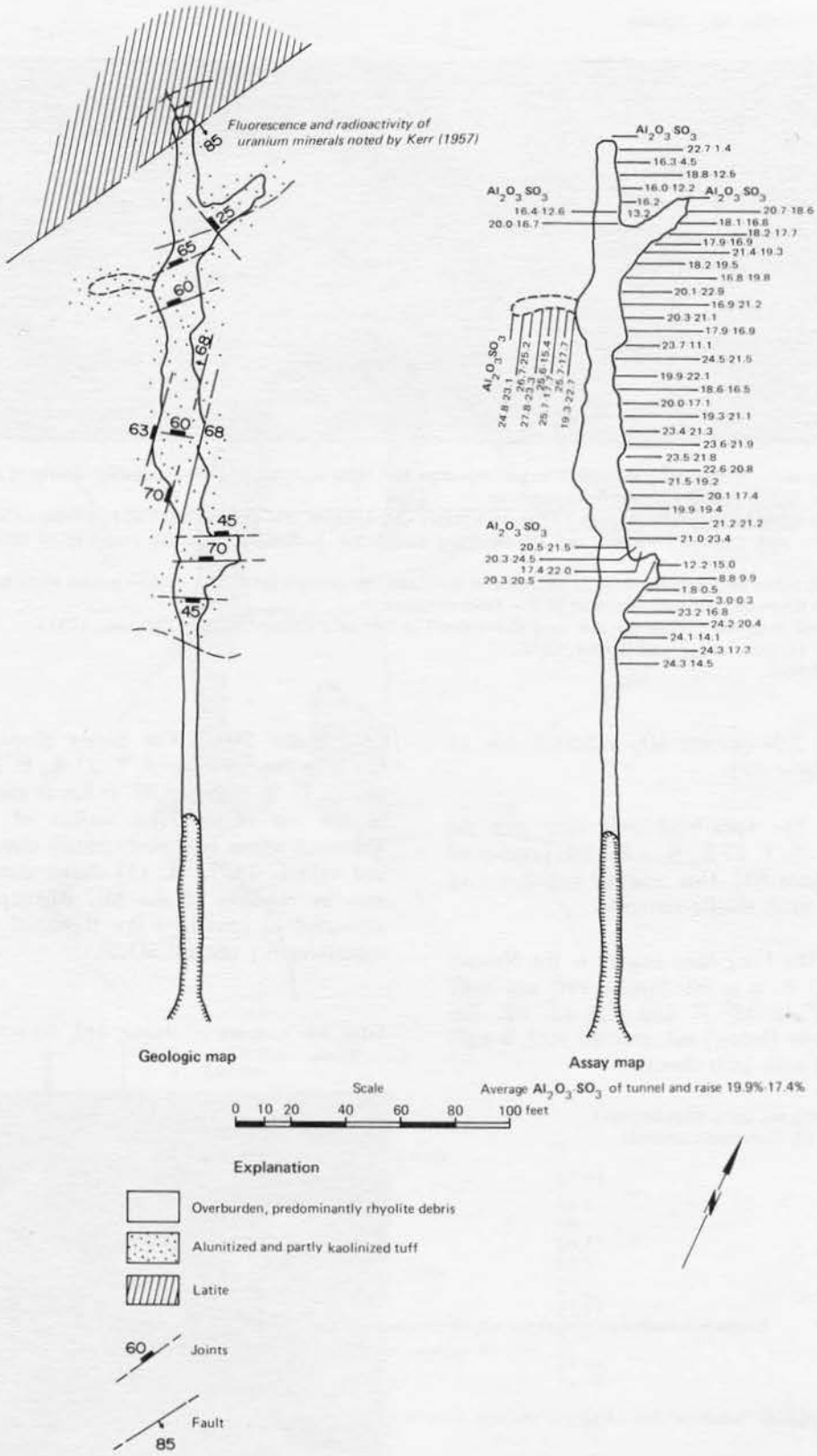


Figure 62. Geologic and assay map of J&L alunite adit (geology by G. L. Bell, assays by U. S. Bureau of Mines; surveyed 1944).

Table 29. Analyses of alunite, J&L deposit.

	1	2	3	4	5	6
Al_2O_3	21.72	22.91	14.64	20.50	32.31	28.84
K_2O	5.34	5.50	2.38	3.87	5.65	7.17
Na_2O	.69	.60	1.16	1.05	1.61	1.06
SO_3	20.93	20.76	13.38	16.8	29.53	27.24
H_2O^+	7.58	7.66	5.83		13.16	9.82
H_2O^-	.21	.10	.06			.06
SiO_2	39.92	38.22	53.50		17.03	23.39
Fe_2O_3	1.50	.99	5.16	1.55	.43	.87
TiO_2	.97	.81	2.74			.42
Insoluble				48.5		
	98.86	97.55	98.85			
Percent alunite	54.2	53.8	34.6	43.6	76.5	

1. Channel sample taken horizontally through 7 feet to represent soft shaly material possibly consisting chiefly of quartz and alunite. Sample taken on west wall of tunnel 130 feet from entrance.
2. Channel sample taken horizontally through 13 feet to represent hard, flinty, fine-grained material reputedly of high grade, white at north and grades into pink toward the south and the adjoining sample no. 3. Sample taken on west wall of tunnel 96.5 feet from entrance.
3. Channel sample taken horizontally through 10.5 feet to represent fine-grained pinkish to reddish brown material. Mottled, whitish to south end. Sample taken on west wall of tunnel 86 feet from entrance.
4. "Sample chipped from the wall of the adit over the entire 135 feet of alunitized zone" (Thoenen, 1941).
5. "Gray alunite" (Knickerbocker and Koster, 1936).
6. J & L alunite deposit.

replace latite, but 7.24 percent SO_3 indicates only 18 percent alunite (figure 63).

April Fool. The April Fool occurrence, near the center of N½ sec. 3, T. 27 S., R. 3 W., was prospected by three pits (figure 64). One analysis indicates 1.18 percent SO_3 or a small alunite content.

Long Shot. The Long Shot deposit in the N½ sec. 9, T. 27 S., R. 3 W. is in interlayered tuff and latite which strikes 35° to 45° E. and dips 22° SE. The analysis of a sample (below) indicates the rock is argillized and silicified with little alunite.

Analyses, Long Shot deposits
(R. E. Stevens, analyst)

Al_2O_3	18.78
K_2O	1.38
Na_2O	.67
SO_3	5.82
H_2O^+	7.03
H_2O^-	.32
SiO_2	61.79
Fe_2O_3	.73
TiO_2	.59
	97.11
Percent alunite	15.1

(Channel sample taken horizontally to represent 5 feet of white altered latite in pit on back of wash.)

Sunny Slope. The Sunny Slope deposit (figure 65) is in the SW¼ sec. 6, T. 27 S., R. 3 W. at the west side of U. S. Highway 89. It lies at the head of a gully at the top of the local section of Bullion Canyon Volcanics where it is immediately overlain. Kerr (Kerr and others, 1957, pl. 13) shows alunite rock in the area by rhyolite of the Mt. Belknap Rhyolite. It is estimated to contain a few thousand tons of material containing 6.1 percent SO_3.

Table 30. Analyses of alunite, J&L deposit (U. S. Bureau of Mines, analyst).

	I	II	III
Al_2O_3	23.0	22.8	22.0
K_2O	4.43	4.26	4.52
Na_2O	1.20	–	.78
SO_3	20.5	19.20	17.87
SiO_2	39.81	41.34	43.22
Fe_2O_3	1.86	1.43	2.04
TiO_2	.75	1.00	1.12
CaO	.60	.16	trace
MgO	.25	.15	0.77
P_2O_5	.26	.53	–
Loss at 600° C (H_2O)	8.63	9.1	6.93
Loss at 1,000° C	–	–	24.78
Available Al_2O_3	20.3	19.3	20.6
Available Al_2O_3, percent of total	88.2	84.6	93.6

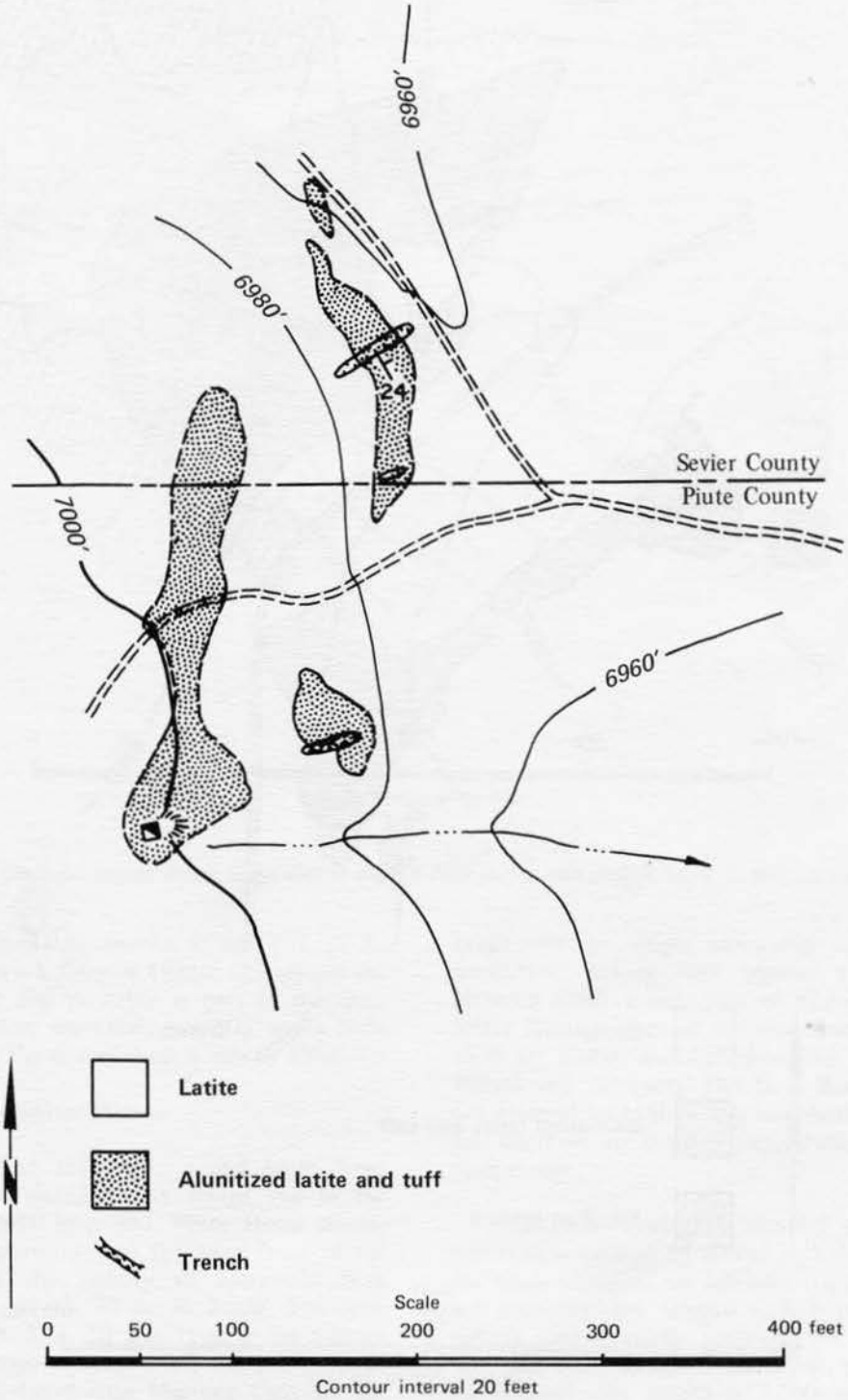


Figure 63. Geologic map of Divide alunite deposit (geology by G. L. Bell, surveyed 1943).

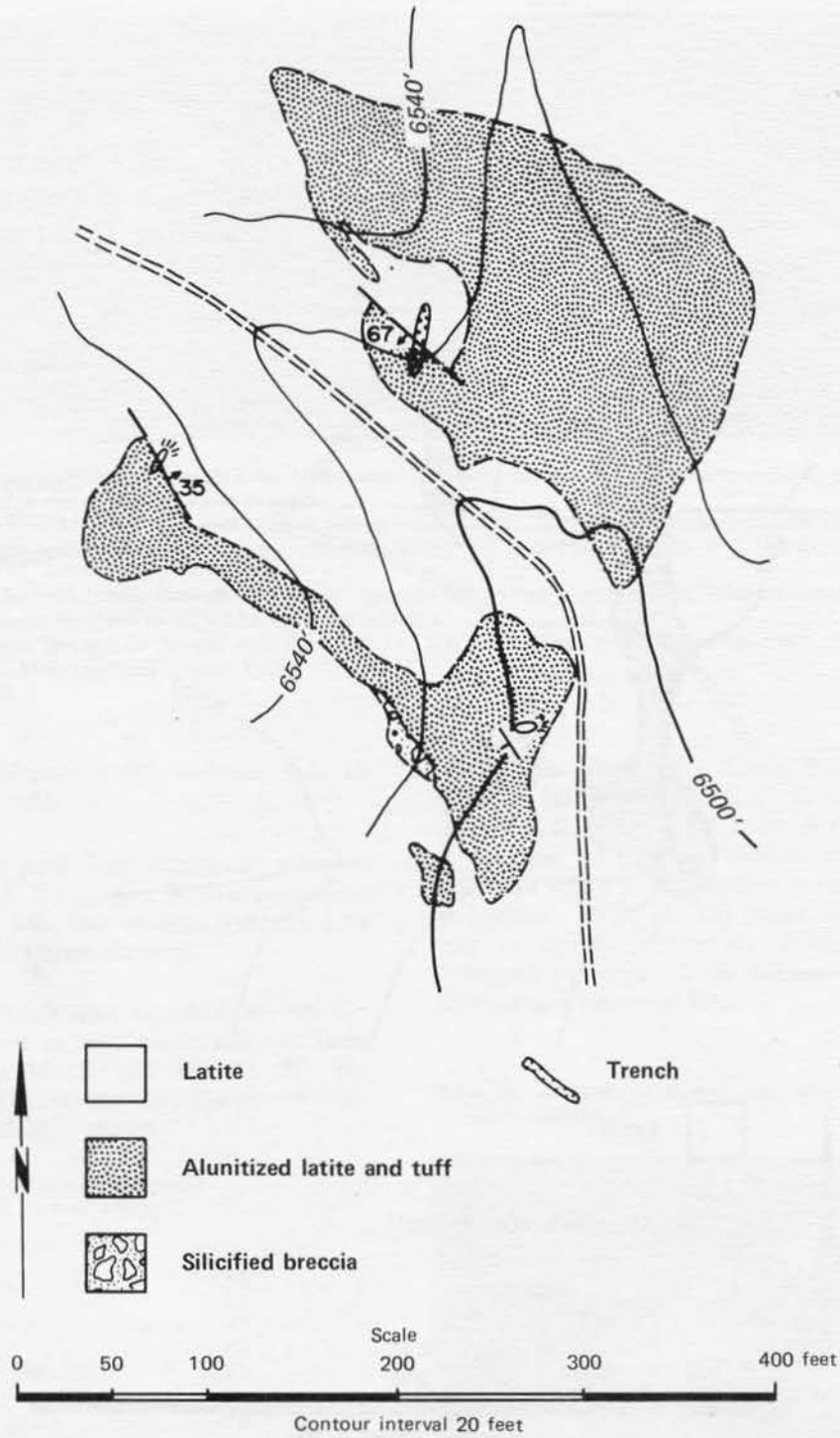


Figure 64. Geologic map of April Fool alunite deposit (geology by G. L. Bell, surveyed 1943).

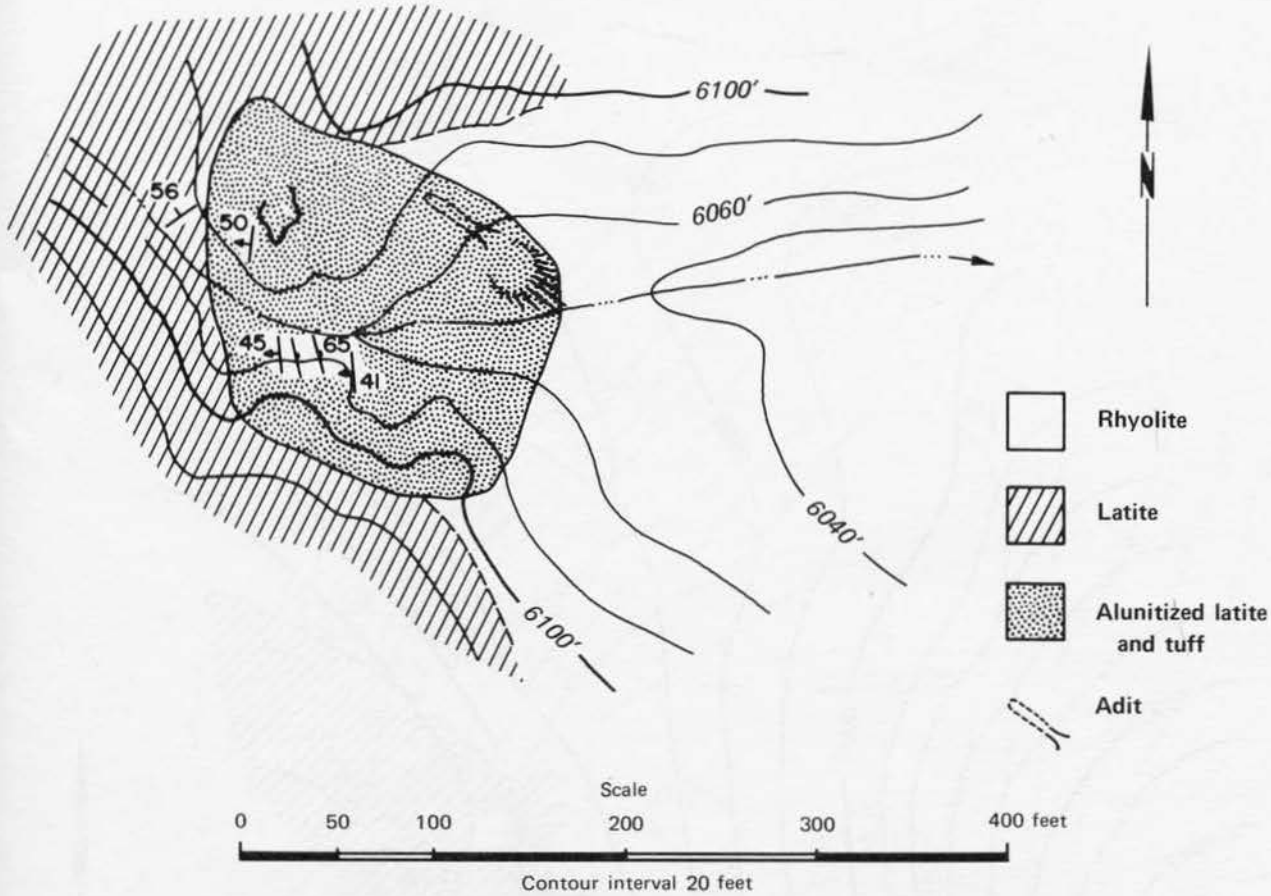


Figure 65. Geologic map of Sunny Slope alunite deposit (topography and geology by G. L. Bell, surveyed 1943).

Moffat. The Moffat occurrence in sec. 2, T. 27 S., R. 4 W. in Deer Creek Canyon (figure 66) adjoins the Winkelman deposit and probably is part of the same altered area. It shows essentially no SO_3 and a little Al_2O_3. Apparently the altered rock is mostly silica.

Sevier Plateau

Areas of altered tuff, breccia and latite flows similar to those in the Antelope Range and in the vicinity of the White Hills and White Horse alunite deposit continue eastward into the west front of the Sevier Plateau in the vicinity of Marysvale Peak (10,850 feet), sec. 10, T. 27 S., R. 2½ W. The common corner of secs. 2, 3, 10 and 11 is at the summit of the peak. Drainage radiates from the well-rounded peak and flows eastward into Manning Canyon, and southward, westward and northward. The rocks are tuffs, breccias and flows of the Bullion Canyon Volcanics (Willard and Callaghan, 1962) but the surface is largely covered by rock debris, and landslides course down the slope into Manning Creek. The rocks at Marysvale Peak appear wholly altered, and altered rock crops out on ridges extending southeastward and southward. Altered rock appears on a tributary of Manning Creek a mile east of where the creek leaves Sevier Plateau. Maps of the altered areas were made in 1938 by Kelley and Callaghan and in 1942 by Max Willard and assistants. The U. S. Bureau of Mines did not attempt to explore this inaccessible area. Workings are confined to the ten excavations of the original prospectors.

Marysvale Peak. The rounded surface of Marysvale Peak is covered by altered rock debris and most of the small outcrops are siliceous (figure 67). Although not apparent, the original rock is probably tuff and breccia dipping gently eastward. No physical exploration was done to determine depth, extent or quality. As mapped, the length is 3,000 feet, the width is 1,700 feet, and the altered rock extends 250 feet down the slope.

Samples taken from shallow openings at the surface were analyzed with the results shown in table 31.

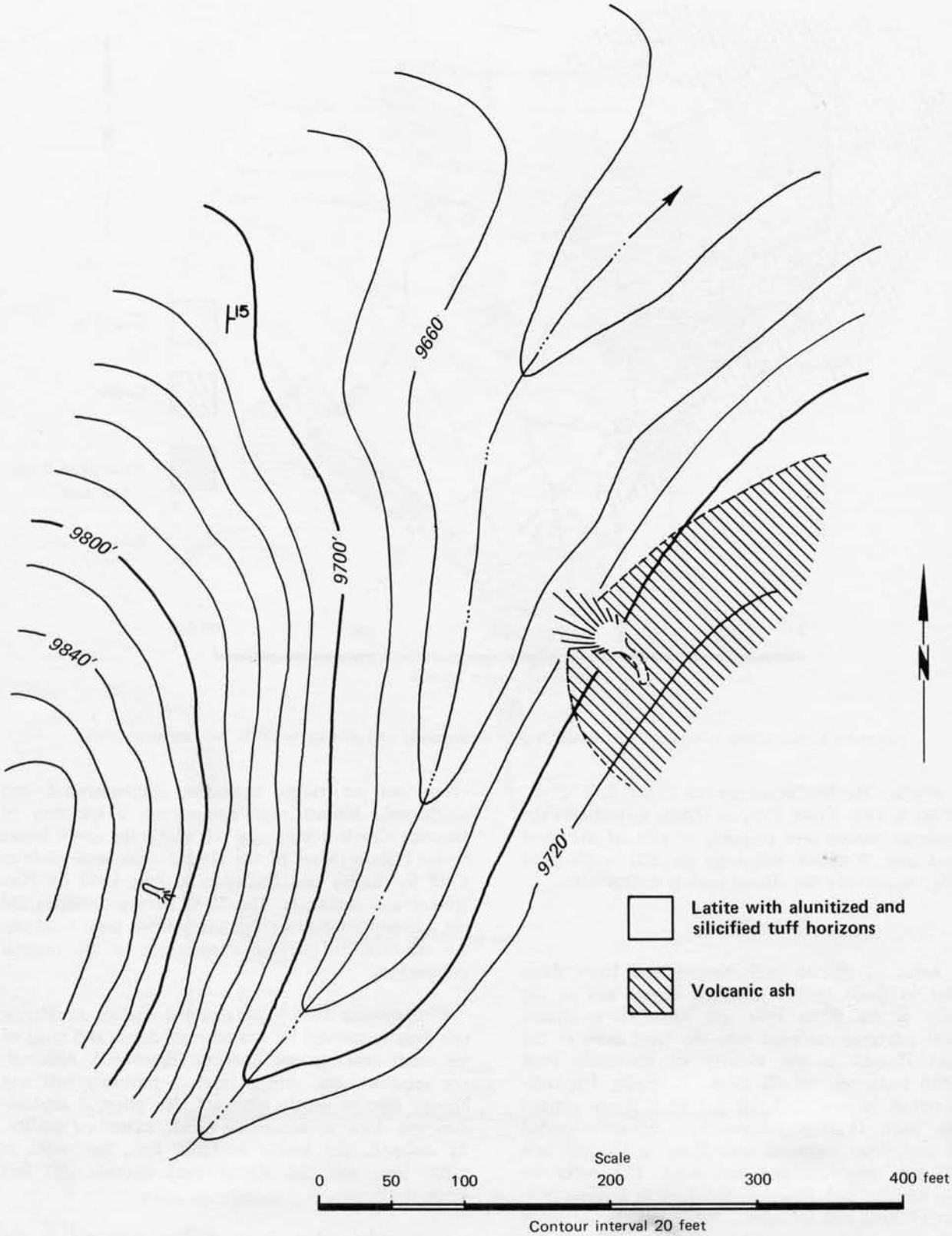


Figure 66. Geologic map of Moffat alunite deposit (topography and geology by G. L. Bell, surveyed 1943).

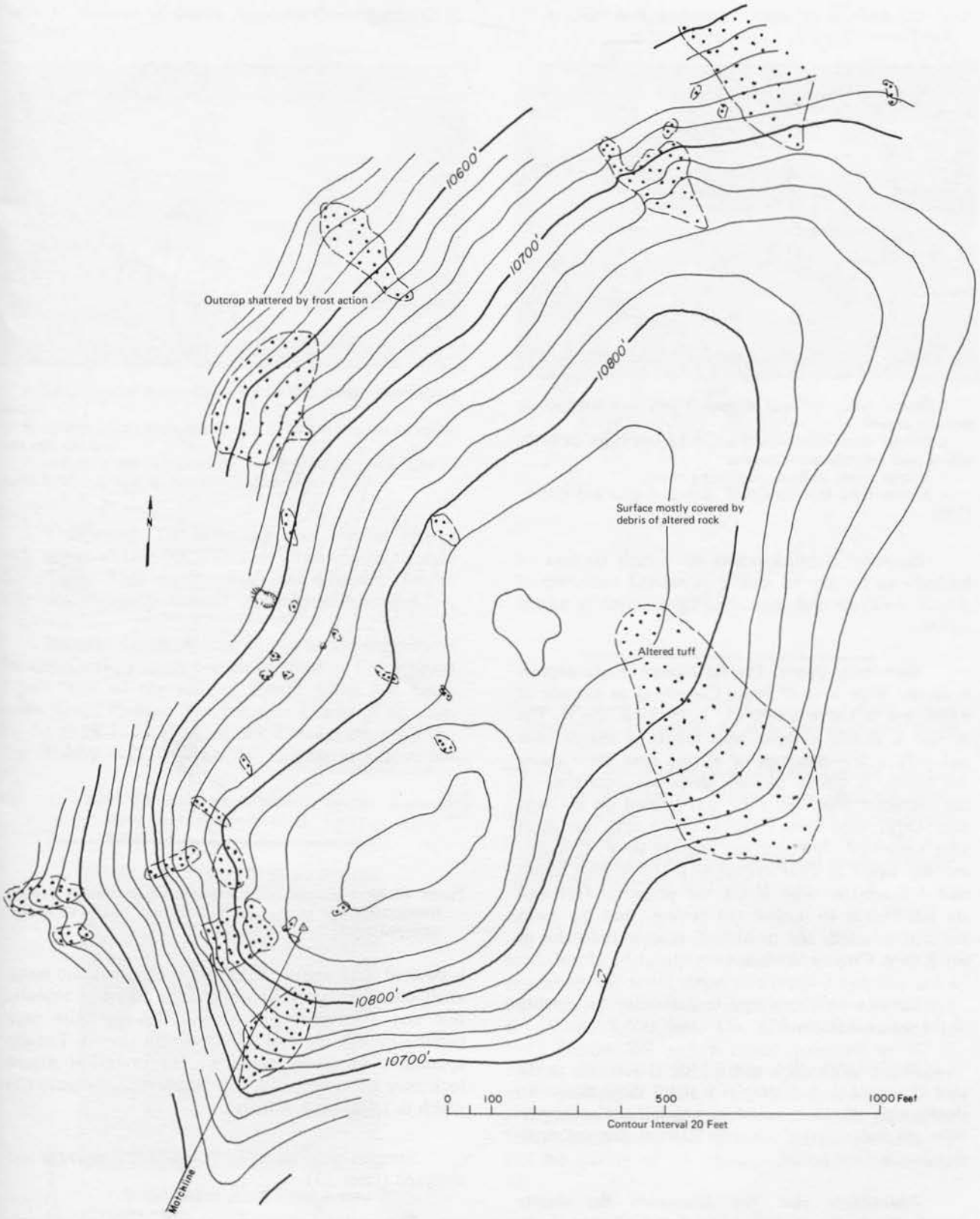


Figure 67. Geologic map of Marysvale Peak alunite deposit (topography and geology by M. E. Willard and P. D. Proctor, surveyed 1942).

Table 31. Analyses of alunite, Marysvale Peak area (J. H. Fahey, analyst).

	1	2	3	4
Al_2O_3	19.40	30.80	15.73	22.07
K_2O	2.21	7.45	3.30	3.79
Na_2O	1.16	.29	.33	.55
SO_3	13.09	25.86	11.96	15.62
H_2O^-	.74	.34	.84	
H_2O^+	7.46	10.62	6.58	
SiO_2	54.68	22.18	59.84	
Fe_2O_3	.12	.96	.92	.41
TiO_2	1.00	.76	.85	
Insoluble				47.50
	99.86	99.26	100.35	
Percent alunite	34	66	31	41

1. Sample taken vertically through 7 feet from large pit on east side of peak.
2. Sample taken horizontally across 15 feet in pit on north side of peak 100 feet below summit.
3. Sample across 10 feet in cut near summit.
4. Sample from Marysvale Peak (Knickerbocker and Koster, 1936).

Excessive alumina points to a high content of kaolinite so the altered rock is considered a mixture of alunite, kaolinite and silica. The low content of iron is notable.

Aluminum Queen. The Aluminum Queen deposit is on the ridge west of Smith Canyon at an altitude of 9,600 feet in the W½ sec. 15, T. 27 S., R. 2½ W. The surface is mostly covered with debris of altered rock and only a few outcrops of altered rock show above the debris. A quarry on two levels was excavated on the southeast slope and a pit was opened on the west side. Other cuts were made in debris and two short adits excavated. The area was mapped by V. C. Kelley and the writer in 1938 (figure 68). The Smith Canyon trail follows the ridge across the property. Outcrops are insufficient to outline the geology, but the rocks are believed to be the usual tuff, breccia and flows of the Bullion Canyon Volcanics.

Samples were analyzed to determine the quality of the material (table 32).

Alunite with silica and a little clay occurs in the area of sample 1, but samples 2 and 3 show almost no alunite with abundant potash and alumina. The proportions are indicative of sericite. Material was not available for physical testing.

Aluminum Bar. The Aluminum Bar alunite deposit lies in the steep head of Smith Canyon south of Marysvale Peak in the SE¼ sec. 10, T. 27 S., R. 2½ W. at an altitude of 9,500 to 10,100 feet. The surface

Figure 68. Geologic map of Aluminum Queen alunite deposit (topography and geology by E. Callaghan and V. C. Kelley, surveyed 1938; assumed datum).

is covered with debris of altered rock; there are many small outcrops but little evidence of physical exploration and development. Tuff and flowage latite were noted although the rock is thoroughly altered. The dip appears to be gently eastward. The extent of altered rock may be greater than the mapped area (figure 69) which is 1,100 by 1,500 feet.

Samples were taken on the central spur ridge and analyzed (table 33).

The analyses show alunite is present in moderate proportion to clay and silica. Trenching and drilling are needed to determine quality and quantity.

Table 32. Analyses of alunite, Aluminum Queen deposit (J. H. Fahey, analyst).

	1	2	3
Al_2O_3	19.64	16.70	20.09
K_2O	4.05	5.90	4.44
Na_2O	.88	.32	.28
SO_3	17.57	1.07	1.05
H_2O^-	.18	1.46	1.44
H_2O^+	6.68	3.68	4.10
SiO_2	48.30	66.68	64.58
Fe_2O_3	1.00	1.55	1.67
TiO_2	.58	.71	.86
	98.88	98.07	98.51
Percent alunite	45	3	3

1. Sample taken horizontally for 10 feet across quarry above tunnel.
2. Sample taken horizontally for 15 feet across cut on southeast side of ridge.
3. Sample taken horizontally for 6 feet on south side of north fork or tunnel 25 feet east of forks.

Evaluation: The large areas of alunitic altered rock in the vicinity of Marysvale Peak apparently contain alunite. They are in a high and relatively inaccessible area, presently without transportation services.

Manning Creek. Alunite occurs on the slope above Straight Creek, a south branch of Manning Creek about a mile east of the canyon mouth where the creek leaves Sevier Plateau. The common corner of secs. 26, 27, 34 and 35, T. 27 S., R. 2½ W. is on the property. The country rock is latite tuff, breccia and flow, but the rock in the immediate area is thin-bedded bleached tuff. A large landslide, broken away from the northwest face of Big Table Mountain, covers a considerable portion of the altered area. The slopes above the slide are mostly covered by rock debris, but outcrops appear along a belt trending northeasterly.

Table 33. Analyses of alunite, Aluminum Bar deposit (J. H. Fahey, analyst).

	1	2
Al_2O_3	21.79	22.67
K_2O	4.04	5.26
Na_2O	.69	1.18
SO_3	14.79	20.50
H_2O^-	.10	.08
H_2O^+	7.30	7.30
SiO_2	50.18	42.56
Fe_2O_3	.28	.16
TiO_2	.91	.69
	100.08	100.40
Percent alunite	38	53

1. Sample taken across 6 feet at crest of central ridge.
2. Sample of sugarlike alunite in pit 500 feet down the ridge southwest of locality of sample 1.

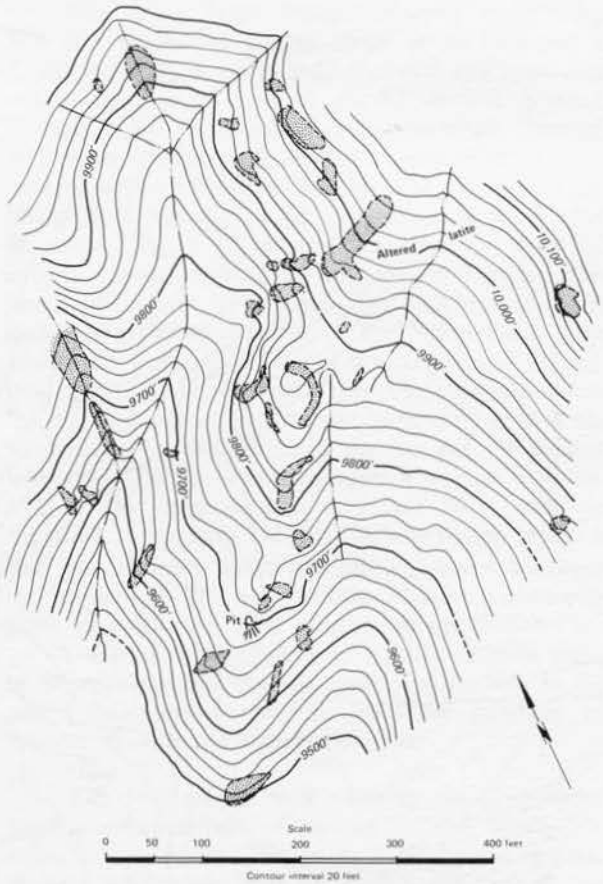


Figure 69. Geologic map of Aluminum Bar alunite deposit (topography and geology by M. E. Willard, surveyed 1943).

A shaft was excavated in the landslide where some blocks of nearly pure alunite occur. A long adit penetrates the south slope at altitude 8,240 feet and a short adit penetrates the slope northeast of the creek at altitude 8,400 feet. The deposit was mapped in 1943 (figure 70) and a report prepared by M. E. Willard; the area is included in the map of the Marysvale quadrangle (Willard and Callaghan, 1962). No exploration was attempted by the U. S. Bureau of Mines during World War II. Results of samples taken to test the quality of the altered rock are shown in table 34.

The tuff beds are highly variable in degree and type of alteration. Samples 2 and 3 are almost average in alunite content and do not show excess alumina

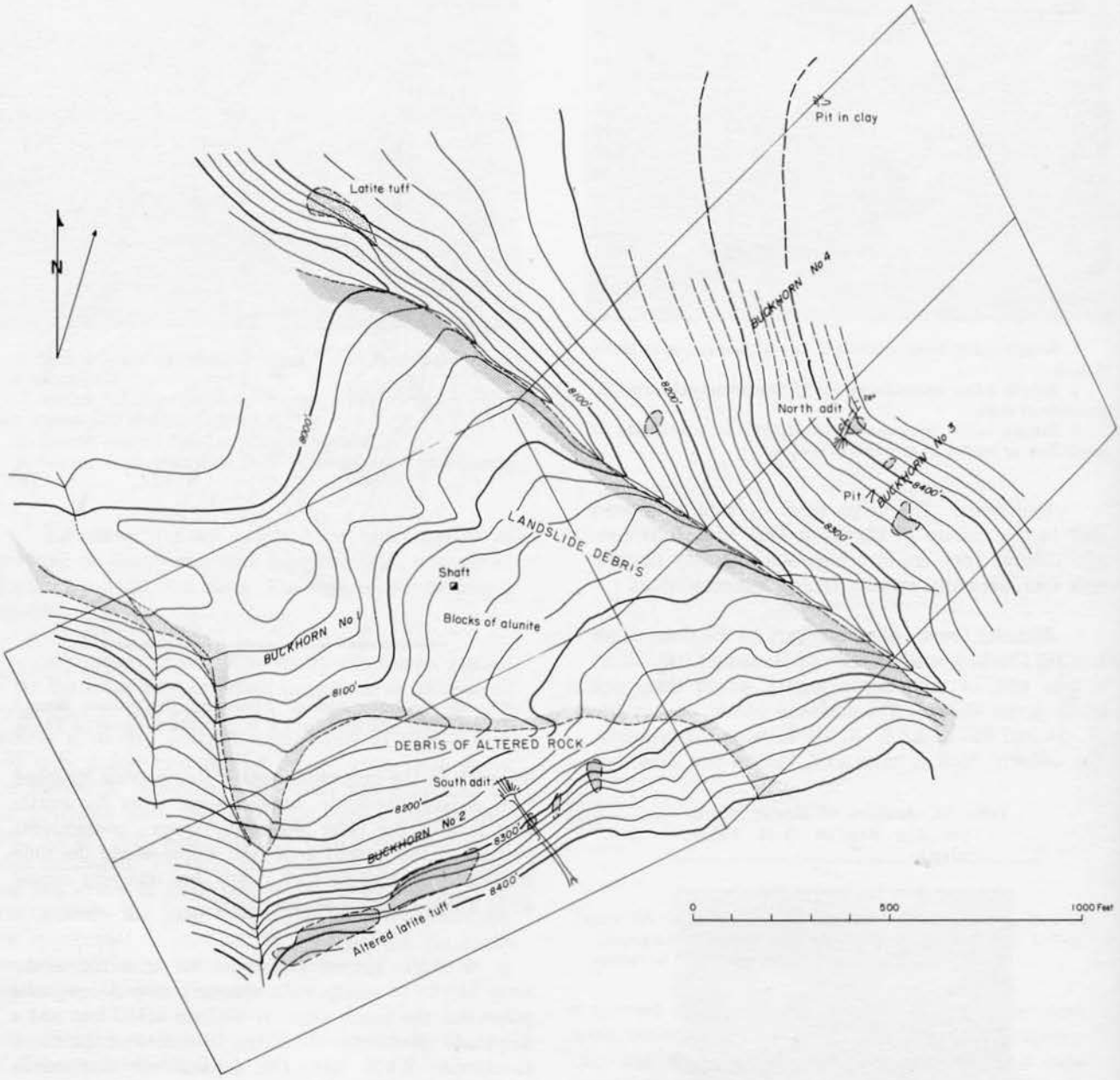


Figure 70. Geologic map of Manning Creek alunite deposit (topography and geology by M. E. Willard, surveyed 1943).

Table 34. Analyses of alunite, Manning Creek deposit (J. G. Fairchild, analyst).

	1	2	3	4	5
Al_2O_3	38.33	17.24	18.18		4.90
K_2O	.16	6.20	4.96		.47
Na_2O	.41	1.42	.92		.06
SO_3	.48	17.99	17.42	.31	.78
H_2O^-	13.72	6.67	6.88		.14
H_2O^+					2.94
SiO_2	44.13	47.46	47.94	69.12	86.18
Fe_2O_3	.92	2.51	2.24		3.66
TiO_2	.67	.31	.35		1.54
P_2O_5	.28	none	.15		
	99.10	99.80	99.04		100.67
Percent alunite	1	47	45	none	2.2

1. Sample of chalky, white material from dump of caved tunnel above cabin at north end of deposit.
2. Sample of thinly layered altered tuff at face of North adit.
3. Sample in North adit.
4. Sample in North adit at portal.
5. Sample taken vertically across 6 feet of porous brown altered tuff 6 feet from portal of North adit.

indicating abundant kaolinite. Sample 1 shows essentially no alunite, but abundant alumina representing high alumina clay minerals. Samples 4 and 5 are mainly silica with iron oxide and a little clay. Willard reports considerable pyrite appearing in the south adit.

Evaluation: Willard estimates 400,000 tons of rock averaging 40 to 45 percent alunite in each of the two blocks outlined on the map (figure 70). Much physical exploration is required to determine if an economically viable operation could be undertaken.

Newton Mining District

Sheep Rock. The Sheep Rock alunite deposit lies at the west base of the Tushar Mountains about 10 miles from Beaver in secs. 7 and 18, T. 28 S., R. 6 W. (plate 2). In 1914 W. A. Wilson, manager of the adjacent Sheep Rock gold mine, sent a sample to B. S. Butler for determination. G. F. Loughlin examined and described the deposit in 1914 (Loughlin, 1915, p. 258-264). Loughlin's data were incorporated in Butler's report (Butler and others, 1920, p. 549-550). The area, including the deposit, was mapped by Callaghan assisted by V. C. Kelley in 1938 (Callaghan and Parker, 1961b) and the geologic and topographic maps of the deposit and the nearby Sheep Rock gold mine (figure 71) were made by Callaghan and Willard in 1943. The gold mine is discussed elsewhere in this report (page 30). The Sheep Rock alunite deposit has not been mined, trenched or drilled.

The Sheep Rock deposit occupies a hill rising 350 feet above the alluvial slope at its base and is 1,600 feet long in a northerly direction and 1,400 feet wide. The outcrop area of altered rhyolite is much smaller; 1,200 feet long in an east-northeast direction and up to 600 feet wide. The remainder of the slope is covered with rock debris and soil. The east side of the Sheep Rock hill adjoins the steep slope of the Tushar Mountains (figure 71) where latite flows, tuff beds and breccia masses making up the Bullion Canyon Volcanics of the area are exposed. These rocks contain the quartz-carbonate-gold veins of the Sheep Rock mine where the wallrock alteration is characterized by sericite, quartz and carbonate. The contact area between the hill and the mountain front is covered so that the relationship of the alunitized rhyolite and the Bullion Canyon Volcanics is not exposed. A normal fault following the base of the mountain front may be expected to separate the two different rock types. A mile east of Sheep Rock, the Bullion Canyon Volcanics are overlain by the Mt. Belknap Rhyolite; assumedly prior to uplift and deep erosion, all the Bullion Canyon Volcanics were covered by rhyolite. A mile south of Sheep Rock, the rhyolite reaches all the way to the valley floor and 3 miles to the north remnants of rhyolite likewise reach the valley floor.

The firm altered rock preserves the complicated banding characteristic of viscous rhyolite flows. The color is grayish white although it may grade to pink. Alunite and quartz have formed in the rock at the expense of the original minerals and glass or lithic material in the flow bands. Loughlin (1915, p. 260-261) described the material:

> In thin section the banding proves to be due to alternating layers of relatively coarse clouded quartz grains and a very fine grained mixture of quartz and alunite. The coarser quartz grains are about 0.25 millimeter in diameter and are full of minute bubbles and specks. The alunite in the fine grained mixture forms minute but distinct laths evenly scattered among fine interlocking quartz granules. The fine and coarse quartz grains of adjacent bands have interlocking boundaries, but the alunite grains end abruptly against the coarse quartz grains. There are, however, a few relatively large alunite laths, as much as 0.5 millimeter in length, scattered among the coarse quartz grains. Minute grains of limonite, some distinctly oxidation products after pyrite cubes, are thinly scattered throughout the rock.
>
> The brecciated variety consists of fragments of the typical finely banded rock cemented by a siliceous matrix. In thin section the fragments have the typical character and composition already described. A few veinlets of alunite are present in them but do not extend into the matrix, which contains no alunite. The relations suggest that the alunite belonging to the fragments recrystallized locally in fractures, but that no second supply of it was introduced after the shattering . . .
>
> The highest-grade material, which has a more distinctly pink color than the rest of the deposit, was found in the talus

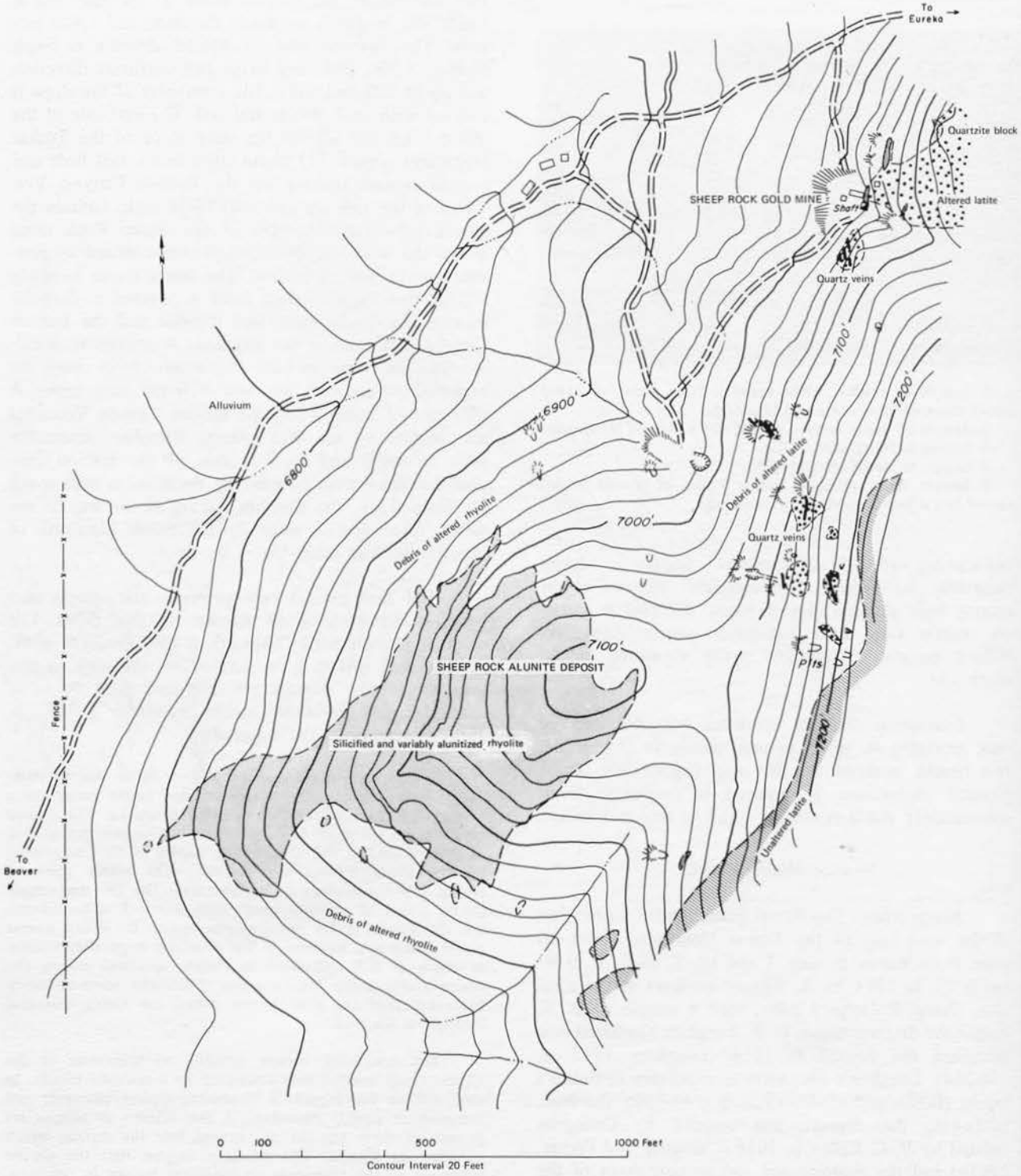


Figure 71. Geologic map of Sheep Rock alunite deposit and Sheep Rock gold mine (topography and geology by M. E. Willard and E. Callaghan, surveyed 1943).

on the north slope of the area. It has in part the typical banded structure and in part a blotchy appearance, the predominating bands or blotches of pink alternating with others of gray color. Some of the gray blotches contain small cavities representing a dissolved mineral, probably feldspar. In thin section the pink part is seen to consist mostly of a mass of alunite inclosing [sic] minute grains of quartz. The alunite occurs mainly as a felty mass of minute laths, in which are scattered larger crystals, single or in feathery aggregates as much as a millimeter long. The relation of the larger to the smaller crystals suggests that the former have grown at the expense of the latter. Alunite makes up about 60 percent of the whole. The gray areas consist of very fine quartz aggregates, the borders of which appear to have been partly replaced by alunite. The quartz areas contain a few grains 0.5 millimeter or less in diameter, which are evidently quartz phenocrysts practically unaffected during the replacement of porphyry by the quartz-alunite mixture; they also include a few minute grains and streaks of limonite, the grains preserving the cubic outline of original pyrite crystals.

Gradation into the country rock is marked by a pale-pink dense rock in which a few megascopic quartz grains and the outlines of original feldspar crystals are preserved. In thin section the feldspar phenocrysts prove to be largely replaced by fine aggregates of alunite, and faint outlines of original black silicates are suggested by fine quartz areas dusted with black specks and grains, the largest of which suggest pyrite. Quartz phenocrysts are very scarce. The groundmass is extremely fine grained and consists almost wholly of quartz with a little alunite and pyrite. This variety is similar to the altered wall rock of the Marysvale alunite veins.

Elsewhere in the Marysvale region the alunitic alteration is confined to the Bullion Canyon Volcanics and overlying rhyolite is unaffected. At Sheep Rock, however, the alunitic alteration apparently represents a later epoch of activity. The Mt. Belknap and Dry Hollow groups of rocks are altered in other places, but the product is clay and quartz rather than alunite. As far as can be surmised, Sheep Rock is an exception.

A sample taken by Willard and Callaghan was analyzed and the results given in table 35; the partial analyses obtained by Loughlin also are reproduced.

Evaluation: From a few samples, the average grade of surface material is 30 percent alunite or less. Nothing is known of grade at depth or the full extent of the deposit. More physical exploration and sampling are necessary to determine the possible worth of the deposit.

Table 35. Analyses of alunite, Sheep Rock deposit (V. North and R. K. Bailey, analysts).

	1	2	3	4
Al_2O_3	11.61			
K_2O	2.46	3.89	2.90	6.87
Na_2O	.98			
SO_3	11.41	13.83	10.56	26.53
H_2O^-	.07			
H_2O^+	4.11			
SiO_2	67.13	60.83	70.78	30.12
Fe_2O_3	2.71			
Cr_2O_3	.01			
P_2O_5	.01			
V_2O_3	.01			
TiO_2	.21			
	100.70			
Percent alunite	29	36	27	68

1. Sample to represent altered banded rhyolite on southwest slope.
2. Average sample at summit.
3. Sample at southwest side of summit.
4. Sample taken on north slope.

Clay

Only recently has clay been utilized in the Marysvale area. Open-pit clay mines are being worked seasonally in the drainage area of Clear Creek and in the upland of the Sevier Plateau in the drainage area of Box Creek. Two pits are operated in sec. 30, T. 26 S., R. 4½ W. on opposite sides of Mill Creek about 5 miles south of the confluence of Mill and Clear creeks at State Highway 4. The pit on the west side of the canyon is operated for the Interstate Brick Division of Entrada Industries, which also operates the Box Canyon deposits on the Sevier Plateau. Interstate has plants in Salt Lake County. The pit east of Mill Creek is operated for Interpace, which has a Utah plant at Harrisville north of Ogden in Weber County. The white burning kaolinite clays are blended with other clays in various proportions to effect certain burning colors or quality of the product. A considerable amount of the clay is used as a mold wash in metal plants. Interstate uses almost 30,000 tons per year including the mold wash sales. Because they are captive mines, only a nominal value is assigned to the product.

Gold Mountain Mining District

Mill Creek Deposits. The Mill Creek deposits are in a fault zone which trends east-northeast and which drops Joe Lott Tuff against the red phase of the Mt. Belknap Rhyolite. The clay developed in pipe-like masses in which a center of intensive kaolinization of Red Rhyolite is surrounded by partly altered rock. The altered rock marked by brick red colors follows the fault zone eastward, but the writer is not aware of any attempt to find additional intensively altered bodies. The clay is firm and stands in vertical walls in the pits (figure 72). Even when exposed to weathering, the clay may shatter to fragments but does not become unctious or develop flowage.

Figure 72. Altered Mt. Belknap Rhyolite in Fullmer clay pit on east side of canyon of Mill Creek south of Clear Creek.

Tests made at the University of Utah show the material to be a kaolinite-type clay. Quartz of the original rhyolite or ignimbrite tends to be preserved, but it was initially fine grained and is not an obvious constituent of the clay. The high-grade material has been mined thus far, so an orderly arrangement of benches has not been necessary. The slope into Mill Creek Canyon to the north of the east deposit is steep. To the west, the Red Rhyolite and Joe Lott Tuff are covered by the Sevier River Formation (Callaghan and Parker, 1962).

Sevier Plateau

Box Creek Deposits. Interstate Brick opened a new pit at the southeast corner of sec. 3 and the northeast corner of sec. 10, T. 27 S., R. 2 W. on the upland surface of the Sevier Plateau at an altitude of 8,710 feet. It is immediately north of the upper Box Canyon Reservoir. A road winds about 9 miles down to State Highway 62 at Greenwich. The clay area is 5½ miles east of the Marysvale Peak alunite deposits, but the clay was formed in porphyritic latite of the Dry Hollow Formation, a volcanic unit much younger than the Bullion Canyon Volcanics in which the alunite was formed. Willard and Callaghan (1962) show the formation as only a few hundred feet thick resting on the Bullion Canyon Volcanics or on remnants of the Roger Park Basaltic Breccia. Williams and Hackman (1971) represent the Dry Hollow as latite and basaltic andesite flows undifferentiated, and the underlying Bullion Canyon Volcanics as andesite breccias. Patches of basalt overlying the Dry Hollow Formation are shown on both maps as Tertiary-Quaternary basalt. Other clay alteration areas occur in the general vicinity of the Box Creek deposit and may involve other units.

The Box Creek deposit, uncovered only a few feet below the original surface, has been measured for several hundred feet in all directions. A rib of unaltered highly porphyritic pinkish Dry Hollow Latite occurs at the southeast side of the deposit and grades into the intensely kaolinized material in the pit by degrees of alteration. The material is a firm rock, slightly greenish white in color, which tends to preserve the structure of the original rock. Much of the rock is laced with an intricate pattern of dense greenish veinlets, mostly less than a millimeter in diameter with dense whole material between the veinlets. The altered rock is fractured and the fractures are coated with a thin film of iron oxide so that the broken rock appears reddish. All the original minerals of the igneous rock are destroyed with the exception of quartz. The behavior in depth is unknown. The kaolinite deposits are believed formed where hot water and steam uncontaminated with hydrogen sulfide gas migrated toward the surface through the latite. No alunite was detected in the rocks.

Sulfur

Sulphurdale

Sulfur in the vicinity of Cove Fort, Millard and Beaver counties, was known to the pioneers in the 1850's; upwards of 1,000 tons per year were mined for many years. The entire output of native sulfur for the nation in 1893 reportedly was 1,200 tons from Sulphurdale. Competition from Gulf Coast sulfur and desulfurization of sulfide ores and oil and gas discouraged sulfur production from Sulphurdale and output ceased in 1952, except for amounts produced experimentally in milling tests. Production between 1885 and 1952 is said to be 30,000 long tons. Maximum production was attained in 1906 (Mount, 1964, p. 228). Nevertheless, it represented a productive segment of the mining industry in Utah and is not exhausted.

Of the several sulfur occurrences, Sulphurdale, 3 miles south of Cove Fort in sec. 7, T. 26 S., R. 7 W., is the largest and has accounted for most of the production. The other occurrences are a mile or two north and northeast of Cove Fort in secs. 17, 19, 20, 21 and 29, T. 25 S., R. 6 W. All are in or near the alluvial slope between altitudes of 6,200 and 6,600 feet and easily reached from the paved highway. Although some sulfur-bearing material was mined from the pits north of Cove Fort, it was all treated at the Sulphurdale plant. Mining was mostly by scrapers drawn by teams of horses until the late years when a power shovel and small bulldozer were used. Mining was selective and the best material was treated in retorts to melt out the sulfur. A flotation mill was installed in 1951. A plant using the solvent extraction process began production in 1955.

No systematic exploration was undertaken in the early years, but in 1937, Freeport Sulfur Company drilled enough to determine that the deposit was not amenable to mining by the Frasch process. In 1950 the Chemical Corporation of America undertook a diamond drilling campaign on the Sulphurdale, Victor Conqueror and Sulphur King locations which was designed and carried out by the firm of King and King. In 1953 a cesspool digger was used at the Excelsior and Prince Albert pits to obtain subsurface information. The King report, which includes geology and ore estimates, was dated 1954 and an article was published by Clarence King in 1953.

The data for this report are based for the most part on Rodriguez' (1960, p. 74) thesis. He included the results of King's subsurface exploration which provided critical information. Rodriguez' geologic map is modified slightly to fit the topographic map now available (figure 73) and pit maps showing the drill locations also are included (figures 74 and 75). The stratigraphic nomenclature is changed slightly; Oquirrh is changed to Callville and Coconino to Queantoweap following the usage of Welsh (Welsh, 1972, p. 13-20). The really valuable interpretations of the Sulphurdale deposits resulted from the drilling campaign, although they were investigated by many geologists and engineers. Russell (1883, p. 31-32) and Lee (1907, p. 485-489) commented on the deposits and they are mentioned in mineral resource compilations (Butler and others, 1920, p. 106; Moore, *in* Hewett and others, 1936, p. 149; and Mount, 1964, p. 228-232).

Sulfur, where prospected or mined, occurs with siliceous sinter in alluvium of the present surface, in rhyolitic tuff and in conglomerate of the Price River Formation. The large deposit at Sulphurdale is in rhyolitic crystal tuff, but the Black mine, Sulfur King, Victor Conqueror and Queen Victoria are in alluvium and the New York, Excelsior, Mariposa and Prince Albert are in the Price River. The deposits may be interpreted as Pleistocene to present age and related closely to the present surface. The underlying rocks and structures, nevertheless, have provided the channelways for the liquids and gasses from which sulfur and underlying iron sulfide (pyrite and marcasite) were deposited.

The sulfur area is complex in geology and succession of events. The older formations shown on figure 73 are part of a belt of Paleozoic rocks which follows the west side of the Pavant Plateau from the vicinity of Fillmore to this location where it disappears under the much later Price River Conglomerate of late Cretaceous age and under still younger Tertiary volcanic rocks. The belt is interpreted as part of a thrust sheet which carries Paleozoic and Triassic rocks over Jurassic rocks. Represented here are the Callville Limestone of Pennsylvanian age (876 feet), Pakoon Limestone (206 feet), Queantoweap Quartzitic Sandstone (594 feet), and Kaibab Limestone (905 feet) of Permian age. They were followed by the Moenkopi of Triassic age. Following thrusting, the formations were eroded and the late Cretaceous Price River Conglomerate (450 feet) was deposited over the edges of the older beds and over the merging line of the thrust. Although the Price River was followed by a thick accumulation of sedimentary rocks farther north, here it is overlain directly by Tertiary volcanic rocks. All the formations are broken and displaced by normal faults mostly trending northerly and northeasterly, but the Prince Albert, an east-west fault, terminates the sedimentary rocks and possibly some of the northeasterly faults.

The volcanic rocks were not divided at this area and may include some of the older Bullion Canyon Volcanics of Oligocene age as well as latite, rhyolite and rhyolite tuff of Miocene age. Some of the material mapped as alluvium may be the older Sevier River Formation of Pliocene age. All the formations and the fault blocks were eroded to produce essentially the present surface configuration. Probably during the Pleistocene a shield type of basalt volcano developed whose flows spread over the area for a width of 5 miles or more and 800 feet above the floor. It was capped by a cinder cone 400 feet high. The event could have been brief. The volcano was broken by a northeasterly trending fault with downthrow to the west which conforms in its trend with the fault labelled Front Range fault in the north part of the area. Only part of the east edge of the volcano is shown on figure 73, but the significance of the volcano and its relation to both pre- and postvolcanic fault movements suggests that the magma chamber below may have furnished heat for the solfataric activity at the leakage centers and probably the sulfur gas and steam. The drainage and alluvial filling have been rearranged since volcanism and sulfur deposits have formed.

Steam and other gasses did not blast out craters, but soaked their way to the surface completely changing the components of the rock to white, light weight porous siliceous sinter. The writer visited the Excelsior pit and found boulders of the Price River Conglomerate, once composed of Cambrian quartzite but now made up of sinter so light that a 2-foot boulder could be balanced in one hand. Limestone boulders also were changed to sinter. In the volcanic rocks the tuff is converted to sinter that preserves the form of original feldspar phenocrysts. In the alluvium, fragments of sedimentary and volcanic rocks are con-

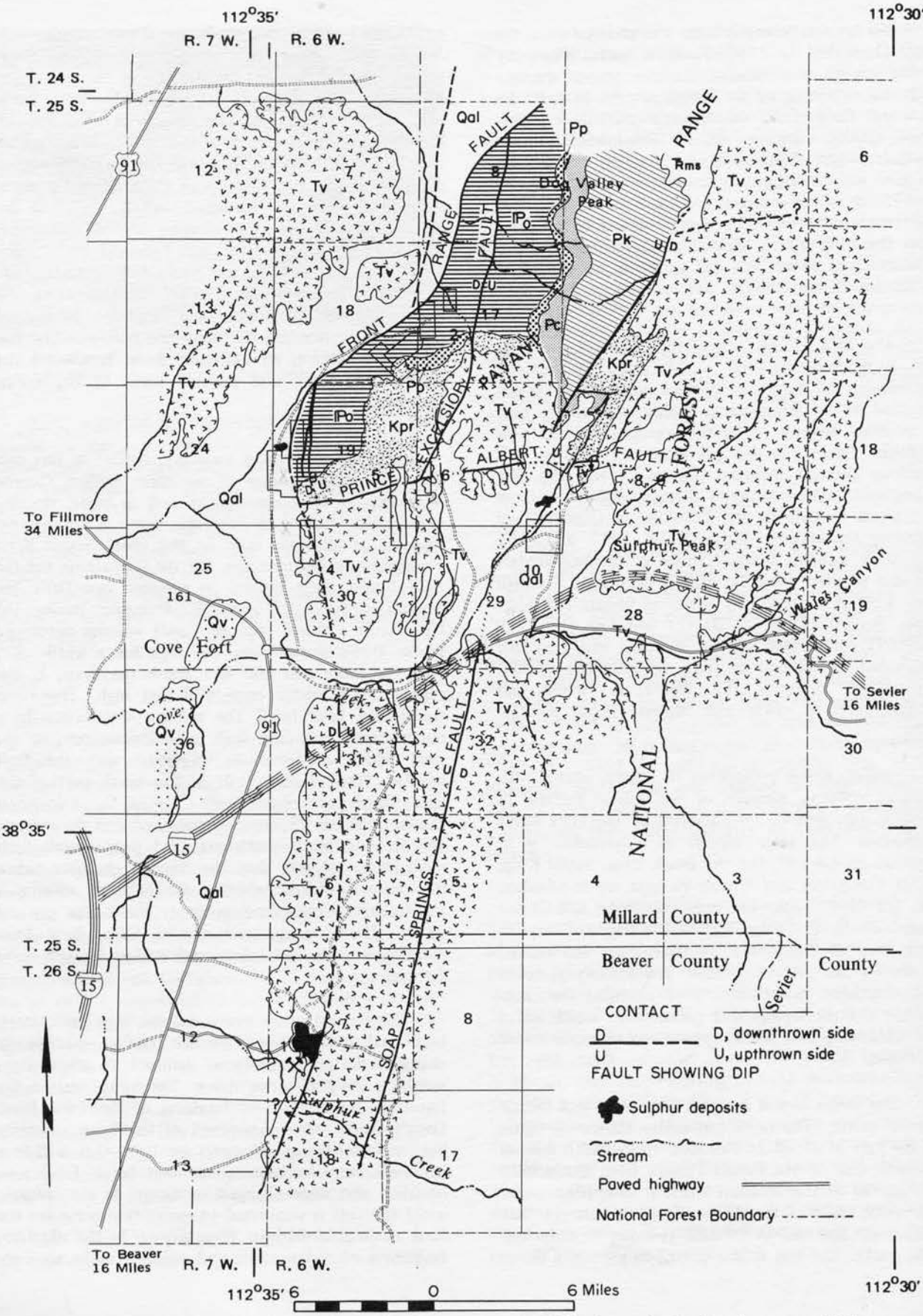


Figure 73. Geologic map of sulfur mines and prospects, Beaver and Millard counties (explanation on page 123).

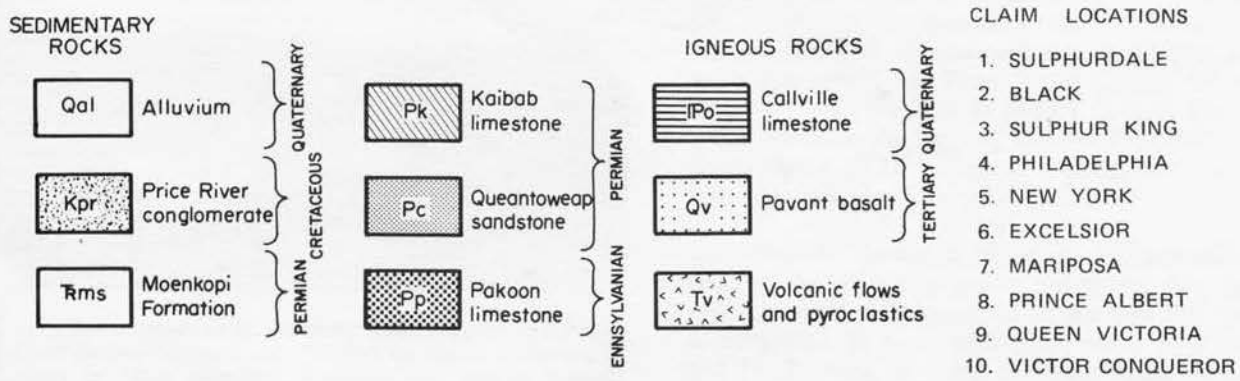


Figure 73. (continued)

verted or partly changed to sinter. The porous sinter and the spaces between fragments provide ample space for later precipitation of sulfur and, at depth, the iron sulfides. Rodriguez (1960) noted a red hematitic soil at the surface at the Mariposa, Prince Albert and Queen Victoria pits and that gypsum abundantly replaces limestone pebbles. Cores of unreplaced rock may be surrounded by sinter or gypsum. Sinter is considered a variety of opal composed of silica and water. Bedding structure in tuff and in the sediments may be preserved in the sinter. Gypsum is most abundant at the surface and occurs as clear selenite crystals, as fibrous aggregates, or as earthy masses replacing or partly replacing limestone boulders and fragments. Quartz grains are regarded as detrital or unreplaced remnants.

In the early stages, steam issuing from leakage channels altered the rocks in the channel to sinter and those near the surface to gypsum. As the temperature declined, hydrogen sulfide gas accompanied the steam, and native sulfur was precipitated in the porous aggregate of sinter. At Sulphurdale, the sulfur formed solid thin beds or was disseminated through the porous altered tuff. Evolution of steam has terminated at all localities and evolution of H_2S has, with the exception of Sulphurdale, terminated. At Sulphurdale H_2S was seen bubbling through wet mud in a trench in which a fault is exposed; masses of iron sulfide as much as 3 feet in diameter were excavated 10 feet below the surface. An analysis of the water made in 1905 showed a content of 4,523 ppm free sulfuric acid, 1,362 ppm iron oxides, 390 ppm combined calcium and magnesium, 3.6 ppm free sulfur, and 1 ppm sodium and 79 ppm chlorine. The sulfate radical is given as 7,602. Potassium is stated at 144 ppm, but no alunite is reported. As indicated by X-ray diffraction the iron sulfide, which has a colloform structure, contains pyrite and marcasite. The iron sulfides undoubtedly formed simultaneously with the sulfur in the later solfataric stages when temperatures were at the boiling point and the gas was oxygen-free.

As determined by drilling and geologic mapping, the dimensions of the ore bodies are shown in table 36.

At the Sulphurdale deposit mineralization continued beyond the depth of the drill holes so the 50- to 60-foot thickness does not represent necessarily the maximum depth. Hole No. 22 in the north end of the ore body was drilled to a maximum depth of 172 feet and showed sulfide from 20 feet to the bottom.

Evaluation: Three estimates of reserves are reproduced (tables 37 to 39). Table 39 is based on drilling and a factor of 16 cubic feet to the short ton. King (1954) defined sulfur ore "as that which has a grade higher than 12 percent combined elemental sulfur and sulfide sulfur and the ratio of overburden to ore is equal to or less than 1.5:1.0." Proved ore is defined as outlined on four sides by drilling; probable ore is outlined on two sides and has a 50 percent certainty. Possible ore is mainly below the limit reached by drilling except Hole 22.

The following illustrates the results of the drilling program undertaken in 1950 and 1951:

Total footage of drill holes	6,316
Average depth of holes (feet)	60
Deepest hole (feet)	172
Shallowest hole (feet)	25
Average direct cost per foot of hole	$4.25
Total short tons of ore proved on 100-foot grid	2,100,000
Short tons proved per foot of drill hole	332.5
Average overburden ratio (overburden thickness/ore thickness)	0.65
Average grade of ore as shown by drill samples (percent elemental and sulfide sulfur)	19.8

The summary made by the U. S. Bureau of Mines (Mount, 1964, p. 232) follows.

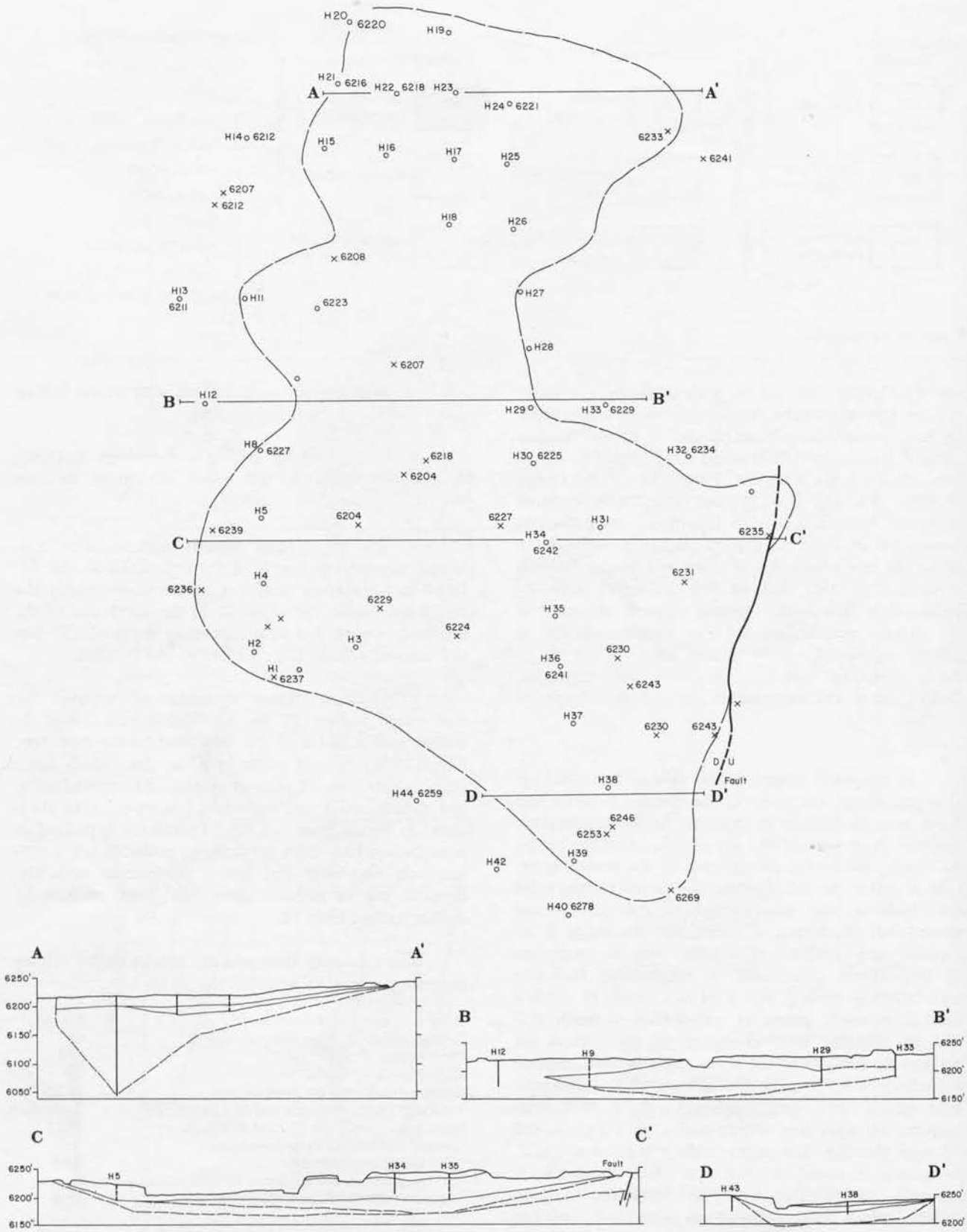


Figure 74. Geologic map and sections, Sulphurdale sulfur deposit.

Table 36. Dimensions of sulfur ore bodies, Marysvale region.

	Dimensions			Thickness
	N-S (feet)	E-W (feet)	Overburden (feet)	ore zone (feet)
Sulphurdale	1,500	800	20	50-60
Victor Conqueror	200	600	10-30	20-50
Prince Albert	300	300		
Excelsior	400	200		
Sulphur King	200	150	10	40-50
Black mine	200	100		

Sulfur resources in the native sulfur deposits of the Cove Creek-Sulphurdale area, as compiled by the U. S. Bureau of Mines in 1953, constitute 2 million long tons of material assaying at least 20 percent sulfur. Resources at the Home mine are 500,000 long tons of 20 percent sulfur minable by open-pit methods; resources of the Sulphur King mine are 300,000 long tons of 25 percent sulfur; and the resources of the Victor Conqueror mine are 1,250,000 long tons of 20 percent sulfur, with the possibility of a larger tonnage in adjacent ground on three sides of the deposit.

Results of assays show a surprising amount of sulfur as sulfide. Table 40 (page 129) presents a selected list of drill-hole data.

Drilling indicates that in spite of a long history of production a large supply of sulfur remains in the Sulphurdale area. How price, cost and profit can be projected to reach an economic ratio is unclear; changes in present technology and market are necessary to establish a proper scale of production.

Fluorspar

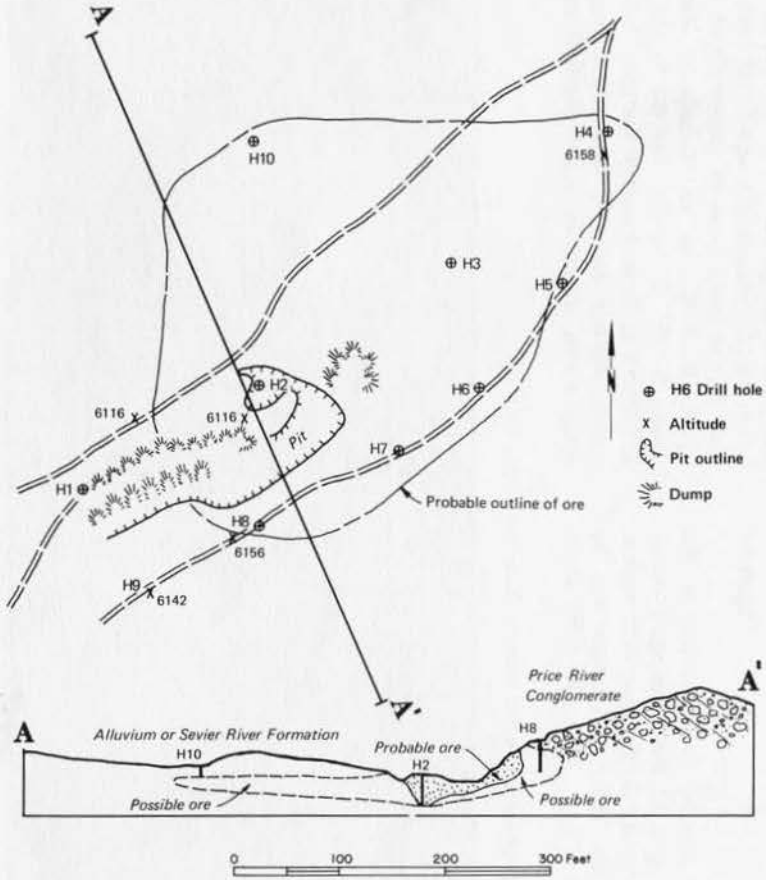
In spite of the demand for fluorspar in the United States and in spite of the widespread occurrence of the mineral fluorite in the Marysvale region, there is no operating mine. The main producer was the Rain Bow mine in sec. 17, T. 25 S., R. 6 W. which produced 2,370 tons of fluorspar in 1946 and 1,730 tons in 1947 (U. S. Bureau of Mines, 1946 and 1947) from a fractured or shattered area in Callville Limestone adjacent to the Front Range fault in the sulfur area north of Cove Fort in Millard County. The mine is 3 miles from the highway at Cove Fort (figure 73). Dasch (1964, p. 167) refers to it briefly as fractures in limestone filled by fluorspar.

Fluorite occurs in many quartz-carbonate-gold veins in the Marysvale region and in the base metal-precious metal veins, generally in amounts that remain unrecognized. In some mineralized areas, as in secs. 9 and 16, T. 27 S., R. 5 W., quartz-carbonate veins contain obvious amounts of greenish to white fluorite. In none of the veins is fluorite sufficient to be commercial.

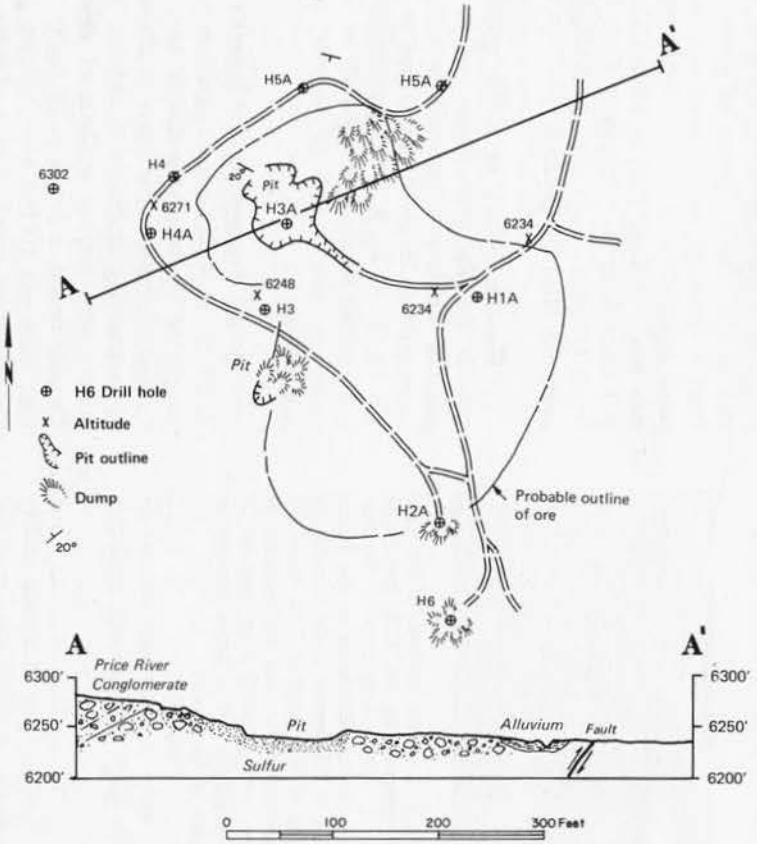
In the drainage area of Beaver Creek in sec. 18, T. 27 S., R. 4 W., two occurrences of fluorspar were prospected by bulldozer cuts in latite of the Bullion Canyon Volcanics. The latite is altered along a group of intersecting fractures to chlorite sericite and carbonate with varying amounts of disseminated pyrite. Fluorite occurs as lenses in the fractures that may be a foot wide and 10 feet long, but are generally smaller. The most abundant mineral, fluorite, is accompanied by quartz and calcite. The fluorite may be green, purple or colorless, and the crystals may be as much as an inch in diameter although poorly formed. Part of the quartz is contemporaneous, but part is younger and lines vugs in the veins. As yet prospecting has not revealed commercially significant amounts of fluorspar. In the south bank of Beaver Creek in sec. 16, T. 27 S., R. 4 W., an adit called the Mary Ellen was driven S. 35° E. by Jim Bolitho in the 1930's. The 335-foot adit showed mainly shattered latite laced with quartz veinlets for 140 feet and strong intersecting gouge seams, quartz veins and silicified rock. Fluorspar

Table 37. Summary of ore and sulfur reserves (King and King, 1954).

Ore body or prospect	Stage of drilling	Average grade of sulfur	Ore (short tons)	Sulfur (long tons)
		Proved Ore		
Sulphurdale	Complete	23.1	900,000	186,350
Sulphur King	Complete	30.0	200,000	53,500
Victor Conqueror	½	14.6	1,000,000	130,400
Total proved ore		19.8	2,100,000	370,250
		Probable Ore		
Victor Conqueror		15.0	1,000,000	134,000
Prince Albert and Mariposa		30.0	400,000	107,000
Excelsior		20.0	200,000	37,500
Black mine		25.0	200,000	44,500
Total probable ore		20.0	1,800,000	323,000

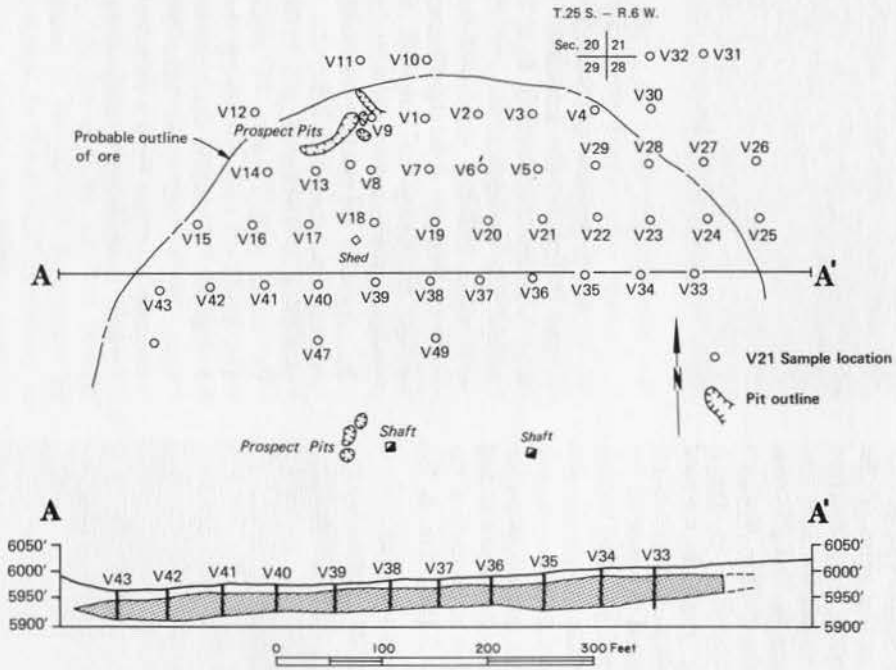


PRINCE ALBERT SULFUR BODY

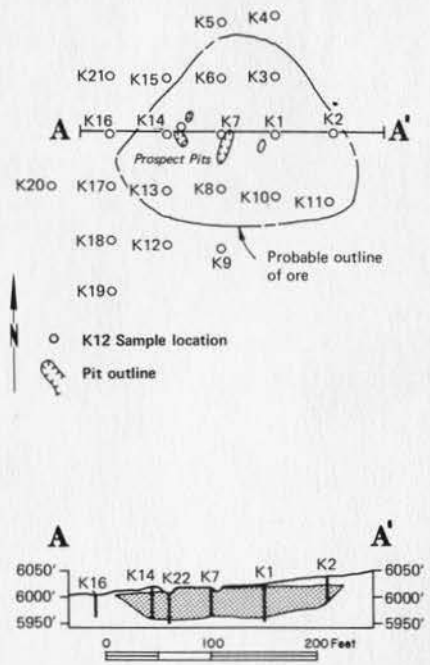


EXCELSIOR SULFUR BODY

Figure 75. Geologic maps and sections of Excelsior, Prince Albert, Sulphur King and Victor Conqueror sulfur deposits.



VICTOR CONQUEROR SULFUR BODY



SULPHUR KING SULFUR BODY

Figure 75. (continued)

Table 38. Tabulation of type of ore and sulfur reserves (Rodriguez, 1960).

Name of deposit	Type of reserves	Grade (percent)	Ore (short tons)	Sulfur (long tons)
Sulphurdale	Proved	24.5	994,187	217,290
	Probable	20.7	583,521	107,803
	Possible	20.0	829,330	148,118
	Total		2,407,038	473,211
Victor Conqueror	Proved	14.8	1,000,000	132,164
	Possible	14.8	1,000,000	132,164
	Total		2,000,000	264,328
Sulphur King	Proved	30.0	200,000	53,580
Excelsior	Probable	30.0	88,000	23,575
Prince Albert and Mariposa	Probable	25.0	120,000	26,790
Black mine	Probable	30.0	30,000	8,037

occurs in fractures in quartz to the face of the drift and is accompanied by adularia; it occurs in minor amounts and is not of commercial interest.

A much younger generation of fluorite accompanying the pitchblende in the uranium veins of the Henry mining district north of Marysvale was described in this report and is treated at length by Kerr and others (1957, p. 138-152). Fractures in Red Rhyolite of the Mt. Belknap Rhyolite in the Bullion Monarch open cut are coated with finely crystalline fluorite. A carload of fluorspar shipped in 1949 is credited (Dasch, 1964, p. 167) to the Bullion Monarch. Kerr (Kerr and others, 1957, p. 147) noted the vein in the Fluorite mine 150 feet northwest of the Bullion Monarch adit contains pale to medium purple fluorite with quartz and adularia. A trace of uranium was located in this fluorite. The vein in granite probably belongs to the quartz-carbonate veins noted above and not to the generation of fluorite that accompanied the pitchblende. The vein ranges up to 2 feet wide. In the Newton mining district, as noted elsewhere in this report (page 51), the vein in the Mystery Sniffer uranium mine contains fluorite as an accessory mineral.

Table 39. Summary of sulfur reserves.

Type of ore	Name of deposit	Sulfur (long tons)
Proved	Sulphurdale Victor Conqueror Sulphur King	404,034
Probable	Sulphurdale Excelsior Prince Albert and Mariposa Black mine	166,205
Possible	Sulphurdale Victor Conqueror	280,282
		850,521

Evaluation: Fluorspar has not been found in commercially significant deposits in the Marysvale region in spite of its wide distribution. A minable deposit is possible if a larger and higher grade occurrence is located. The current over supply (Montgomery, 1973, p. 34-35) dulls incentive for fluorspar prospecting, although a good deposit would almost certainly find a ready market.

Corundum

An occurrence of corundum and spinel in the Sevier Plateau in the canyon of Pine Creek, approximately in sec. 22, T. 28 S., R. 2 W., is of mineralogical rather than commercial interest. Float blocks of a dark dike rock, evidently weathered out of volcanic breccia, were studied by S. O. Agrell some years ago at Cambridge University in England. The rock fragments contain an unusual group of minerals (as determined by Agrell, personal communication): nepheline, corundum, spinel, hibonite, diaspore, forsterite, clinohumite, sillimanite and orthoclase. Agrell found the rocks ranged up to 70 percent alumina content. The blocks of rock containing the minerals, which are foreign to the natural sequence of igneous rocks in the Marysvale region, must have been broken loose by volcanic processes from a deep-seated source and incorporated in an eruptive outpouring of volcanic breccia.

Sand, Gravel, Aggregate and Borrow Material

Sand and gravel deposits are abundant along the valleys in the Marysvale region (plate 2) and many pits

Table 40. Assays of drill-hole data, sulfur deposits, Marysvale area.

Drill hole	Ore (feet)	Percent		Total
		Elemental sulfur	Sulfide-sulfur	
		Sulphurdale		
1	14	18.5	4.1	22.6
2	25	5.0	4.5	9.5
3	25	6.0	6.5	12.5
4	18	15.7	1.4	16.1
5	21	18.1	0.3	18.4
11	15	14.6	15.4	30.0
15	21	10.3	11.0	21.3
16	15	20.3	2.1	22.4
17	32	24.2	2.1	26.3
31	28	15.9	5.2	21.1
		Victor Conqueror		
V1	41	19.0	3.5	22.5
V2	30	9.6	0.6	10.2
V3	33	8.4	0.2	8.6
V4	36	5.2	7.6	12.8
V7	42	16.5	0.2	16.7
V13	58	15.6	0.2	15.8
V28	40	4.4	2.3	6.7
V35	54	18.0	0.3	18.3
V40	15	22.6	0.9	23.5
V44	23	3.5	0.5	4.0
		Sulphur King		
K1	57	36.4	0.5	36.9
K6	35	28.7	2.0	30.7
K7	47	19.7	0.9	20.6
K17	10	14.0	1.5	15.5
K22	31	20	10.0	30.0

have been opened along the roads and highways near construction sites or right-of-way. The material is sorted in portable sand and gravel plants nearest the site of emplacement and used as needed. The writer is not aware of any large permanent sand and gravel operations in the region. Sites along the highways have been evaluated by Utah State Highway Department personnel, and the results issued as Materials Inventory reports by counties. Materials inventories are available for the following counties: Beaver, Millard, Sevier, Sanpete, Piute, Wayne, Garfield and Kane.

Sand and gravel in the Marysvale region is dominantly in alluvial fans and terraces. Because the streams are small, the amount of desirable stream channel material is limited. Probably the best source is Circle Valley in south Piute County. The source material, mostly volcanic tuffs and breccias of the Bullion Canyon Volcanics, contains a high alkali content and tends to be soft, porous and to weather readily. Crystal tuffs and flows in the younger formations are more resistant to abrasion. In the immediate vicinity of Marysvale the alluvial material is mainly quartzite excavated from the canyons during periods of glaciation. The material tends to be bouldery. The Sevier River Formation contains fragmented rock which is angular and poorly sorted.

Building and Dimension Stone

No commercial stone quarries are operated in the Marysvale region and, except for the welded tuff in the Joe Lott Tuff, no stone in the area has been used. Welded tuff was used for construction during the pioneer epoch, as in other localities in the Great Basin, before reinforced concrete became readily available. Welded tuff is light and easily shaped and, if free of clay, lasts almost indefinitely in a dry climate. The white to salmon pink color also is pleasing. The stone, however, is out of fashion and undoubtedly cannot compete in cost with reinforced concrete or concrete building block.

Several abandoned quarries in welded tuff are shown on the mineral locality map (plate 2) in the vicinity of Monroe and Joseph at the south end of Central Sevier Valley. The stone probably was used for churches, public buildings and some homes during pioneer times. The buildings of old Fort Cameron east of Beaver which are long since dismantled were built of pink welded tuff, but the writer does not know the site of the quarries.

The brownish red crystal tuff or porphyritic latite of the Dry Hollow Formation perhaps could be used as a dimension stone. Most of the other igneous rocks are too closely jointed to be worked economically as dimension stone.

The sedimentary rocks do not appear to be attractive as building stone. The limestone tends to shatter and does not have a lively color and the quartzite would be too difficult to work.

Water Resources

With the exception of eastern Beaver County and southeastern Millard County, all of the Marysvale region is included in the drainage basin of Sevier River. Because of their altitude, the High Plateaus in the Marysvale region intercept considerable precipitation which commonly ranges from 10 inches in the valleys to 30 inches or more on the high surfaces where winter snows may accumulate to depths of 10 feet. Many streams draining the high regions, especially the Tushar Mountains and the Sevier Plateau, are perennial. Otter Creek and Piute reservoirs in the area regulate the flow of Sevier River, which has its maximum flow during the irrigation season.

The total precipitation ranges widely over a period of time so that prolonged periods of drought

may alternate with periods of above average precipitation, or there may be wide differences between successive years. Groundwater accumulates in the gravel-filled portions of the valleys. Until recent resort development in the Tushar Mountains, there was no permanent population in the high areas so water has been obtained from springs, streams, or mine openings, when the occasion demanded.

No investigation of water resources was made as a part of this study. The reader is referred to the offices of the State Engineer at the Utah State Capitol and the U. S. Geological Survey in the Federal Building, Salt Lake City, for current information. For groundwater information on the drainage area of Sevier River above Kingston the reader is referred to Carpenter, Robinson and Bjorklund (1967) and for that part below Kingston to Young and Carpenter (1965). Surface water in the entire region is covered by Woolley (1947).

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REFERENCES

Anderson, C. A., 1935, Alteration of the lavas surrounding the hot springs in Lassen Volcanic National Park: Am. Min., v. 20, p. 240-252.

Anonymous, 1900, The mines at the Marysvale country: Salt Lake Min. Rev., v. 2, p. 5-7 and 16-17.

Austin, C. F. and J. K. Pringle, 1970, Geologic investigations at the Coso thermal area: Naval Weapons Center TP 4878, Copy 131.

Bailey, E. H., 1962, Mercury in the United States: U. S. Geol. Survey Min. Inv. Map MR-30.

Barock, C. T. and others, 1945, Alunite, J&L claims, Marysvale, Utah—dehydration in rotary kiln: U. S. Bur. Mines War Minerals Rept. 429.

Bassett, W. A. and others, 1960, Potassium-argon ages, Marysvale, Utah, Tertiary volcanic rocks (abs.): Geol. Soc. Am. Bull., v. 71, p. 1822.

———1963, Potassium-argon dating of the Late Tertiary volcanic rocks and mineralization of Marysvale, Utah: Geol. Soc. Am. Bull., v. 74, p. 213-220.

Bethke, P. M., 1957, The sulfo-selinides of mercury and their occurrences at Marysvale, Utah: Ph. D. thesis, Columbia Univ.

Bethke, P. M. and P. K. Kerr, 1954, Uranium occurrences in the older sedimentary rocks of the Marysvale district: U. S. Atomic Energy Comm. RME 3096, pt. I., p. 60-74.

Blakey, R. C., 1973, Stratigraphy and origin of the Moenkopi Formation (Triassic) of southeastern Utah: Mountain Geologist, v. 10, no. 1, p. 1-18.

Brill, K. G., Jr., 1963, Permo-Pennsylvanian stratigraphy of western Colorado Plateau and eastern Great Basin regions: Geol. Soc. Am. Bull., v. 74, p. 307-330.

Brophy, G. P., E. S. Scott and R. A. Snellgrove, 1962, Sulfate studies, 11–solid solution between alunite and jarosite: Am. Min., v. 47, p. 112-126.

Brophy, G. P. and P. F. Kerr, 1951, Preliminary memorandum on the Flat Tire prospect, Marysvale, Utah: U. S. Atomic Energy Comm. RMO-863.

_____1953, Hydrous uranium molybdate in Marysvale ore: Annual Report from June 30, 1952 to April 1, 1953, U. S. Atomic Energy Comm., RME-3056, p. 45-51.

Brush, G. J., 1881, On American sulfo-selenides of mercury–with analyses of onofrite from Utah by W. J. Comstock: Am. Jour. Sci., Ser. 3, v. 21, p. 312-316.

Bullock, K. C., 1970, Iron deposits of Utah: Utah Geol. and Mineralog. Survey Bull. 88, 101 p.

Burchfiel, B. C. and C. W. Hickcox, 1972, Structural development of central Utah–Plateau Basin and Range transition zone, central Utah: Utah Geol. Assoc. Publ. 2, p. 55-66.

Bureau of Economic and Business Research, College of Business, 1967, Utah's central six county region, an economic profile: Univ. of Utah, Center for Economic and Community Development.

Butler, B. S. and others, 1920, Ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, 672 p.

Butler, B. S. and H. S. Gale, 1912a, Alunite near Marysvale, Utah: Mine and Sci. Press, p. 104, 210-211.

_____1912b, Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511.

Callaghan, E., 1938, Preliminary report on the alunite deposits of the Marysvale region, Utah: U. S. Geol. Survey Bull. 886-D, p. 91-134.

_____1939a, Volcanic sequence in the Marysvale region in southwest central Utah: Trans. Am. Geophys. Union, pt. 3, p. 438-452.

_____1939b, Preliminary report on the alunite deposits of the Marysvale region, Utah: U. S. Geol. Survey Bull. 886-D.

_____1947, Geologic features, *in* Utilization of surface-water resources of Sevier Lake basin, Utah: U. S. Geol. Survey Water-Supply Paper 920.

Callaghan, E. and R. Parker, 1951, Geologic map of Marysvale and vicinity: U. S. Geol. Survey, Open-file, 1951.

_____1961a, Geology of the Monroe quadrangle, Utah: U. S. Geol. Survey Map GQ-155.

_____1961b, Geologic map of part of the Beaver quadrangle, Utah: Min. Inv. Field Studies Map MF-202.

_____1962a, Geology of the Delano Peak quadrangle, Utah: U. S. Geol. Survey Map GQ-153.

_____1962b, Geology of the Sevier quadrangle, Utah: U. S. Geol. Survey Map GQ-156.

Callaghan, E. and H. E. Thomas, 1939, Manganese in a thermal spring in west central Utah: Econ. Geol., v. 34, no. 8, p. 905-920.

Carpenter, C. H., G. B. Robinson, Jr., and L. J. Bjorklund, 1964, Selected hydrologic data, upper Sevier River Basin, Utah: U. S. Geol. Survey Open-file Rept. [duplicated as Utah Basic-data Rept. 8], 29 p.

Carpenter, C. H. and R. A. Young, 1963, Groundwater data, central Sevier Valley, parts of Sanpete, Sevier and Piute counties, Utah: U. S. Geol. Survey Open-file rept. [duplicated as Utah Basic data Rept. 3], 34 p.

Carpenter, C. H. and others, 1967, Ground-water conditions and geologic reconnaissance of the upper Sevier River Basin, Utah: U. S. Geol. Survey Water-Supply Paper 1836, 91 p.

Carr, S. L., 1972, The historical guide to Utah ghost towns: Western Epics, Salt Lake City, 166 p.

Christiansen, F. W., 1937, The geology and economic possibilities of the alunite deposits in Sevier and Piute counties, Utah: M. S. thesis, Univ. of Utah.

Condie, K. C. and C. K. Barsky, 1972, Origin of Quaternary basalts from the Black Rock Desert region, Utah: Geol. Soc. Am. Bull., v. 83, p. 333-352.

Crittenden, M. D., Jr., 1951, Manganese deposits of western Utah: U. S. Geol. Survey Bull. 979-A, 52 p.

Crosby, G. W., 1959, Geology of the South Pavant Range, Millard and Sevier counties, Utah: M. S. thesis, Brig. Young Univ., p. 59.

Dahl, H. M. and P. F. Kerr, 1953, Geochemical aspects alteration, Marysvale, Utah: U. S. Atomic Energy Comm., Ann. Rept. June 30, 1952 to April 1, 1953, RME-3044, 58 p.

Dasch, M. D., 1964, Fluorine, *in* Mineral and water resources of Utah: Utah Geol. and Mineralog. Survey Bull. 73, p. 162-168 (reprinted 1969).

Day, D. T., 1885, Sulphur: U. S. Geol. Survey Min. Res., 1883-1885, p. 866.

Dixon, H. B., 1938, The building and monumental stones of the State of Utah: Thesis, Brig. Young Univ.

Doelling, H. H., 1972, Tertiary strata, Sevier-Sanpete region–Plateau Basin and Range transition zone, central Utah: Utah Geol. Assoc. Publ. 2, p. 41-54.

DuFaur, A. F., 1887, The sulphur deposits of southern Utah: Eng. and Min. Jour., v. 44, p. 450.

Duncan, D. C. and W. H. Myers, U. S. Geological Survey open-file maps.

Dutton, C. E., 1880, Report on the Geology of the High Plateaus of Utah, with atlas: U. S. Geog. and Geol. Survey, Rocky Mtn. Region, p. 169-188.

Eardley, A. J. and E. L. Beutner, 1934, Geomorphology of Marysvale Canyon and vicinity, Utah: Utah Acad. Sci. Proc., v. 11, p. 149-159.

El-Mahdy, O. R., 1966, Origin of ore and alteration in the Freedom No. 2 and adjacent mines at Marysvale, Utah: Ph.D. thesis, Univ. of Utah, 217 p.

Eppich, G. K., 1973, Aeromagnetic survey of south central Utah: M. S. thesis, Univ. of Utah, 78 p.

Eppich, G. K., R. T. Shuey and D. K. Shellinger, 1973, Aeromagnetic map of south central Utah: Thesis, Univ. of Utah (37°00' – 39°00' and 110°54'–113°05').

Evans, M. T., 1953, Geology and ore deposits of the Great Western mine, Marysvale region, Utah: Compass of Sigma Gamma Epsilon, p. 102-108.

Everett, F. D., 1961, Tungsten deposits in Utah: U. S. Bur. Mines Inf. Circ. 8014, 44 p.

Feltis, R. D. and G. B. Robinson, Jr., 1963, Test drilling in the upper Sevier River drainage basin, Utah, 1962: U. S. Geol. Survey Open-file Rept., 32 p.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., 534 p.

Field, C. W. and G. Lambard, 1972, Sulfur isotopic evidence for the supergene origin of alunite deposits, Tolfa district, Utah: Mineral Deposit (Berl.) 7, p. 113-125.

Fleisher, A. and J. Glasser, 1951, Production of aluminum from kalunite alumina: Am. Inst. Min. Met. Eng. Trans., Jour. of Metals, v. 8, p. 634-636.

Fleisher, A., 1944, The Kalunite process: Am. Inst. Min. Met Eng. Tech Publ., no. 1713.

Gabriel, A. and J. Dasher, 1942, Benefication of alunite: U. S. Bur. Mines, Rept. Inv. 3610, 20 p.

Gates, A. O., 1922, Bully Boy Mines Corp. now operating big mines at Marysvale, Utah: Salt Lake Min. Rev., v. 24, no. 6, p. 9-13.

Gibbs, J. F., 1905, The Deer Trail mine near Marysvale, Utah: Salt Lake Min. Rev., v. 6, p. 19-20.

_____ 1916, Marysvale Red Blood: Publ privately.

_____ 1925, Geological outlines of formations and structural conditions obtaining in the Marysvale mining district; Utah's "Last Mining Frontier," 20 p.

Gilbert, R. E., 1958, Notes on the geophysical work of Marysvale, Utah: U. S. Atomic Energy Comm. RME-2050.

Greaves-Walker, A. F., 1911, The commercial clays of Utah: Trans. Am. Ceramic Soc., v. 13, p. 277-300.

Green, J. and P. F. Kerr, 1951, Preliminary memorandum, East Slope area, Marysvale, Utah: U. S. Atomic Energy Comm., 64 p.

Green, J., 1953, Geochemical table of the elements for 1953: Geol. Soc. Am. Bull., v. 64, p. 1001-1012.

Grim, R. E., 1953, Clay mineralogy: McGraw-Hill, New York.

Gromme, C. S., E. H. McKee and M. C. Blake, Jr., 1972, Paleomagnetic correlations and potassium-argon dating of middle Tertiary ash-flow sheets in the eastern Great Basin, Nevada and Utah: Geol. Soc. Am. Bull., v. 83, p. 1619-1638.

Gruner, J. W., L. Gardiner and D. K. Smith, Jr., 1953, Annual Report, July 1, 1952 to March 31, 1953: U. S. Atomic Energy Comm. RME-3044, 58 p.

Gruner, J. W. and L. Gardiner, 1951, Fifth progress report, for period Nov. 1, 1950 to February 28, 1950: Univ. Minn., Minneapolis, Minn. Rept. to U. S. Atomic Energy Comm., 21 p.

Gruner, J. W., W. G. Fetzer and I. Rapaport, 1951, The uranium deposits near Marysvale, Piute County, Utah: Econ. Geol., v. 46, p. 243-251.

Hamilton, P. K. and P. F. Kerr, 1954a, Uranophane and Buranotile, Marysvale, Utah: U. S. Atomic Energy Comm. RME-3096, pt. 1, Ann. Rept. June 30, 1953 to April 1, 1954, p. 38-48.

_____ 1954b, Phosphuranylite at Marysvale, Utah: U. S. Atomic Energy Comm. RME-3096 pt. 1, Ann. Rept. June 30, 1954 to April 1, 1954, p. 49-51.

Hardy, C. T., 1952, Eastern Sevier Valley, Sevier and Sanpete counties, Utah: Utah Geol. and Mineralog. Survey Bull. 43.

Haven, R. and W. W. Agey, 1949, Concentrations of manganese ores from Piute and Kane counties, southern Utah: U. S. Bur. Mines Rept. Inv. 4551, 9 p.

Hawkes, H.E. and J. S. Webb, 1962, Geochemistry in mineral exploration: Harper and Row, New York, 415 p.

Hemley, J. J., 1967, Aqueous solutions and hydrothermal activity: U. S. National Rept., 1963-1967, Am. Geophys. Union Trans., v. 48, no. 2.

Hemley, J. J. and others, 1969, Some stability relations of alunite: Econ. Geol., v. 64, no. 6, p. 599-612.

Hewett, D. F. and others, 1936, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 148-149.

Heyl, A. V., 1963, Oxidized zinc deposits of the United States, pt. 2, Utah: U. S. Geol. Survey Bull. 1135-B.

Higgins, W. C., 1909a, The attractions of Marysvale, Utah: Salt Lake Min. Rev., v. 11, p. 17-19.

_____ 1909b, The Sevier Consolidated mine of Gold Mountains, Piute County, Utah: Salt Lake Min. Rev., v. 11, p. 15-18.

Hild, J. H., 1946, Exploration of alunite deposits, Marysvale, Piute County, Utah: U. S. Bur. Mines Rept. Inv. 3972, 74 p.

Hintze, L. F., 1963, Geologic map of southwestern Utah: Brig. Young Univ., Geol. Dept.

Hobbs, S. W., 1945, Tungsten deposits in Beaver County, Utah: U. S. Geol. Survey Bull. 945-D.

Holmes, A., 1960, Geological time-scale: Geochron Laboratories, Inc., Mass.

Hunt, C. B., 1956, Cenozoic geology of the Colorado Plateau: U. S. Geol. Survey Prof. Paper 279.

_____1967, Physiography of the United States: San Francisco, W. H. Freeman, 480 p.

Huntley, D. B., 1885, Precious metals: Tenth Census U. S., v. 13, p. 462-463.

Intermountain Association of Petroleum Geologists, 1952, Cedar City, Utah, to Las Vegas, Nevada: Intermtn. Assoc. Petrol. Geol. Guidebook, no. 7.

Jarvis, J. S. and D. M. Marrott, 1972, Annual report, 1972: Six county overall economic development program, Juab, Millard, Piute, Sanpete, Sevier and Wayne.

Johnson, M. G., 1973, Placer gold deposits of Utah: U. S. Geol. Survey Bull. 1357, 26 p.

Kashkai, M. A., 1970, Alunites, their genesis and utilization: "Nedra" Publishing House, Moscow, v. 1 and 2.

Kaiser, E. P., 1950, The Papsy's Hope autunite prospect, Marysvale district, Piute County, Utah: U. S. Geol. Survey TEM Rept. 145.

Kelley, K. K. and others, 1946, Thermodynamic properties of ammonium and potassium alums and related substances, with reference to extraction of alumina from clay and alunite: U. S. Bur. Mines Tech. Publ. 688.

Kennedy, R. R., 1963a, Geology of Piute County, Utah: Ph. D. thesis, Univ. of Ariz.

_____1963b, Sedimentary stratigraphy of the Tushar Range, Piute County, Utah: Intermtn. Assoc. Petrol. Geol. Guidebook, 12th Ann. Field Conf., p. 118-124.

Kerr, P. F., 1950, Mineralogical studies of uraninite-bearing deposits: Tech. Rept., July 1, 1949 to June 30, 1950, Columbia Univ., New York.

_____1963, Geologic features of the Marysvale uranium area, Utah: Intermtn. Assoc. Petrol. Geol. Guidebook, 12th Ann. Field Conf., p. 125-135.

Kerr, P. F. and P. K. Hamilton, 1953, Alteration of a vitrophyre dike, Bullion Monarch mine, Marysvale, Utah: U. S. Atomic Energy Comm. RME-3046, Ann. Rept. June 30, 1952 to April 1, 1953, p. 8-25.

_____1954, Pitchblende and manganocalcite at the Deer Trail mine, Marysvale, Utah: U. S. Atomic Energy Comm. RME-3096, pt. 1, Ann. Rept., June 30, 1953 to April 1, 1954, p. 38-48, 52-55.

_____1968, The Marysvale, Utah, uranium deposits, *in* J. D. Ridge, ed., Ore deposits in the United States: AIME (Graton/Sales volume), p. 1020-1042.

Kerr, P. F. and J. L. Kulp, 1949, Reference clay localities, United States: Am. Petrol. Inst., Proj. 49, Prel. Rept. 3.

Kerr, P. F., J. L. Kulp and P. K. Hamilton, 1949, Differential thermal analyses of reference clay mineral specimens: Am. Petrol. Inst. Proj. 49, Prelim. Rept., no. 3, Columbia Univ., New York, 48 p.

Kerr, P. F., W. L. Simpson and P. K. Hamilton, 1953, Deer Trail area, Marysvale, Utah: U. S. Atomic Energy Comm. RME-3046, Ann. Rept. June 30, 1952, to April 1, 1953, p. 52-57.

Kerr, P. F. and others, 1951, Preliminary memorandum, Marysvale, Utah: U. S. Atomic Energy Comm., Div. Raw Materials, Ann. Rept. July 1, 1950 to June 30, 1951.

_____1952, A geologic guide to the Marysvale area: U. S. Atomic Energy Comm. RMO-924, p. 1-57.

_____1957, Marysvale, Utah uranium area: Geol. Soc. Am. Spec. Paper 64, p. 1-212.

King, C. R., 1953, Cove Creek sulphur: Min. Eng., p. 375-387.

_____1954, Report upon the Cove Creek sulphur properties, Sulphurdale, Utah: Unpubl. rept. King and King, Los Angeles, Calif.

Knickerbocker, R. G. and J. Koster, 1936, Electrometallurgical studies on the treatment of alunite, pt. 3: U. S. Bur. Mines, Rept. Inv. 3322.

Knizek, J. O. and H. Fetter, 1950, The refractory properties of alunite: Trans., The British Ceramic Soc., v. XLIX, p. 202-285.

Koster, J. and others, 1939, Progress report: U. S. Bur. Mines, Metall. Div., Rept. Inv. 3438.

Lautenschlager, H. K., 1954, The geology of the central part of the Pavant Range, Utah: Ph. D. thesis, Ohio State Univ.

Leaming, G. F. and others, 1971, Minerals in the economic development of the Four Corners region: Prepared for the Four Corners Comm., College of Business Public Administration, Univ. of Ariz.

Lee, W. T., 1907, The Cove Creek sulphur beds, Utah: U. S. Geol. Survey Bull. 315, p. 485-489.

Lemmon, D. M. and O. L. Tweto, 1962, Tungsten in the United States: U. S. Geol. Survey Min. Inv. Res. Map MR-25.

Lessentine, R. H., 1965, Kaiparowits and Black Mesa basihs–stratigraphic synthesis: Am. Assoc. Petrol. Geol. Bull., v. 49, p. 1997-2019.

Lewis, R. S. and T. Varley, 1919, The mineral industry of Utah: Utah Univ. Bull. 10, no. 11 (Utah Eng. Sta. Dept. Met. Research Bull. 12).

Lindgren, W., 1906, The Annie Laurie mine, Piute County, Utah: U. S. Geol. Survey Bull. 285, p. 87-90.

Loughlin, G. F., 1915, Recent alunite deposits near Marysvale and Beaver, Utah: U. S. Geol. Survey Bull. 620, p. 237-270.

Mackin, J. H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: Am. Jour. Sci., v. 258, p. 81-131.

Malloy, M. W. and P. F. Kerr, 1960, X-ray spectrochemical analysis–an application to certain light elements in clay minerals and volcanic glass: Am. Min., v. 45, p. 911-936.

_____1962, Tushar uranium area, Marysvale, Utah: Geol. Soc. Am. Bull., v. 73, p. 211-236.

Mardirosian, C. A., 1966, Mining districts and mineral deposits of Utah (map): Privately published.

Maxey, G. B., 1946, Geology of part of the Pavant Range, Millard County, Utah: Am. Jour. Sci., v. 244, p. 324-356.

McCaskey, H. D., 1912, Quicksilver: U. S. Geol. Survey Min. Res., p. 914.

McKee, E. D., 1933, The Coconino Sandstone–its history and origin: Carnegie Inst., Wash., Publ. 440, Paper 7, p. 79-115.

_____1938, The environment and history of the Toroweap and Kaibab formations of northern Arizona and southern Utah: Carnegie Inst., Wash., Publ. 492, 268 p.

Mehnert, H. H., P. W. Lipman, T. A. Steven, 1973, Age of mineralization at Summitville, Colorado, as indicated by K-Ar dating of alunite: Econ. Geol., v. 68, p. 399-401.

Montgomery, Gill, 1973, Fluorspar: Min. Eng., v. 25, no. 1, p. 34-36.

Moore, B. N., 1936, Sulphur, *in* Mineral resources of region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 148-149.

Mount, Priscilla, 1964, Sulfur, *in* Mineral and water resources of Utah: Utah Geol. and Mineralog. Survey Bull. 73, p. 228-232.

Nackowski, M. P., S. D. Brown and J. M. Botbol, 1962, Alunite annotated bibliography: Univ. of Utah Bull., v. 53, no. 27 (Utah Eng. Experiment Sta. Bull., no. 124).

Nolan, T. B., 1943, The Basin and Range Province in Utah, Nevada, and California: U. S. Geol. Survey Prof. Paper 197-D.

Osmond, J. C., 1960, Tectonic history of the Basin and Range Province, in Utah and Nevada: Min. Eng., v. 12, no. 3, p. 251-265.

Palache, Charles, Harry Berman and Clifford Frondel, 1949, Alunite series, *in* The system of mineralogy, seventh ed. of J. D. Dana and E. S. Dana, v. 11: John Wiley and Sons, Inc., Chapman and Hall, Ltd., London, p. 556-560.

Parker, R. L., 1954, Alunitic alteration at Marysvale, Utah: U. S. Geol. Survey Open-file Rept.; Ph. D. thesis, Columbia Univ.

_____1962, Isomorphous substitution in natural and synthetic alunite: Am. Min., v. 47, p. 127-136.

_____1964, Alunite, *in* Mineral and water resources of Utah: Utah Geol. and Mineralog. Survey Bull. 73, p. 151-154.

Penfield, S. L., 1885, Crystallized tiemannite and metacinnabarite: Am. Jour. Sci., ser. 3, v. 29, p. 449-451.

Proctor, P. D., 1943, Geology of the Bulley Boy mine, Piute County, Utah: M. S. thesis, Cornell Univ.

Prokopovich, N. P. and L. L. Resler, 1973, Epigenetic alunite pisolites formed by natural gas, western Merced County, California: Preprint of a paper presented at the Rocky Mountain Section meetings of American Association of Petroleum Geologists, Salt Lake City, Utah, March, 1973.

Raymond, R. W., 1847, Statistics of mines and mining in the states and territories west of the Rocky Mountains: U. S. Treasury Dept., Wash., 6th Ann. Rept.

Richardson, G. B., 1908, Antimony in southern Utah: U. S. Geol. Survey Bull. 340-D, p. 253-256.

Ritzma, H. R., 1972, Six Utah "Hingeline" wells Utah–Plateau-Basin and Range transition zone, central Utah: Utah Geol. Assoc. Publ. 2, p. 75-90.

Rodriguez, E. L., 1960, Economic geology of the sulphur deposits at Sulphurdale, Utah: M. S. thesis, Univ. of Utah, 74 p.

Romney, M. P., 1963, Historical review of mining in Utah: Min. Cong. Jour., v. 49, no. 5.

Ross, C. S. and R. L. Smith, 1960, Ash-flow tuffs, their origin, geologic relations and identification: U. S. Geol. Survey Prof. Paper 366, 81 p.

Rovirosa, N. Y., 1965, La Alunita [Recopilacion y analisis de estudios de los yacimientos mexicanos y de los procesos para su aprovechamiento]: Nacional Financiera, S. A. Fideicomiso De Minerales No Metalicos, 190 p.

Russell, I. C., 1883, Sulphur deposits of Cove Creek, Utah: Am. Jour. Sci., v. 125 (3 S,25), p. 158.

Sandberg, G. W., 1966, Groundwater resources of selected basins in southwest Utah: Utah State Engineer Tech. Publ. 13, 46 p.

Schnable, R. W., 1955, The uranium deposits of the United States: U. S. Geol. Survey Min. Inv. Map MR-2.

Silberman, M. L. and R. P. Ashley, 1970, Age of ore deposition at Goldfield, Nevada from potassium-argon dating of alunite: Econ. Geol., v. 65, p. 352-354.

Smith, R. L., 1960a, Ash flows: Geol. Soc. Am. Bull., v. 71, p. 795-842.

_____1960b, Zones and zonal variations on welded ash flows: U. S. Geol. Survey Prof. Paper 345 F.

Smith, T. L., 1957, The geology of Antimony Canyon area, Garfield and Piute counties, Utah: M. S. thesis, Univ. of Utah, 39 p.

Speiker, E. M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U. S. Geol. Survey Prof. Paper 205-D.

_____1949, The transition between the Colorado Plateaus and the Great Basin in central Utah: Utah Geol. Soc. Guidebook, no. 4, 106 p.

Stokes, W. L., J. A. Peterson and M. D. Picard, 1955, Correlation of Mesozoic formations of Utah: Am. Assoc. Petrol. Geol., v. 39, no. 10, p. 2003-2019.

Taylor, A. O. and others, 1951, Geology and uranium deposits of Marysvale, Utah: U. S. Atomic Energy Comm. RMO-896.

Thoenen, J. R., 1941, Alunite resources of the United States: U. S. Bur. Mines Rept. Inv. 3561.

Thompson, R. B., 1937, Utah sulphur industries: Compass, v. 17, p. 166-169.

Thornburg, W. D., 1965, Regional geomorphology of the United States: New York, Wiley, 609 p.

Thurston, W. R. and others, 1954, Fluorspar deposits of Utah: U. S. Geol. Survey Bull. 1005.

Traver, W. M., 1949, Investigation of Coyote Creek antimony deposits, Garfield County, Utah: U. S. Bur. Mines Rept. Inv. 4470.

U. S. Bureau of Mines, 1946, Minerals Yearbook.

_____1947, Minerals Yearbook.

U. S. Bureau of Mines and U. S. Geological Survey, 1948, Mineral resources of the United States: Washington, D. C., Public Affairs Press, 212 p.

U. S. Geological Survey, 1971, Aeromagnetic map of west part of west AA central Utah: Open-file map (39°30'–40°45' and 112°00'–114°05').

_____1972a, Aeromagnetic map of parts of the Richfield and Cedar City 1° by 2° quadrangles, Utah: Open-file map (37°00'–39°30' and 112°30'–114°00').

_____1972b, Aeromagnetic map of parts of the Delta and Richfield 1° by 2° quadrangle, Utah: Open-file map (38°30'–39°30' and 112°00'–114°00').

Utah Geological and Mineralogical Survey, circa 1966, Geologic map of Utah: Utah Geol. and Mineralog. Survey Map 23.

Utah Mining Association, 1959, Utah's mining industry (an historical, operational and economic review): Utah Mining Assoc., p. 24-27, 41, 58-60, 75-77.

Van Sant, J. N., 1964, Refractory-clay deposits of Utah: U. S. Bur. Mines Rept. Inv. 8213.

Walker, G. W. and F. W. Osterwald, 1956a, Relation of secondary uranium minerals to pitchblende-bearing veins at Marysvale, Piute County, Utah, *in* Geology of uranium and thorium: Internat. Conf. for the Peaceful Uses of Atomic Energy, Geneva, Prog., v. 6, p. 263, 287.

_____1956b, Relation of secondary uranium minerals to pitchblende-bearing veins at Marysvale, Piute County, Utah: U. S. Geol. Survey Prof. Paper 300, p. 123-129.

Welsh, J. E., 1972, Upper Paleozoic stratigraphy plateau–Basin and Range transition zone central Utah-Plateau-Basin and Range transition zone, central Utah: Utah Geol. Assoc. Publ. 2, p. 13-20.

White, D. E., 1962, Antimony in the United States: U. S. Geol Survey Min. Inv. Res. Map MR-20.

Wideman, F. L., 1957, A reconnaissance of sulphur resources in Wyoming, Colorado, Utah, New Mexico and Arizona: U. S. Bur. Mines Inf. Circ. 770, p. 28-37.

Willard, M. E. and E. Callaghan, 1962, Geology of the Marysvale quadrangle, Utah: U. S. Geol. Survey Map GQ-154.

Willard, M. E. and P. D. Proctor, 1946, White Horse alunite deposit, Marysvale, Utah: Econ. Geol., v. 41, p. 619-643.

Williams, P. L., 1972, Map showing landslides and areas of potential landsliding in the Salina quadrangle, Utah: U. S. Geological Survey Map I-591.

Williams, P. L. and R. J. Hackman, 1971, Geology, structure and uranium deposits of the Salina quadrangle, Utah: Misc. Geol. Inv. Map I-591.

Wollard, L. E. and P. F. Kerr, 1951, Preliminary memorandum on the Dark Horse and Saturday areas, Marysvale, Utah: U. S. Atomic Energy Comm. RMO-860, 15 p.

Woolley, R. R., 1947, Utilization of surface-water resources of Sevier Lake Basin, Utah: U. S. Geol. Survey Water-Supply Paper 920, 393 p.

Wyant, D. G., 1951, The East Slope No. 2 uranium prospect, Piute County, Utah: U. S. Atomic Energy Comm. TEM-211, pt. 1, 12 p.

Wyant, D. G. and F. Stugard, Jr., 1951, U. S. Geol. Survey Open-file Rept.

Young, R. A., 1960, Groundwater areas and well logs, central Sevier Valley, Utah: U. S. Geol. Survey Open-file Rept., 21 p.

Young, R. A. and C. H. Carpenter, 1965, Groundwater conditions and storage in the central Sevier Valley, Utah: U. S. Geol. Survey Water-Supply Paper 1787, 95 p.

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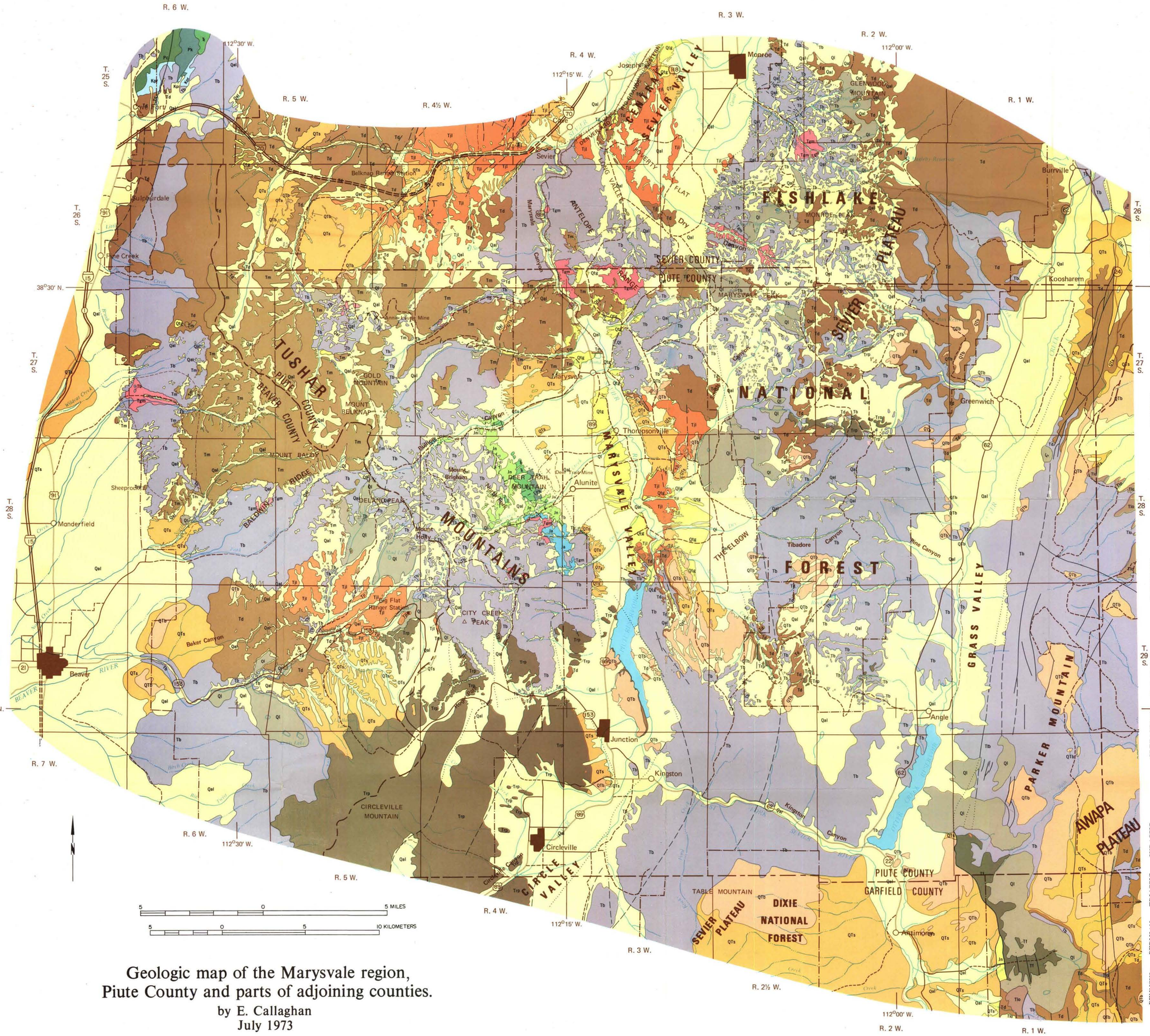

EXPLANATION

PLEISTOCENE HOLOCENE

- **Qal:** *Talus, slope wash, fan and stream deposits*
- **Qtg:** *Gravel above present drainage*
- **Ql:** *Landslide debris*

PLIOCENE

- *Basalt flows interlayered with or above Sevier River Formation*
- **Sevier River Formation** — *Partly consolidated fanglomerate, sand and silt mainly of local origin.*

MIOCENE

- **Joe Lott tuff** — *Light gray ashy tuff with rhyolite fragments.*
- **Mt. Belknap rhyolite** — *Reddish brown tuffaceous rhyolite and welded tuff and local occurrences of gray flow structure rhyolite.*
- **Osirus tuff of Awapa Plateau** — *Welded crystal ashflow tuff.*
- **Dry Hollow Formation** — *Reddish brown and gray porphyritic latite; reddish brown crystal ashflow tuff; gray basaltic andesite, locally vesicular. Thick in northeastern portion of map area.*
- **Roger Park basaltic breccia** — *Brownish black to olive black vesicular breccia of basaltic andesite composition.*

Unconformity

OLIGOCENE

- *Quartz monzonite and associated intrusive rocks*
- **Bullion Canyon volcanics** — *Latite tuff, breccia and minor flows containing locally blocks of quartzite and conglomerate; hornfelsed near intrusives, extensively altered and contains precious–base metal veins and alunite deposits.*

Unconformity

PALEOCENE

- **Flagstaff Formation** — *Includes Tertiary conglomerate of Tushar Mtns. and conglomerate sandstone, shale and minor limestone of Antimony Canyon.*

Unconformity

CRETACEOUS

- **Price River Formation** — *Conglomerate composed of Paleozoic quartzite and limestone boulders overlying thrust faults in SE Millard County.*

Unconformity

JURASSIC

- **Arapien Formation** — *Red sandstone, red and gray shale and gray limestone.*
- **Navajo Sandstone** — *Mostly light brownish gray quartzite*

TRIASSIC

- **Chinle and Moenkopi Formations** — *Red shale, siltstone and sandstone. Some conglomerate sandstone*

PERMIAN

- **Kaibab, Toroweap and Queantoweap (Talisman) formations** — *Limestone, sandstone, shale, dolomite and quartzite.*

PENNSYLVANIAN

- **Callville Limestone** — *Limestone, shale and sandstone*

Geologic map of the Marysvale region, Piute County and parts of adjoining counties.

by E. Callaghan
July 1973

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PLATE 2. MINERAL OCCURRENCES AND MINES, QUARRIES AND PITS OF THE MARYSVALE REGION, PIUTE, BEAVER, MILLARD, SEVIER AND GARFIELD COUNTIES. MINING DISTRICTS ARE OUTLINED.

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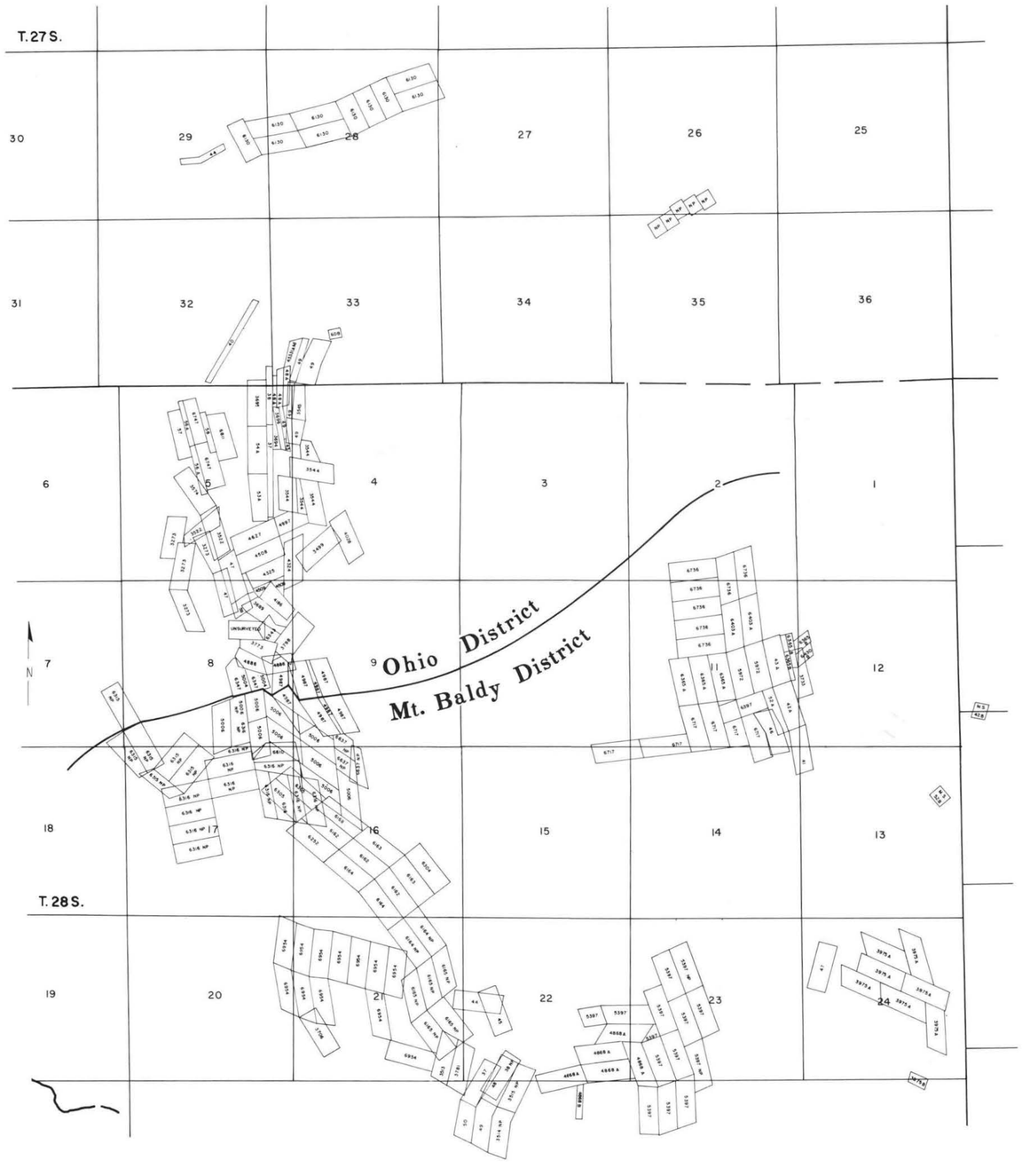
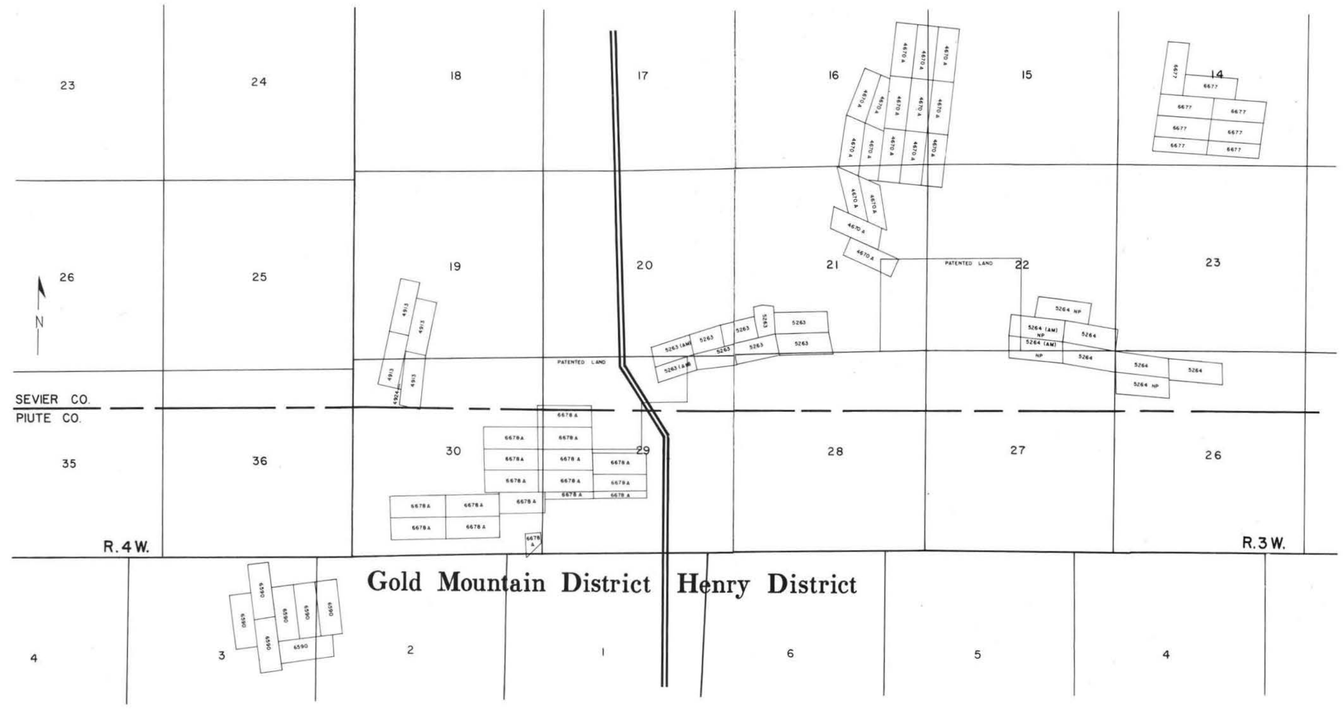
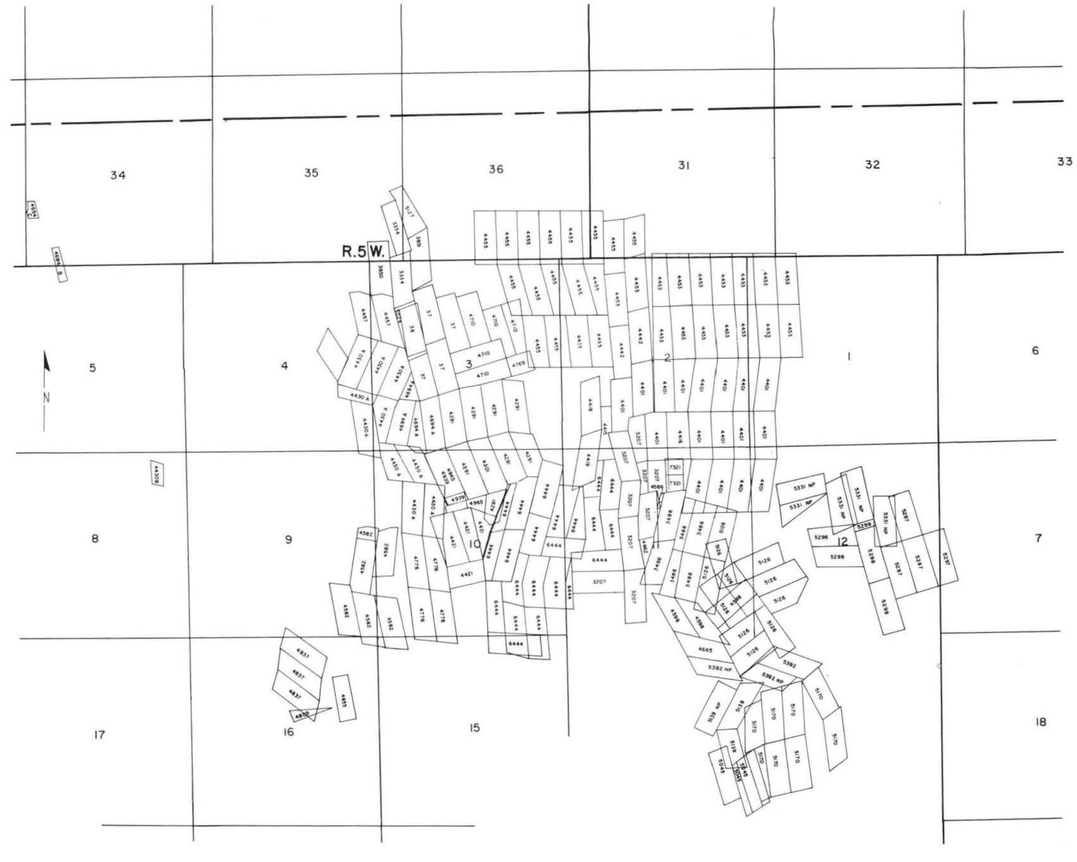
PLATE 3. PATENTED CLAIMS AND CLAIMS SURVEYED FOR PATENT (NP) IN GOLD MOUNTAIN, HENRY, OHIO AND MT. BALDY MINING DISTRICTS OF THE MARYSVALE REGION (see figure 17 for Gordon mining district).



Mt. Baldy mining district



Henry mining district and eastern part of Gold Mountain district



Gold Mountain mining district

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Plat books of State Division of Lands should be consulted for status of Mineral Rights

LAND STATUS MAP OF MARYSVALE REGION, PIUTE, BEAVER, MILLARD, SEVIER AND GARFIELD COUNTIES

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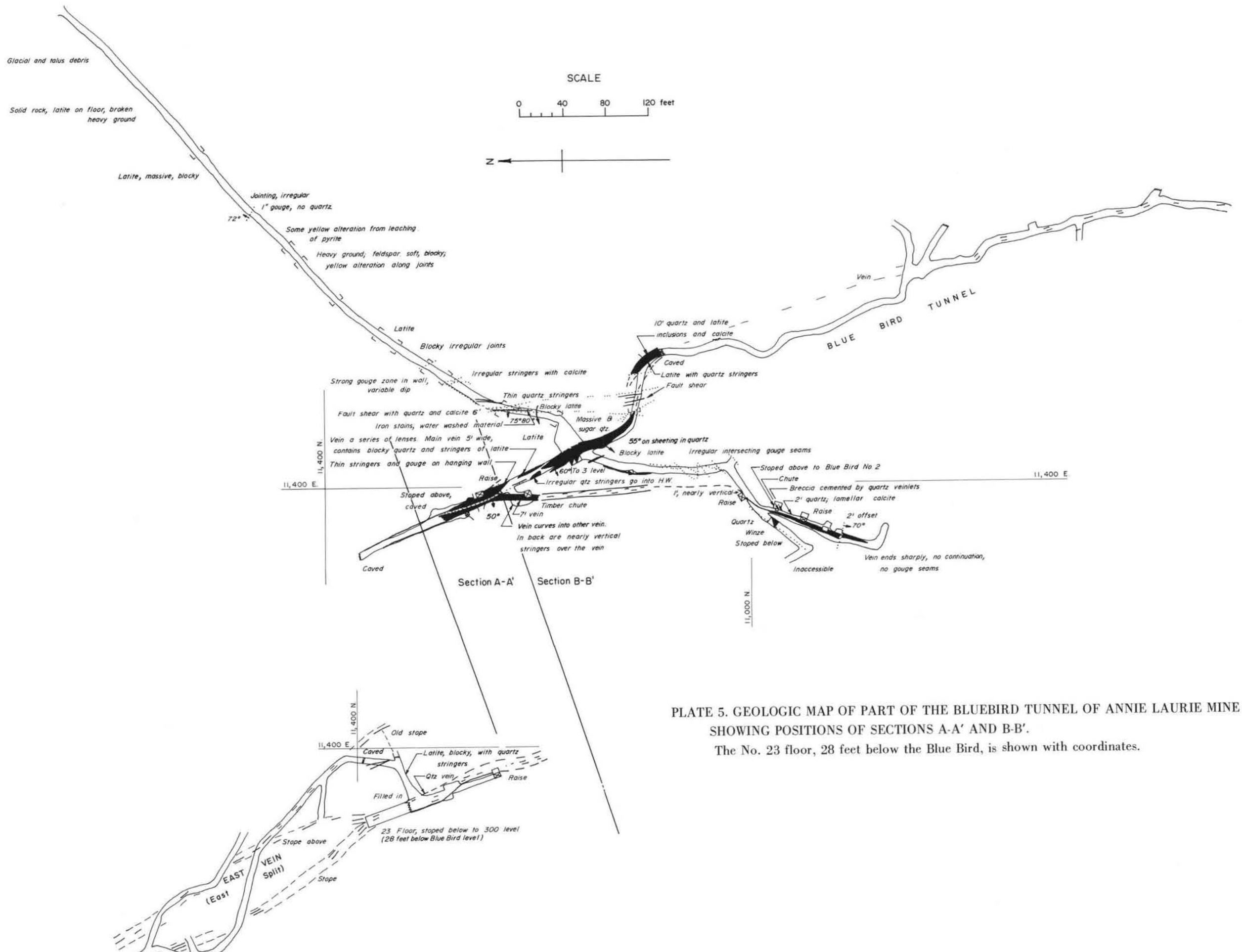

PLATE 5. GEOLOGIC MAP OF PART OF THE BLUEBIRD TUNNEL OF ANNIE LAURIE MINE SHOWING POSITIONS OF SECTIONS A-A′ AND B-B′.

The No. 23 floor, 28 feet below the Blue Bird, is shown with coordinates.

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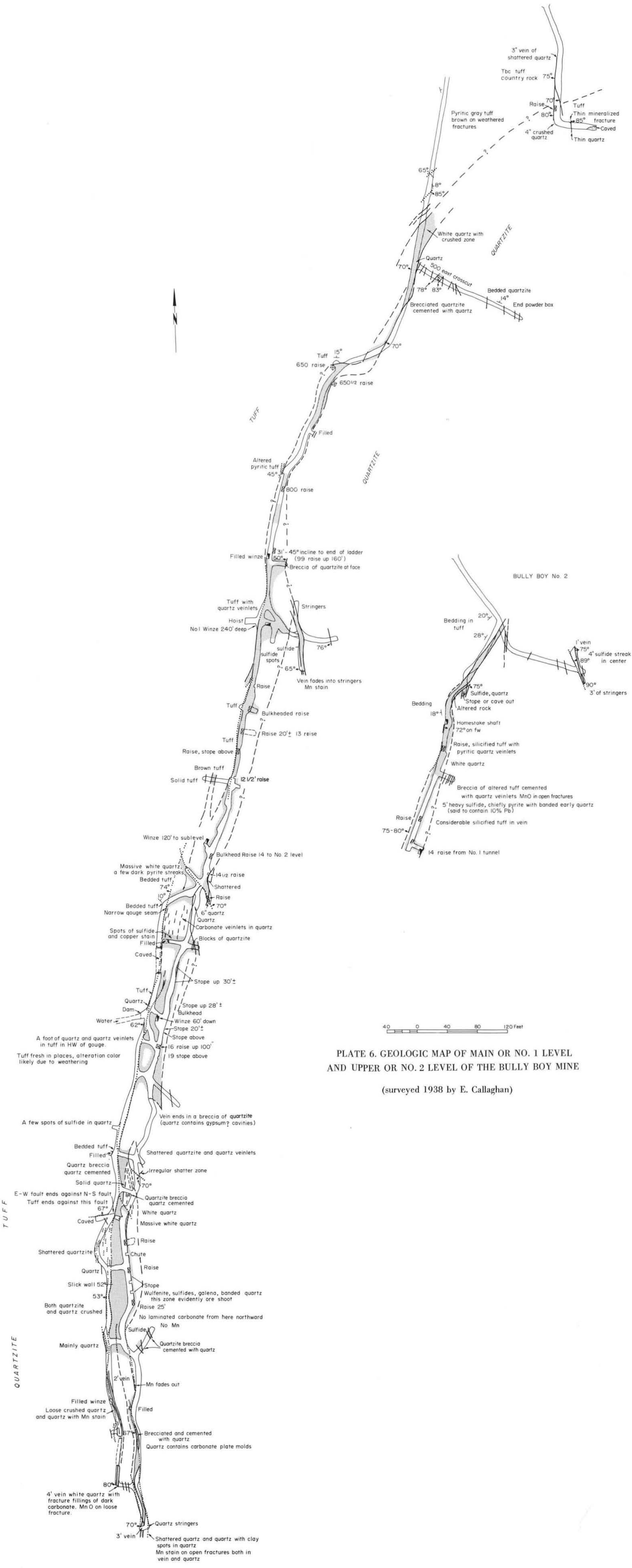

PLATE 6. GEOLOGIC MAP OF MAIN OR NO. 1 LEVEL AND UPPER OR NO. 2 LEVEL OF THE BULLY BOY MINE

(surveyed 1938 by E. Callaghan)

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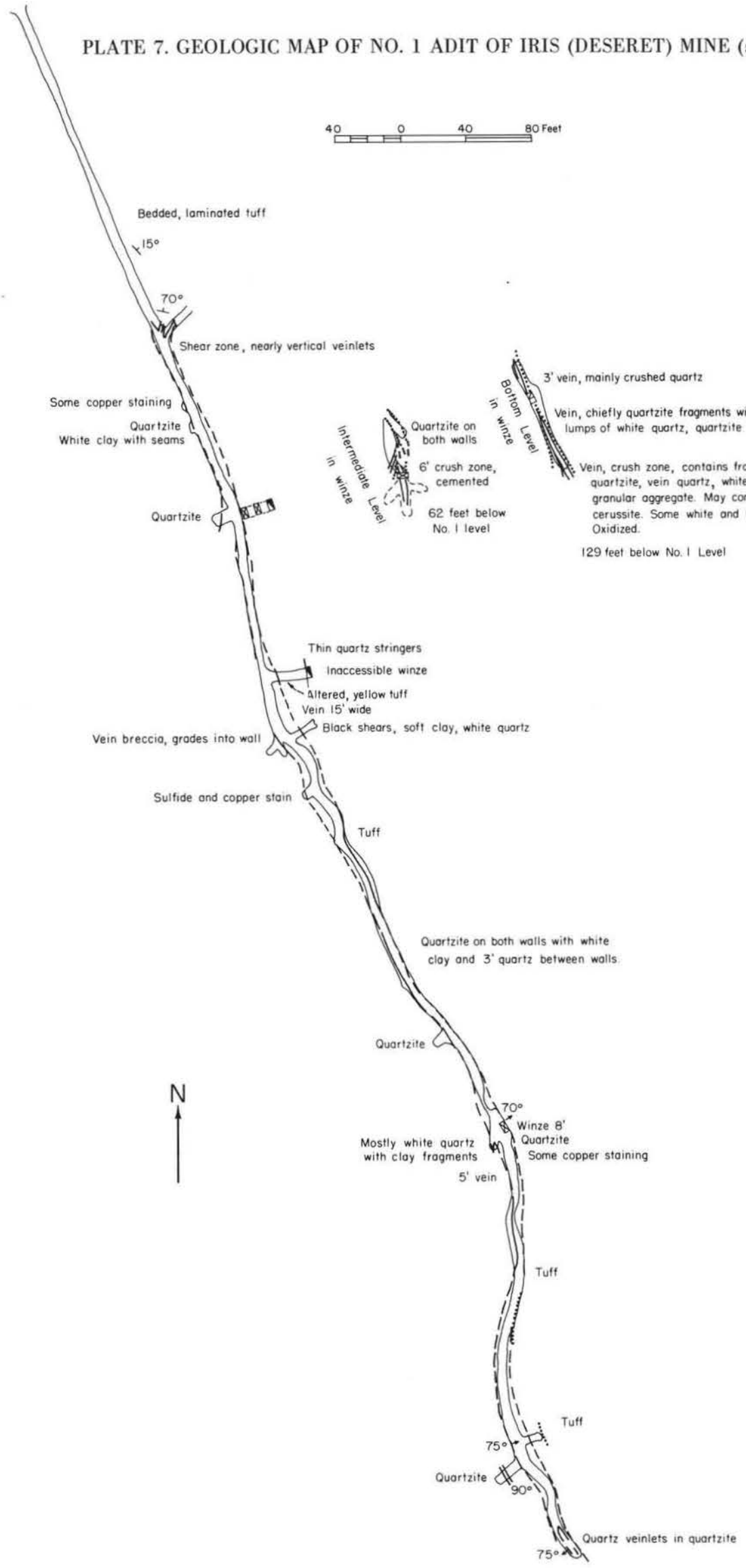
PLATE 7. GEOLOGIC MAP OF NO. 1 ADIT OF IRIS (DESERET) MINE (surveyed 1938 by E. Callaghan)



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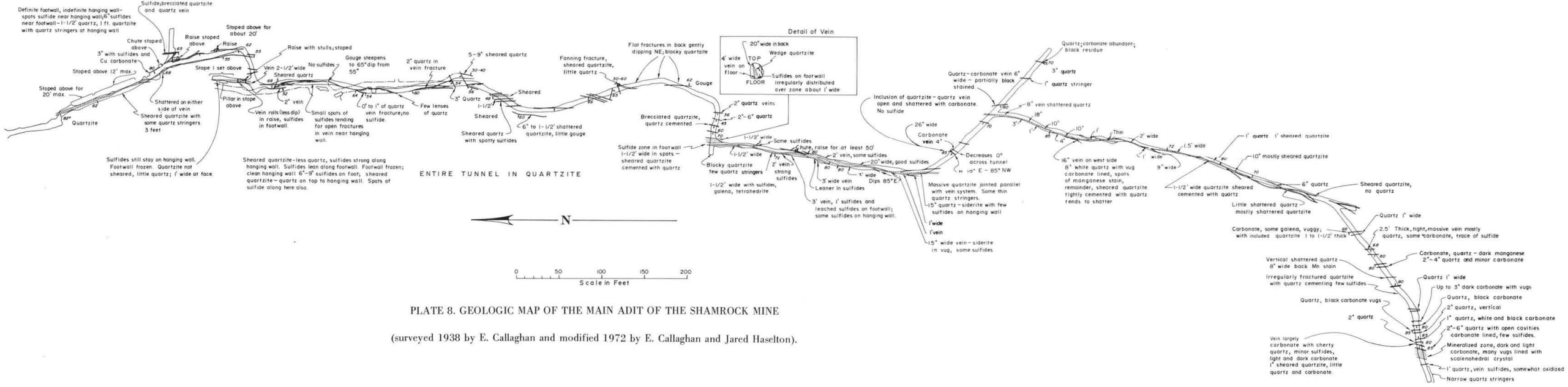

PLATE 8. GEOLOGIC MAP OF THE MAIN ADIT OF THE SHAMROCK MINE

(surveyed 1938 by E. Callaghan and modified 1972 by E. Callaghan and Jared Haselton).

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1 0 1 MILE

EXPLANATION

CENOZOIC

Quaternary

- Qal — Alluvial and Colluvial Deposits
- Qls — Landslide Deposits
- QTb — Olivine Basalt

Tertiary

- Tvs — Sevier River Formation
  Sediments derived from volcanics
- Tla — **Tuff of Osiris where differentiated**

CENOZOIC

Tertiary

- Tla — **Latite and basaltic andesite flows where differentiated**
- Tola — Tuff of Osiris, latite and basaltic andesite flows undifferentiated
  (Tlo, Tla, Tola equivalent to Dry Hollow Formation)
- Tvb — Bullion Canyon Volcanics
  Andesite breccia

Unconformity?

- Tfc — Flagstaff Formation, Unit c
- Tfb — Unit b
- Tfa — Unit a

Unconformity?

MESOZOIC

Jurassic

- Jc — Carmel Formation
- Jn — Navajo Sandstone

Unconformity?

Triassic?

- Rc — Chinle Formation

PLATE 9. GEOLOGIC MAP OF ANTIMONY CANYON AREA
(compiled from geologic map of Salina quadrangle by Williams and Hackman, 1971, and MS thesis map by Smith, 1957)
Adjusted to 1/24,000 topographic base Angle, Flossie Knoll, Antimony and Pollywog Lake quadrangles of U. S. Geological Survey.

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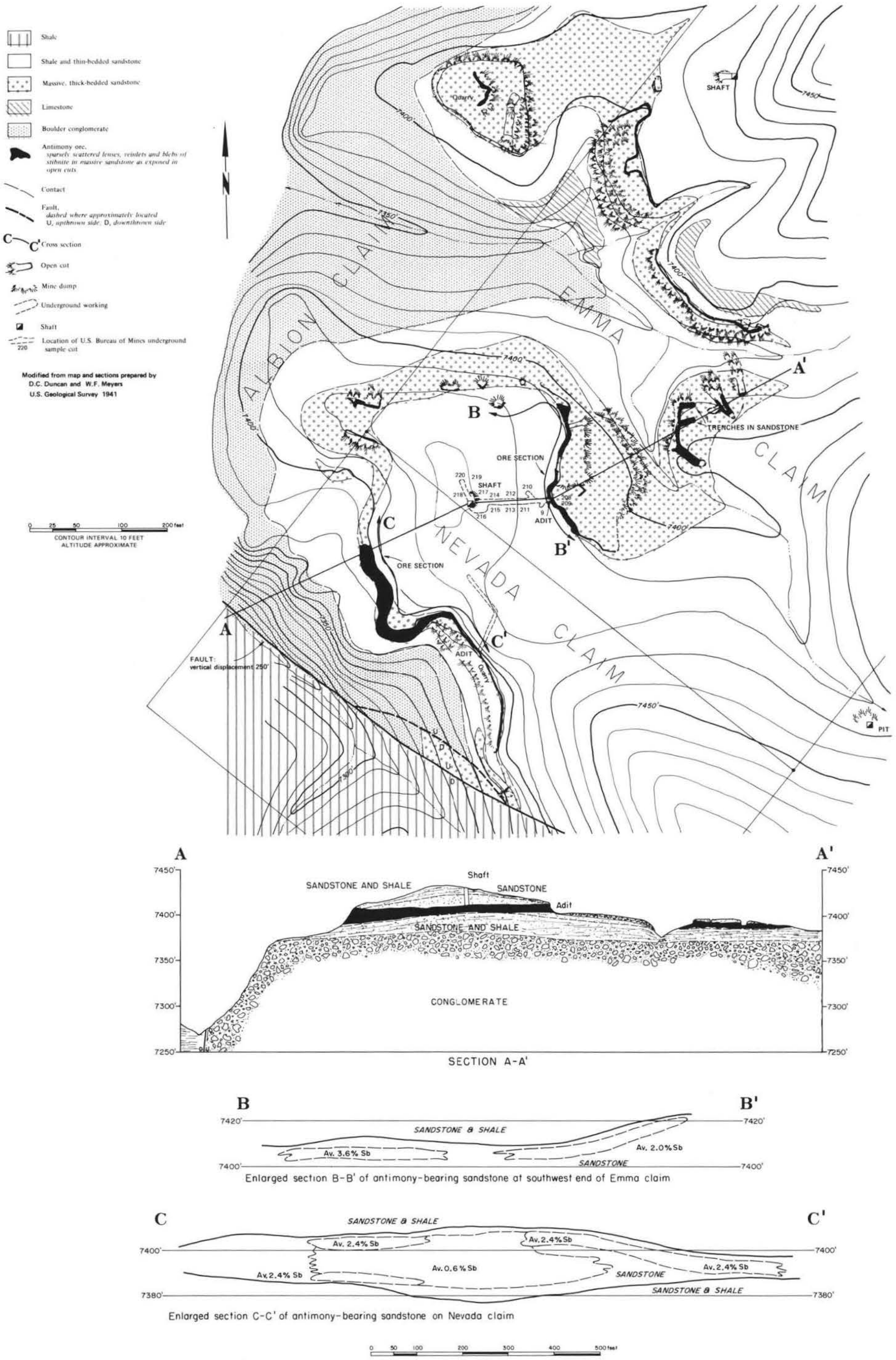

PLATE 10. GEOLOGIC MAP AND SECTIONS OF ANTIMONY WORKINGS ON PARTS OF NEVADA, EMMA (LITTLE EMMA) AND ALBION CLAIMS

(modified from map and sections prepared by D. C. Duncan, W. H. Myers, U. S. Geological Survey; surveyed 1941)

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PLATE 11. GEOLOGIC MAP SHOWING DISTRIBUTION OF ANTIMONY ORE CONCENTRATIONS IN SANDSTONE ON STEBINITE, STELLA, AND WEST END OF MAMMOTH CLAIMS
(modified from map by F. M. Byers, D. C. Duncan, W. H. Myers, U. S. Geological Survey; surveyed 1941).

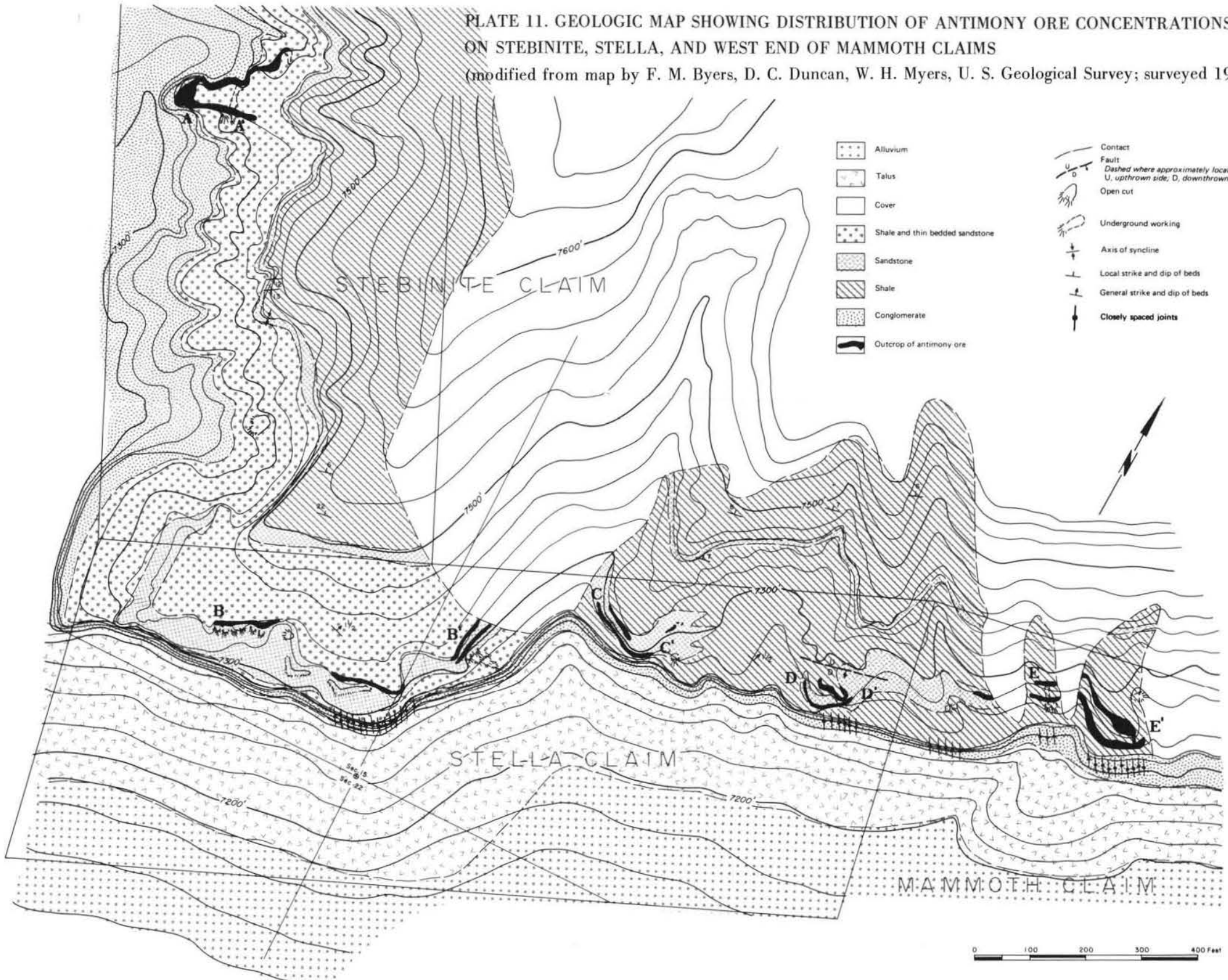

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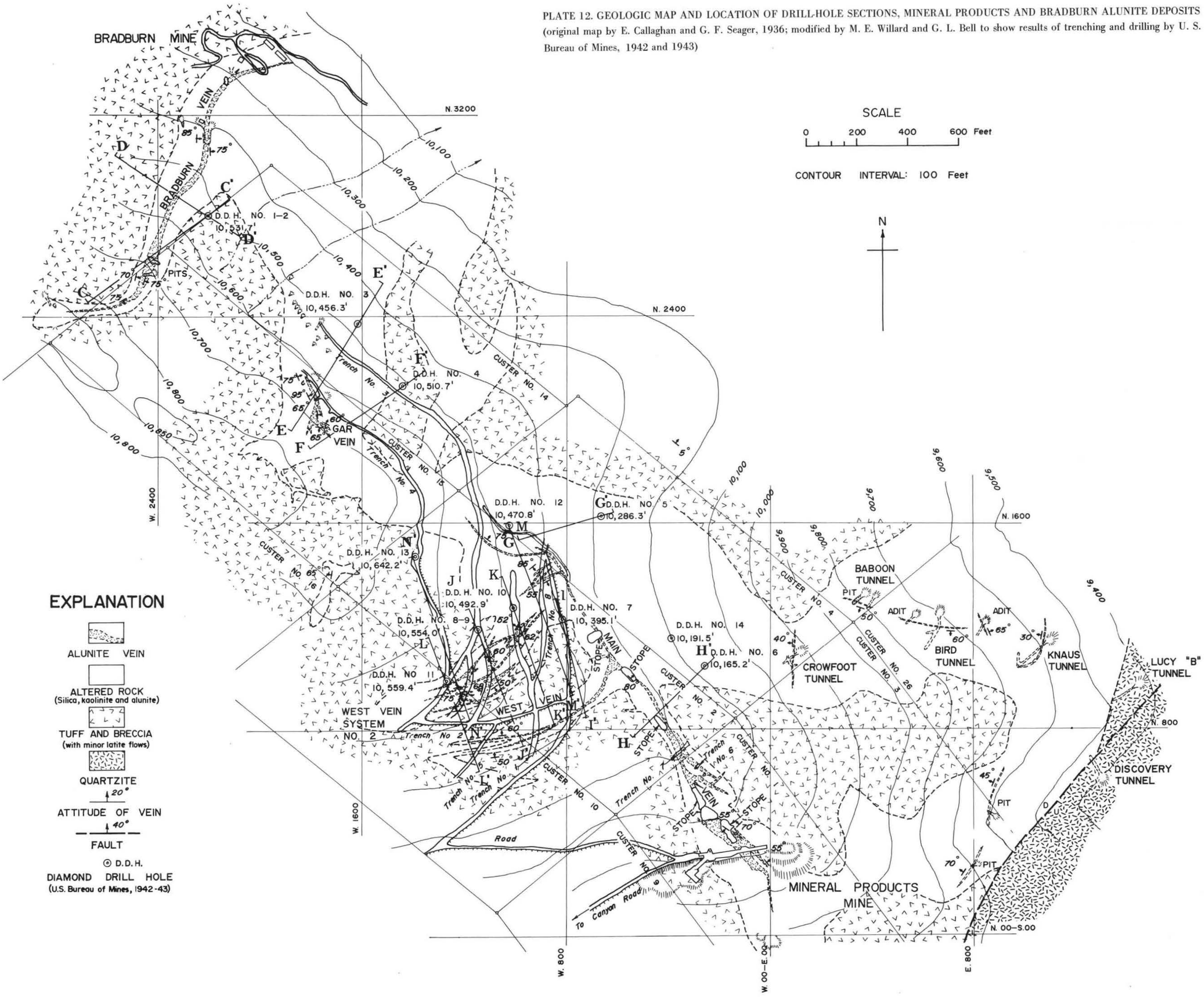
PLATE 12. GEOLOGIC MAP AND LOCATION OF DRILL-HOLE SECTIONS, MINERAL PRODUCTS AND BRADBURN ALUNITE DEPOSITS (original map by E. Callaghan and G. F. Seager, 1936; modified by M. E. Willard and G. L. Bell to show results of trenching and drilling by U. S. Bureau of Mines, 1942 and 1943)



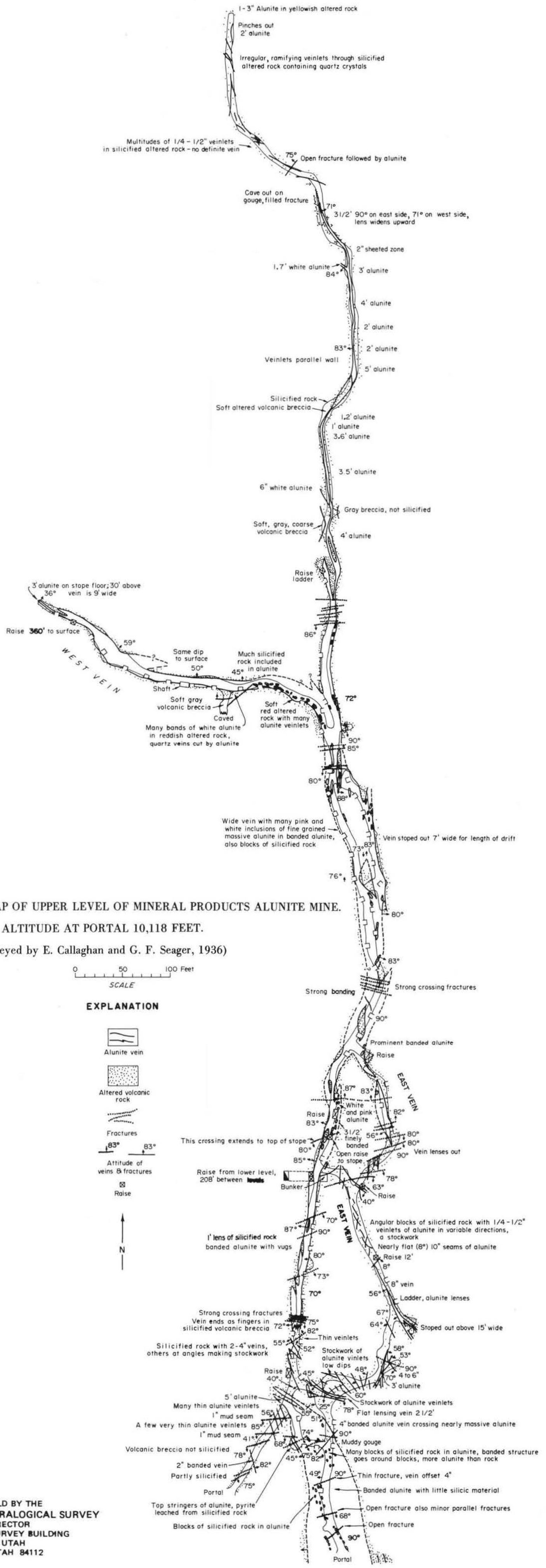


PLATE 13. GEOLOGIC MAP OF UPPER LEVEL OF MINERAL PRODUCTS ALUNITE MINE.

ALTITUDE AT PORTAL 10,118 FEET.

(Surveyed by E. Callaghan and G. F. Seager, 1936)

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BULLETIN 102 PLATE 14

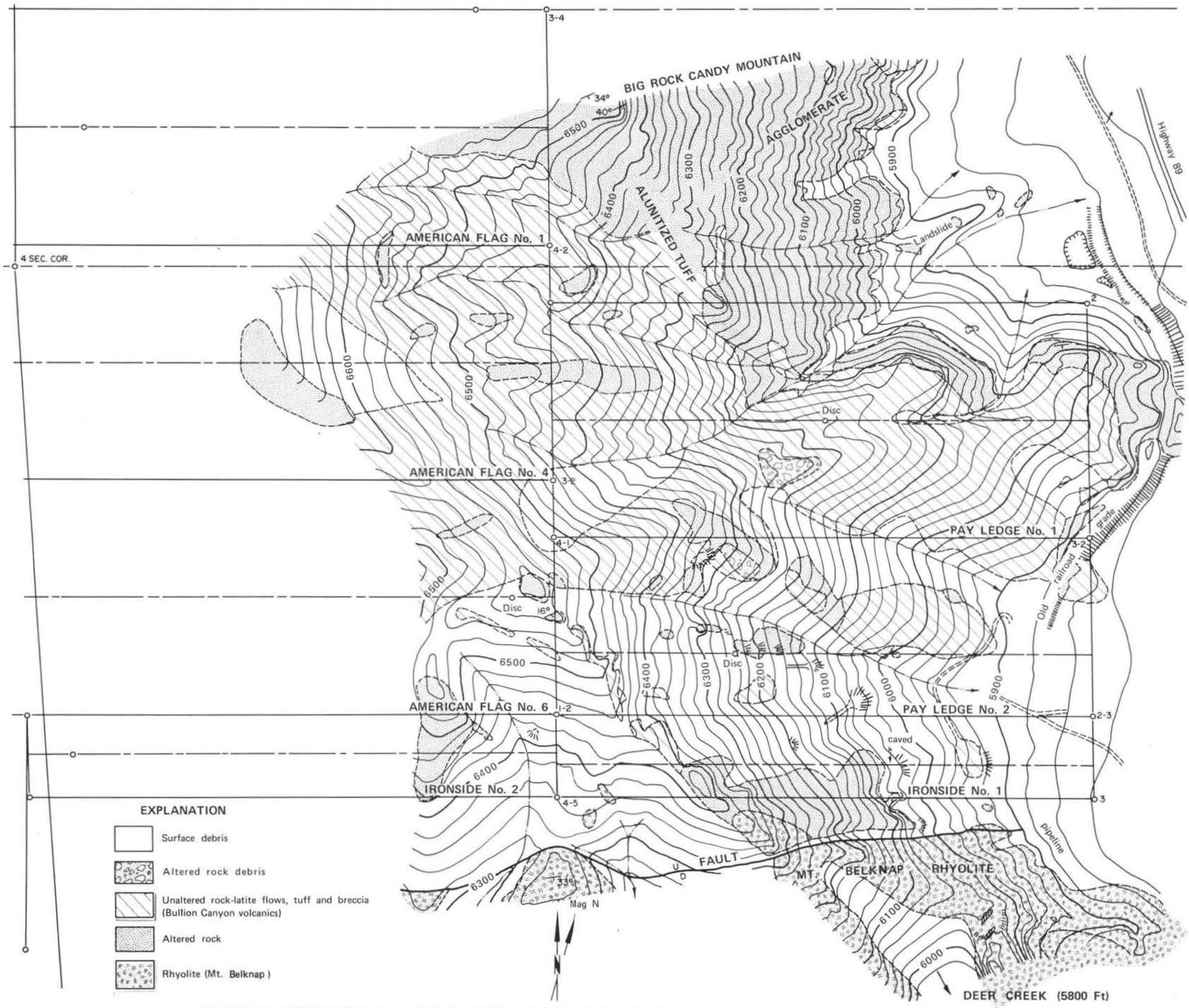

PLATE 14. GEOLOGIC MAP OF EASTERN PART OF PITTSBURGH ALUNITE DEPOSIT
(topography and geology by V. C. Kelley and E. Callaghan, surveyed 1938).

Scale
0 50 100 500 1000 feet

Contour interval 20 feet
1"=200'

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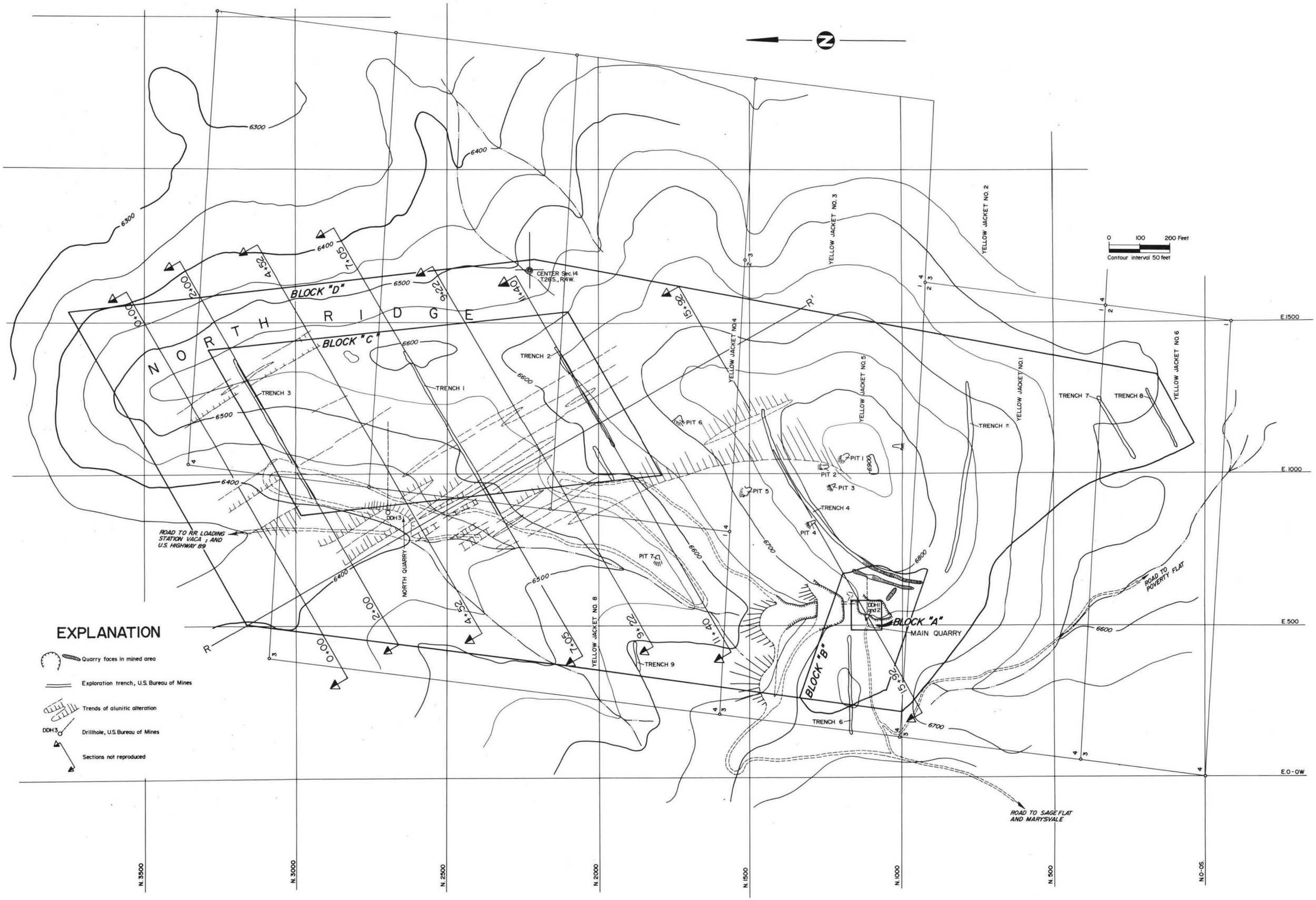

PLATE 15. EXPLORATION MAP OF YELLOW JACKET ALUNITE DEPOSIT SHOWING LOCATION OF U. S. BUREAU OF MINES TRENCHES AND DRILL HOLES (adapted from map by G. L. Bell, 1945).

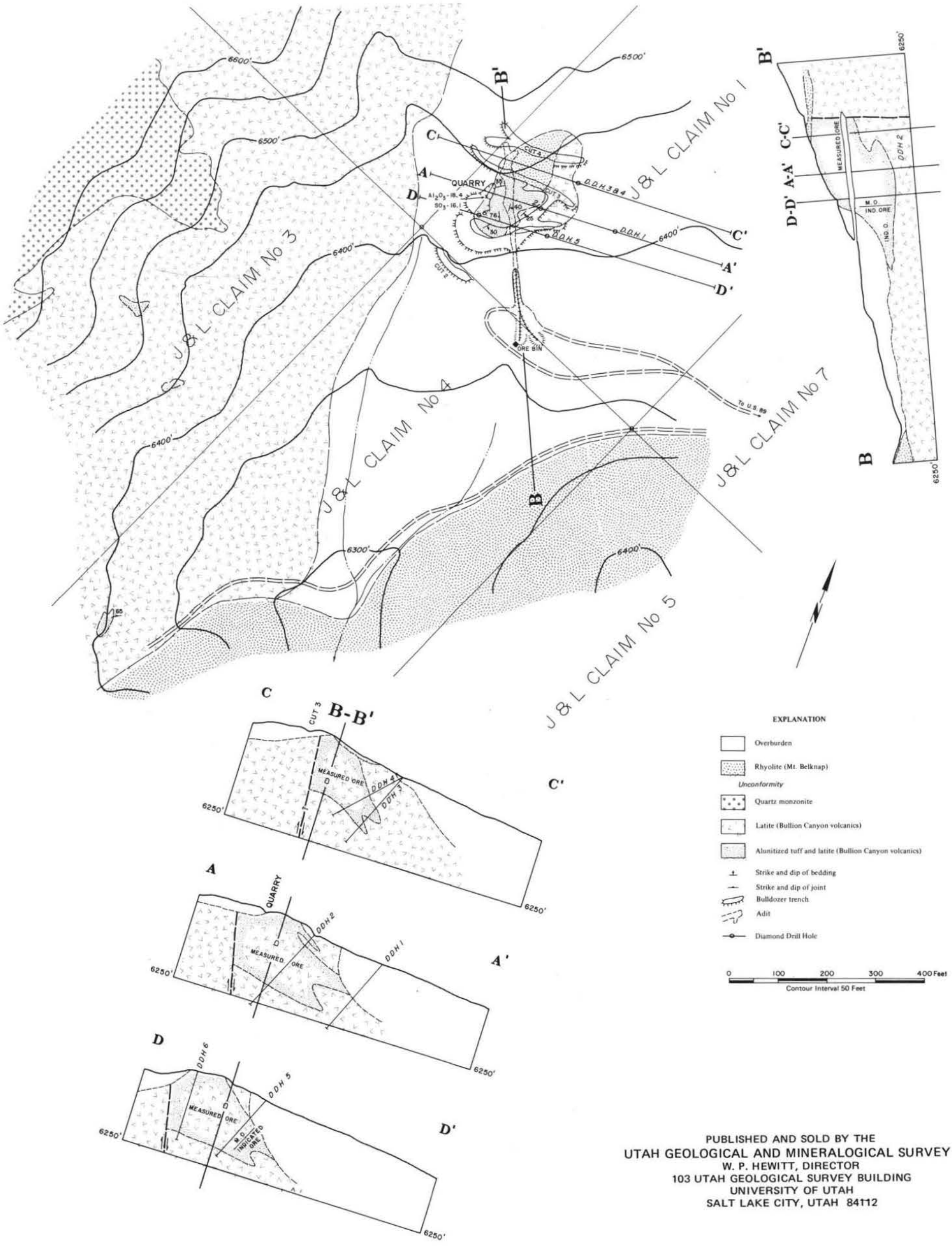

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PLATE 16. GEOLOGIC MAP AND SECTIONS OF J&L ALUNITE DEPOSIT (geology by V. C. Kelley, 1938, and G. L. Bell, 1943).