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Multiple Episodes of Igneous Activity, Mineralization, and Alteration in the Western Tushar Mountains, Utah

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ABSTRACT

Igneous activity in the Marysvale volcanic field of western Utah can be separated into many episodes of extrusion, intrusion, and hydrothermal activity. The rocks of the western Tushar Mountains, near the western part of the volcanic field, include early intermediate-composition calc-alkalic volcanic rocks erupted from scattered volcanoes in Oligocene through earliest Miocene time, and related monzonitic intrusions emplaced 24-23 m.y. ago. Beginning 22-21 m.y. ago and extending through much of the later Cenozoic, a bimodal basalt-rhyolite assemblage was erupted widely throughout the volcanic field. Only volcanic and intrusive rocks belonging to the rhyolitic end member of this bimodal assemblage are present in the western Tushar Mountains; most of these either fill the Mount Belknap caldera (19 m.y.) or are related to the rhyolite of Gillies Hill (9-8 m.y.).

Episodic hydrothermal activity altered and mineralized rocks at many places in the western Tushar Mountains during Miocene time. The earliest activity took place in and adjacent to monzonitic calc-alkalic intrusions emplaced in the vicinity of Indian Creek and Cork Ridge. These rocks were widely propylitized, and gold-bearing quartz-pyrite-carbonate veins formed in local fractures. Hydrothermal activity associated with the Mount Belknap caldera mobilized and redeposited uranium contained in the caldera-fill rocks and formed primary concentrations of lithophile elements (including molybdenum and uranium) in the vicinity of associated intrusive bodies. Hydrothermal activity associated with the rhyolite of Gillies Hill altered and mineralized rocks at several places along the fault zone marking the western margin of the Tushar Mountains. The zoned alunite and gold deposits at Sheep Rock, the gold deposit at the Sunday Mine, and an alunite deposit near Indian Creek were thus produced. Resetting of isotopic ages suggests that another center of hydrothermally altered rocks associated with a buried pluton about 16 m.y. old may exist near Indian Creek just west of the Mount Belknap caldera. The mineral potential of the different hydrothermal systems, and the types of resources involved, probably vary considerably from one period of mineralization to another, and from one depth environment to another within a given system.

INTRODUCTION

Volcanic rocks in the western Tushar Mountains of west-central Utah (fig. 1) show widespread evidence of hydrothermal activity and local mineralization. The area has been prospected off and on for about 100 years and small quantities of gold, silver, lead, zinc, uranium, and alunite have been produced from numerous ore deposits. Although all known deposits are small, the extent of hydrothermally altered rocks near the deposits is sufficiently large to suggest that more substantial undiscovered ore deposits may exist. The area has been subjected to recurrent episodes of igneous intrusion, hydrothermal alteration, and mineralization, and the mineral-resource potential of the different mineralized areas is directly related to local geologic history. The mineral commodities to be expected vary from one hydrothermal system to another, and from one level to another within any given system. Uranium and molybdenum seem likely to have the greatest economic potential, although significant concentrations of gold may also exist.

The western Tushar Mountains lie near the western part of the Marysvale volcanic field. This volcanic field occurs at the eastern end of the Pioche-Marysvale mineral belt, which extends east-northeast from southeastern Nevada into west-central Utah. The western Tushar Mountains were first studied by Callaghan and Parker (1961) who began mapping in the late 1930's and completed it in the early 1950's. Preliminary investigations of some of the uranium occurrences were reported by Wyant and Stugard (1951). Callaghan (1973) discussed the area as part of a general review of the mineral deposits of Piute County, Utah. More recently, the U.S. Geological Survey (Steven and others, 1978a,b, 1979a, 1980; Cunningham and others, 1978, 1980, 1981; Cunningham and Steven, 1979a,b,c,d, 1980; Rowley and others, 1981a,b, and unpub. mapping; Anderson and others, 1980, 1981) remapped most of the Marysvale volcanic field at scales of 1:24,000 and 1:50,000, and pointed out many areas with potential for major undiscovered deposits of molybdenum, uranium, and base and precious metals. Tucker and others (1980, 1981) presented the results of a geochemical sampling program and considered their significance to the occurrence of mineral deposits. The present paper outlines the complex history of igneous activity and associated alteration and mineralization in the western Tushar Mountains, and points out implications for minerals exploration.

GEOLOGIC SETTING

Field relations and isotopic ages of rocks in the Marysvale volcanic field distinguish many episodes of extrusion, intrusion, and hydrothermal activity. Early calc-alkalic volcanic rocks, in part called Bullion Canyon Volcanics (Callaghan, 1939; Steven and others, 1979b), were erupted from scattered stratovolcanoes in Oligocene and earliest Miocene time; these gave way 22-21 m.y. ago to a bimodal assemblage of basaltic lava flows and rhyolitic lava flows and pyroclastic rocks. The basaltic rocks were erupted widely in low volume until late Pleistocene time. The rhyolites, on the other hand, formed a succession of local, small to large accumulations that were erupted episodically in one part of the volcanic field or another from early Miocene to Pleistocene time.

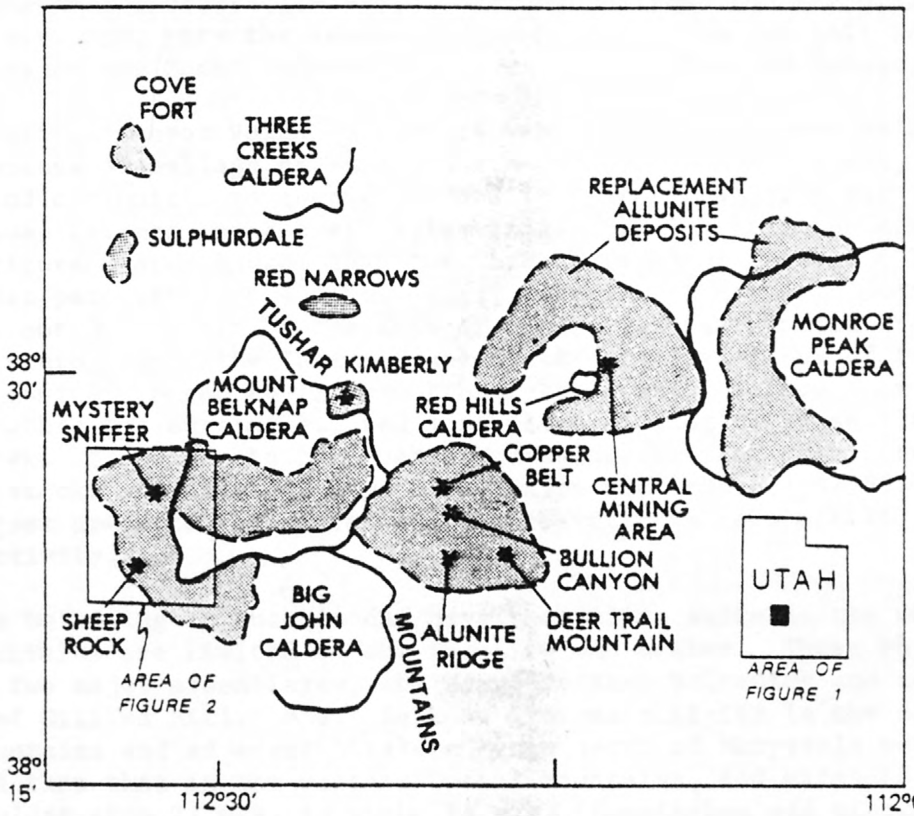

Figure 1.--Index map showing location of calderas, major mining centers (starred), and principal altered and mineralized areas (stippled) in and adjacent to the Tushar Mountains.

Calderas formed episodically at different places in the volcanic field in response to eruptions of silicic ash-flow tuff (fig. 1) of both the calc-alkalic and bimodal suites. These tuffs accumulated as nearly flat sheets whose tops provide convenient, well-dated, datum planes at different horizons within the volcanic field. The Three Creeks caldera formed 27 m.y. ago (Steven and others, 1979b) in response to the eruption of the Three Creeks Tuff Member of the Bullion Canyon Volcanics (Steven, 1982). The Osiris Tuff, erupted about 23 m.y. ago, had its source in the Monroe Peak caldera (Rowley and others, 1981a,b, and unpub. mapping); and the Delano Peak Tuff Member of the Bullion Canyon Volcanics was erupted shortly thereafter from the Big John caldera (Steven and others, 1979a). The Mount Belknap and Red Hills calderas, formed 19 m.y. ago, were the respective sources for the Joe Lott and Red Hills Tuff Members of the Mount Belknap Volcanics (Cunningham and Steven, 1979d).

The Bullion Canyon Volcanics in the western Tushar Mountains consists of a heterogeneous assemblage of intermediate-composition lava flows, volcanic breccia, and monzonitic to quartz monzonitic stocks that crop out between the Mount Belknap caldera and Beaver Valley (fig. 2). The Bullion Canyon rocks shown on figure 2 are younger than the Three Creeks Tuff Member (27 m.y.), and for the most part are only slightly older than the 23-m.y.-old Osiris Tuff that crops out just north of the area of figure 2. Near Indian Creek, a monzonite pluton named the Indian Creek Stock cuts lava flows of the Bullion Canyon Volcanics. Seven to 12 km north of the area of figure 2, monzonite stocks breached the surface and fed lava flows similar to those flanking Indian Creek. Elsewhere in the Tushar Mountains, similar monzonite and quartz monzonite stocks are about 23 m.y. old (Steven and others, 1979b), and were emplaced just prior to the petrologic changeover from calc-alkalic to bimodal igneous activity.

Rocks belonging to the bimodal basalt-rhyolite suite in the western Tushar Mountains are limited to the rhyolite end member. These rhyolites belong to two major assemblages, the Mount Belknap Volcanics and the younger rhyolite of Gillies Hill. Mount Belknap igneous activity in the eastern Tushar Mountains and adjacent Antelope Range north of Marysvale was much more long-lived than that in the western Tushar Mountains, and extended from slightly older than 21 m.y. to about 14 m.y. (Cunningham and others, 1982). Most rocks of the Mount Belknap Volcanics within the area of figure 2 were deposited within the Mount Belknap caldera after eruption of the Joe Lott Tuff Member (Cunningham and Steven, 1979d). Most are rhyolite lava flows and ash-flow tuff that filled the caldera and overflowed it. Late during caldera evolution, the intracaldera fill was cut by silicic stocks intruded mostly along the southern ring fracture of the caldera. The U-Beva stock, along the North Fork of North Creek (fig. 2), cuts the lava flows and domes of the Mount Baldy Rhyolite Member of the Mount Belknap Volcanics. The stock is characterized by prominent flow-alined sanidine phenocrysts. A fission-track age on zircon from it is 19.8±1.2 m.y. (table 1), which is within analytical uncertainty of the age of the caldera fill. Small rhyolite dikes of devitrified and altered glass located southwest of the caldera and trending parallel to the caldera wall, appear to be cone-sheet intrusions. A sample from one of these dikes gives a fission-track age on zircon of 20.3±0.9 m.y. (table 1, M336), also about the same age as the caldera fill. Apatite from the U-Beva stock (M330) gives an anomalously younger age of 13.4±2.7 m.y. and apatite from another of the dikes is 9.5±1.9 m.y. (table 1, M335) which indicates that some minerals in these rocks have been reset. (See section on Significance of Reset Isotopic Ages.)

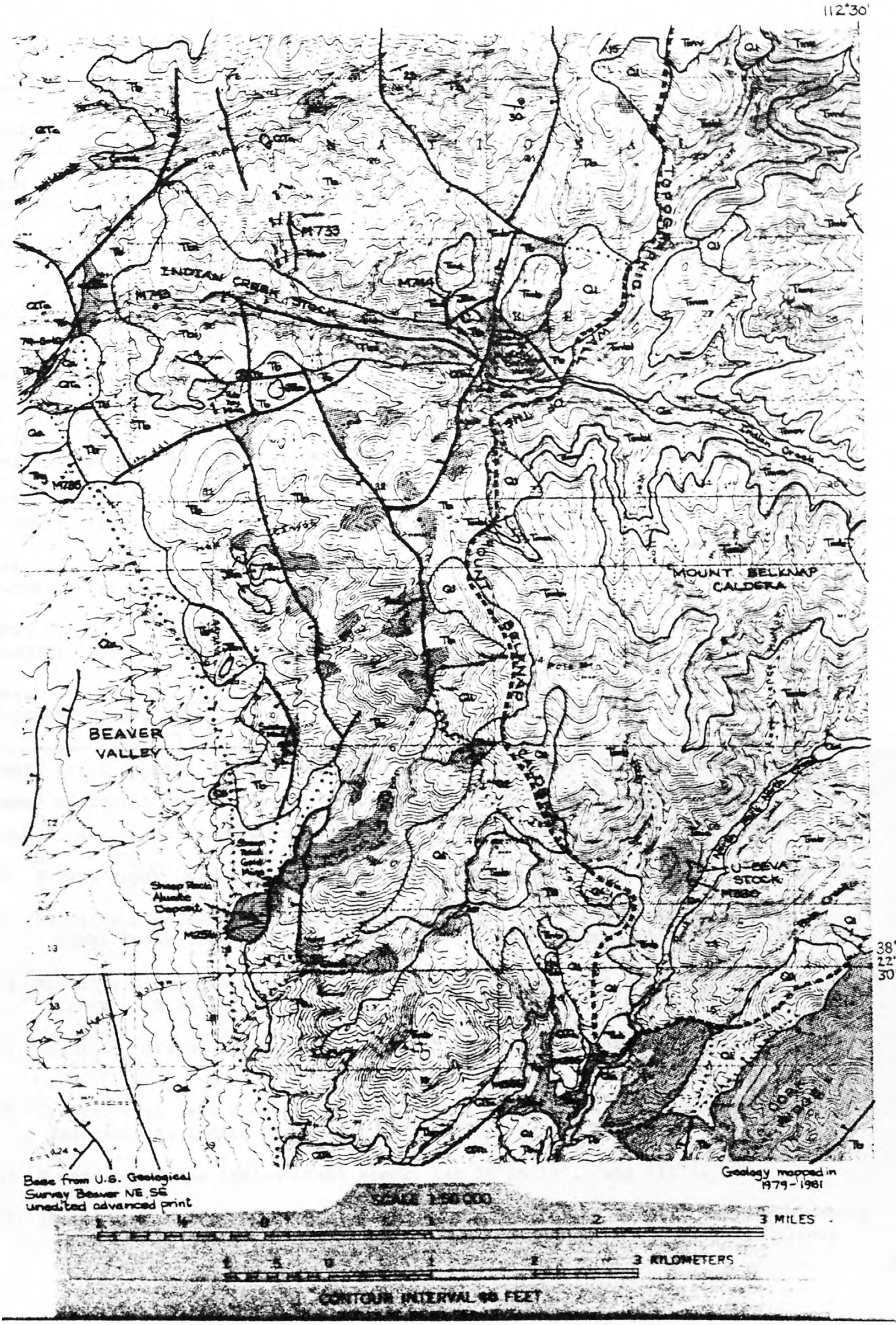

Figure 2.--Geologic map of the western Tushar Mountains, Utah, showing areas of argillic and advanced argillic alteration, mineralized rocks, and sample localities.

Table 1.--Data for fission-track ages of rocks

Sample	Rock Unit	Mineral	ρs[1]	No. tracks[2]	ρi[3]	No. tracks[4]	ϕ[5]	Age[6]	U (ppm)
M330 (DF-1745)	U-Beva stock	zircon	17.51	1135	31.72	1028	0.599	19.8±1.2	1500
M330 (DF-1746)	U-Beva stock	apatite	0.122	254	0.589	1227	1.08	13.4±2.7	16
M335 (DF-1747)	rhy dike	apatite	0.081	169	0.552	1151	1.08	9.5±1.9	15
M336 (DF-1748)	rhy dike	zircon	3.27	605	5.72	530	0.596	20.3±0.9	280
M733 (DF-2996)	rhy dike	zircon	3.86	536	14.75	1024	1.00	15.6±1.1	420
M735 (DF-2997)	lava flow	zircon	1.84	315	12.84	1100	0.985	8.4±0.6	380
M743 (DF-2998)	Tbi	zircon	6.41	890	19.43	1349	0.978	19.3±1.0	570
M743 (DF-3000)	Tbi	apatite	0.080	166	0.392	816	1.05	12.8±2.1	11
M744 (DF-2999)	rhy dike	zircon	5.41	651	19.47	1172	0.969	16.1±0.8	540

[1]Fossil track density (tracks/cm^2)x10^6

[2]Number of fossil tracks counted

[3]Induced track density (tracks/cm^2)x10^6

[4]Number of induced tracks counted

[5]Neutron dose (neutrons/cm^2)x10^{15}

[6]Age (m.y.) ± 2σ. $\lambda_F = 7.03 \times 10^{-17}$/yr

M330 U-Beva stock, along North Fork of North Creek; lat 38°22′57", long 112°31′10".

M335 Rhyolite dike cutting altered Bullion Canyon Volcanics along North Fork of North Creek; lat 38°21′25", long 112°31′55" (Anderson and others, 1981).

M336 Rhyolite dike cutting altered Bullion Canyon Volcanics near North Fork of North Creek; lat 38°21′17", long 112°32′22" (Anderson and others, 1981).

M733 Rhyolite dike on ridge between Wildcat and Indian Creeks; lat 38°26′30", long 112°33′50".

M735 Crystal-rich lava flow of the rhyolite of Gillies Hill from southwest of the entrance to Indian Creek; lat 38°25′15", long 112°35′20".

M743 Monzonite of the Indian Creek stock; lat 38°26′10", long 112°34′30".

M744 Rhyolite dike feeding overlying lava flow and cutting Bullion Canyon Volcanics west of the Mystery Sniffer mine, along Indian Creek; lat 38°26′15", long 112°33′00".

The rhyolite of Gillies Hill forms a series of nearly aphyric to crystal-rich rhyolite lava flows and domes that form low hills at the northern end of the Beaver Valley (Evans and Steven, 1982). The main source area (8 km northwest of the area of figure 2) is along the main fault separating the Mineral Mountains and Tushar Mountains structural blocks, where flows have been dated as about 9.1 m.y. old (Evans and Steven, 1982). Some flows belonging to the rhyolite of Gillies Hill occur in the western part of the area of figure 2, where a fission-track age of 8.4±0.6 m.y. (table 1, M735) on zircon was obtained from a lava flow just south of Indian Creek.

Extensional tectonism began 22-21 m.y. ago, broadly coincident with the change in chemistry of the igneous rocks from calc-alkalic to bimodal rhyolite-basalt. The Tushar Mountains block is a tilted horst, whereas Beaver Valley to the west is a graben formed by basin-range faulting related to this period of tectonism. The valley is filled with Miocene to Pleistocene fluviatile and lacustrine sedimentary rocks derived from the adjacent mountains.

MINERAL DEPOSITS

Mineralized areas associated with the Bullion Canyon Volcanics

Mineral deposits and altered rocks genetically associated with the Bullion Canyon Volcanics in the Tushar Mountains are generally in or adjacent to 24-23-m.y.-old monzonite or quartz monzonite stocks. Precious metals commonly occur in veins that cut either the higher parts of the stocks or the adjacent volcanic wall rocks. The most productive deposits of this type in the Tushar Mountains are the epithermal gold-quartz-pyrite-carbonate veins at the old gold camp of Kimberly (fig. 1), which near the turn of the century yielded about $3.5 million worth of precious metals at $20.67 an ounce for gold (Callaghan, 1973). The ore occurs in veins that cut a 24.1±1.2-m.y.-old propylitized quartz monzonite stock (Steven and others, 1979b). The veins are cut off on the north by a major basin-range fault and on the south by the topographic wall of the 19-m.y.-old Mount Belknap caldera. Primary ore includes native gold and sparse silver-bearing sulfides in manganese oxides (Lindgren, 1906).

Several other gold prospects related to the Bullion Canyon Volcanics occur in similar geologic settings on the eastern side of the Tushar Mountains. The top of a monzonitic stock exposed near the headwaters of Deer Creek (Cunningham and others, 1981) contains epithermal gold-quartz-pyrite veins that were explored at the Butler and Beck mine (Callaghan, 1973). In the Antelope Range north of Marysvale, gold-quartz-pyrite veins were explored at the Antelope mine (Callaghan, 1973); recent mapping (Cunningham and others, 1981) shows that these veins are also located in the carapace of a monzonite stock.

In the western Tushar Mountains, small to medium sized, epithermal gold-quartz-pyrite veins, similar to those in the eastern Tushar Mountains, occur at the Rob Roy mine (fig. 2) near the western end of the Indian Creek quartz monzonite stock. The veins cut the stock and adjacent hornfelsed volcanic rocks. These veins, which appear to have formed late in the thermal history related to emplacement of the stock, are localized in fractures that appear related to doming, probably caused by forceful emplacement of the stock. One prominent fracture zone strikes east-west along the axis of the stock and localized the present course of Indian Creek. The selvages of the veins are argillically altered and contain disseminated pyrite, and the adjacent volcanic and intrusive rocks are propylitically altered. The main producing vein strikes north and dips westward. The Rob Roy mine produced at least $7,000 worth of gold in 1892 and 1893 (Butler and others, 1920).

The Cork Ridge area, near the southeastern corner of the area of figure 2, is underlain by highly altered rocks that probably were altered by hydrothermal activity related to Bullion Canyon igneous activity. Another area of pervasive argillically altered rocks occurs near the head of Pine Creek, 1.5 km east of the southeastern corner of the mapped area (Anderson and others, 1980; Cunningham and others, 1981). These rocks occur adjacent to a quartz monzonite stock and probably were altered during its emplacement. Although the alteration halo around the stock has not been dated directly, it is cut off by the topographic wall of the 19-m.y.-old Mount Belknap caldera (fig. 2), and thus is older than the caldera.

Some of the many other altered areas between Indian Creek and the Cork Ridge area (fig. 2) also may have formed during the Bullion Canyon period of igneous activity, but these cannot be identified from available evidence.

Throughout the Tushar Mountains, stream-sediment samples derived from the Bullion Canyon Volcanics contain a distinctive suite of elements. Tucker and others (1981) found that heavy mineral concentrates from these samples contain elevated concentrations of magnesium, calcium, copper, chromium, iron, strontium, and nickel. Many of these concentrations (Mg, Ca, Cr, Fe, Sr, Ni) seem to reflect heavy accessory or phenocrystic minerals derived from unaltered volcanic rocks of mafic- to intermediate-composition, but at least some of the copper may have come from the many hydrothermally altered areas in the Bullion Canyon terrane, and thus may reflect potentially important metal concentrations.

The abundant occurrence in the Tushar Mountains and elsewhere in the world of gold-bearing quartz-pyrite-carbonate veins in propylitized hypabyssal plutons and their adjacent volcanic wall rocks implies a common origin. Circulating hot waters carrying CO_2 and H_2S will cause propylitic alteration, and the core plutons are a convenient heat source. The source of the gold and associated metals--whether scavenged from the altering wall rocks or supplied by the magma--cannot be determined from the data available for the western Tushar Mountains.

Mineralized areas associated with the Mount Belknap Volcanics

Anomalous concentrations of lithophile elements genetically associated with the Mount Belknap Volcanics occur in several geologic settings within and adjacent to the Mount Belknap caldera. Uranium and molybdenum are the most important of the known concentrated elements, and potentially may form significant ore deposits. Tungsten may be important locally. The anomalous concentrations appear to have formed from both primary (hypogene) processes and from secondary dispersal and redeposition.

The ash-flow tuffs and rhyolite lava flows filling the Mount Belknap caldera are widely bleached where they have been steamed and altered within the caldera and they are locally silicified and argillized where affected by late hydrothermal solutions related to intrusion of stocks that are cogenetic with the caldera-filling rocks. The general steaming and alteration resulted in remobilizing a significant amount of the uranium contained in the original rock. Delayed neutron analyses of the uranium contents of volcanic glasses and their altered equivalents show that 3 ppm uranium was lost during devitrification, and as much as 6 ppm was lost when the rocks were subjected to more intense alteration (Steven and others, 1981). The quantity of uranium remobilized from Mount Belknap Volcanics source rocks is estimated at 2-4 billion pounds. Much of this uranium went into the hydrologic environment, to be reconcentrated in adjacent basins if the necessary depositional conditions were met (Steven and others, 1981). Some of the uranium, on the other hand, appears to have migrated out of the caldera along fractures or other channelways. The mafic, reduced Bullion Canyon lava flows outside the caldera may have provided an environment for precipitation of some of this mobile uranium. The analytical results for 122 water samples collected from within and adjacent to the Mount Belknap caldera (McHugh and others, 1980) indicate several areas of such concentrations adjacent to the caldera wall that are enriched in uranium. One area is near the headwaters of Pine Creek, 5 km north of the mapped area, and the other is along Pole Creek, near the southeast corner of the mapped area. The Twitchell Canyon area (fig. 2), near the topographic wall within the caldera, appears to contain secondary concentrations of uranium deposited in permeable landslide breccia.

Other areas both within and adjacent to the caldera show anomalous concentrations of lithophile elements that seem to reflect primary deposition around local sources. Several areas near intrusions along the southern ring fracture zone, east of the area shown on figure 2, contain anomalous concentrations of uranium and molybdenum (Cunningham and Steven, 1979b; Steven and others, 1981). The U-Beva contains minor autunite and torbernite.

Several areas just outside the topographic wall of the caldera also warrant attention because of their anomalous concentrations of lithophile elements, including uranium. Tucker and others (1981) pointed out one area east of the Sheep Rock alunite deposit and another one south of the Mystery-Sniffer mine that are enriched in Be, Y, Mn, Pb, Mo, Sn, Ag, Ga, and Nb, and depleted in Mg, Ca, Ba, and Fe. Analytical results from water samples (McHugh and others, 1980) show that water in the area near the Mystery-Sniffer mine contains high concentrations of Li, Be, F, Mo, U, As, and Mn. If the presence of these assemblages is indicative of primary deposition, a local source at depth near the Mystery-Sniffer mine area may be indicated.

Other areas containing anomalous concentrations of lithophile elements in incompatible Bullion Canyon host rocks have been reported in the western Tushar Mountains. Tungsten is not a common element in the Bullion Canyon Volcanics, yet several occurrences have been noted near the southeast corner of the area of figure 2. Butler and others (1920) report wolframite near the head of North Creek; this report may be the reason for the name Tungsten Hollow for a small tributary 2 km east of the mapped area. Everett (1961) reportedly found huebnerite in quartz stringers nearby on Pole Creek.

The uranium deposits of the Mystery-Sniffer mine located along Indian Creek just west of the Mount Belknap caldera, may have been formed both from remobilized uranium derived from the caldera fill and from primary uranium derived from a magmatic source at depth. The known areas of mineralized rock contain torbernite and autunite (Wyant and Stugard, 1951) concentrated along east-striking faults that cut argillically altered Bullion Canyon Volcanics. Records (Osterstock and Gilkey, 1956) indicate that 35 tons of ore averaging 0.17 percent U_3O_8 were shipped in 1952. Pitchblende was tentatively reported from the mine by Callaghan and Parker (1961), but several samples of pitchblende collected from the dump almost certainly came from a completely different location in eastern Utah (Cunningham and Ludwig, 1980), and most of the mined ore contained only secondary uranium minerals. These minerals may have been deposited by solutions percolating outward from the altering core of the Mount Belknap caldera, although they also may have formed by oxidation of primary minerals deposited from a local source. On the other hand, some veinlets and irregular blebs of purple fluorite cut the altered host rocks, and Osterstock and Gilkey (1956, p. 6) report that a "rock unit exposed in the underground workings is a brecciated and intensely altered rhyolite dike(?) which has apparently been intruded along the east-striking Mystery fault zone." This evidence, along with the nearby areas reported by Tucker and others (1981) to contain anomalous concentrations of lithophile elements, suggests primary deposition.

Just west of the Mystery-Sniffer mine, a prominent fault (fig. 2) strikes generally north-south, parallel to the trace of the topographic wall of the Mount Belknap caldera, and dips west, opposite to the slope of the wall. Prospect pits show that the walls of the fault are irregularly altered and locally contain traces of autunite and torbernite (Callaghan, 1973). Nearby rhyolite dikes that cut Bullion Canyon Volcanics contain local anomalous uranophane; these dikes, along with the dike reported by Osterstock and Gilkey (1956) in the Mystery-Sniffer mine, suggest that the local source for the anomalous concentrations of lithophile elements in this area may be an epizonal pluton hidden at depth. Such a pluton probably would not have been emplaced as part of the Mount Belknap caldera cycle, but must have been significantly younger inasmuch as two statistically identical fission-track ages on zircon of about 16 m.y. have been obtained from the dikes. (See section on Significance of Reset Radiometric Ages.)

Late Miocene mineralized areas

Hydrothermal activity associated with the period of volcanism that produced the rhyolite of Gillies Hill 9-8 m.y. ago also produced advanced argillic alteration and precious-metal mineralization in places along the western base of the Tushar Mountains. The Sheep Rock alunite deposit, first described by Loughlin (1915), is a 9-m.y.-old replacement alunite deposit located about 16 km northeast of Beaver (fig. 2). It forms a prominent, light-colored, rounded hill at the base of the mountains, and is in fault contact with the dark lava flows of the Bullion Canyon Volcanics. The alunite replaces 19-m.y.-old flow-layered rhyolite lava flows of the Mount Baldy Rhyolite Member of the Mount Belknap Volcanics that poured out over the lip of the Mount Belknap caldera. Erosional remnants of this outflow mass cap several hills near the Sheep Rock deposit. The alunitic rock is pink to cream colored, containing prominent bands of alunite and quartz that preserve the original flow structures of the rock. Alunite from this deposit has been dated by the K-Ar method as 9.4±0.5 m.y. old (table 2). Farther north along the same fault system, near the mouth of Indian Creek (fig. 2), alunite replacing Bullion Canyon Volcanics lava flows has been dated as 9.18±0.33 m.y. old (table 2).

Table 2.--Data for K-Ar ages of alunite

Sample	K_2O%[1]	$*Ar^{40}$ (10^{-10} moles/gram)	$\%*Ar^{40}$	Age[2]
M256	9.00, 9.11	1.234	49.2	9.4±0.5
79-S-10 (DKA-3896)	7.88, 7.86	1.042	67.1	9.18±0.33

[1]Determined by atomic absorption.

[2]Age (m.y.) ± 2σ.

Constants

K^{40} $\lambda_\varepsilon = 0.581 \times 10^{-10}$/yr

$\lambda_\beta = 4.962 \times 10^{-10}$/yr

$^{40}K/K = 1.67 \times 10^{-4}$

M256 Replacement alunite from the Sheeprock Alunite Deposit, 13 km north-northeast of Beaver, Utah; lat 38°22′50″ N., long 112°34′05″ W. (From Steven and others, 1979b, p. 19.)

M79-S-10 Replacement alunite from altered Bullion Canyon Volcanics near mouth of Indian Creek; lat 38°25′45″ N., long 112°35′30″ W. (From H. H. Mehnert, written commun., 1981.)

The Sheep Rock gold mine is just north of the Sheep Rock alunite deposit (fig. 2). It was described by Butler and others (1920), who noted that gold and silver ore occurs in a quartz-calcite vein that strikes N. 20° E., dips 65°-75° E., and increases in width from 5 ft at the surface to a maximum of 25 ft at the bottom of a 300-ft shaft. The area of the gold mine consists of propylitized Bullion Canyon Volcanics cut by numerous quartz veins that trend generally north-south parallel to the major faults in the area. The wall rock adjacent to the veins contains sericite and pyrite and is locally highly silicified. Butler and others (1920) report that calcite and fluorite are present at the bottom of the shaft. They also report that the ore occurs in shoots containing manganese oxide, native gold, pyrite, and possibly argentite, cerargyrite, ruby silver, and tellurium.

The presence of 9- to 8-m.y.-old rhyolite lava flows, alunitically altered rocks, and precious metal deposits along the fault zone marking the western margin of the Tushar Mountains indicates that basin-range faulting was active in that area at least as far back as late Miocene time. This same relation was reported by Evans and Steven (1982) in the Gillies Hill area northwest of the area of figure 2, where the source of the 9-m.y.-old lavas appears to have been localized along one of the faults.

The Sheep Rock alunite deposit appears to have formed by the near-surface oxidation of H_2S in hydrothermal solutions. The resulting sulfuric acid-dominated waters reacted with alkali rhyolite lava flows, in part converting them to alunite. The Sheep Rock gold mine and the precious metal deposits at the Sunday mine (fig. 2), located one kilometer to the north, are along the same segment of the fault zone that localized the alunite deposit. The Sheep Rock gold deposit appears to be marginal to the alunite deposit and appears to have formed at the periphery of a hydrothermal system where the temperature was lower and the pH higher than toward the center of the system. The mineralized rock at the Sunday mine may have formed from the same hydrothermal system, or from a separate system localized along the same fault. Sulfur isotope evidence (R. O. Rye, oral commun., 1981) indicates that the sulfur in the alunite had a magmatic source, which we postulate was a local epizonal pluton beneath this area. The Sheep Rock alunite deposit thus may mark the former outlet of a paleo-hot spring located above the pluton. The associated zoned hydrothermal system potentially could have deposited economically important mineral concentrations at several depths ranging from a porphyry environment at the top of the pluton, a skarn or replacement environment adjacent to the pluton, and vein environments now exposed at the surface.

SIGNIFICANCE OF RESET ISOTOPIC AGES

The multiple episodes of igneous and hydrothermal activity in the western Tushar Mountains are reflected in the isotopic ages that have been obtained by both the K-Ar and fission-track methods. The different susceptibilities of the various minerals to resetting, either by argon loss in the K-Ar method or by annealing in the fission-track method, provides a powerful tool to sort out superimposed episodes of thermal activity (Naeser, 1979). Recent studies using these techniques have identified the youngest mineralized rhyolite in Colorado and have located a paleothermal anomaly believed to be related to the rhyolite's unexposed source pluton (Naeser and others, 1980). The disparity between the zircon (~20 m.y.; sample M336) and apatite (~9 m.y.; sample M335) ages of two close (~0.5 km) rhyolite dikes near North Fork North Creek apparently indicates that the rock from which sample M335 was collected was reheated enough during the Gillies Hill period of volcanism to completely reset the apatite (annealing threshold ~105°C), whereas the zircon (annealing threshold ~150°C) in the rock of sample M336 was not reset at all. Farther from the fault zone separating the Tushar Mountains from the Beaver Valley, at the U-Beva stock, the apatite in sample M330 was only partly reset to 13.4 m.y., whereas zircon (19.8 m.y.) was not affected.

Geologic relationships combined with isotopic ages indicate that the Indian Creek Stock has been subjected to three thermal events. The stock was initially emplaced late in the period of Bullion Canyon eruptions, probably 24-23 m.y. ago, based on crosscutting relations and comparison with similar well-dated plutons elsewhere in the Tushar Mountains. A sample (M743, table 1) from within the stock shows that the heat associated with Mount Belknap magmatism and the development of the nearby Mount Belknap caldera apparently completely reset the zircon to 19.3±1.0 m.y. A later thermal event related to Gillies Hill magmatism and associated hydrothermal activity did not affect the zircon in the stock but partly reset the apatite in the same sample to 12.8±2.1 m.y.

Fission-track ages on zircons from two rhyolite dikes north of Indian Creek and west of the Mystery-Sniffer mine indicate that there may be yet another, until now unrecognized, episode of igneous and hydrothermal activity with potential economic overtones. Sample M733 is from a rhyolite dike cutting hornfelsed Bullion Canyon Volcanics on the ridge north of Indian Creek. The dike contains fluorite and secondary uranium minerals, and zircons from the dike have a fission-track age of 15.6±1.1 m.y. About 1 1/2 km east of that locality and less than 1/2 km west of the Mystery-Sniffer mine, another northerly trending rhyolite dike contains zircon with a fission-track age of 16.1±0.8 m.y. (table 1, M744). Both rhyolites have identical ages at the 95th percent confidence level; they do not appear to be related to the Mount Belknap caldera (19 m.y.) nor partly reset by rhyolite of Gillies Hill (9 m.y.). The rhyolite of Gillies Hill was hot enough, long enough, to reset the apatite but not the zircon in the Indian Creek Stock (M743) at a location closer to the known area of Gillies Hill magmatism and presumably toward the heat source. Thus, it would have been difficult for zircons from the two dikes to have been reset at all, let alone partially to exactly the same degree in late Miocene time. The fluorite and secondary uranium noted in association with the westernmost dike, in combination with the anomalous concentrations of lithophile elements near the Mystery-Sniffer mine discussed earlier, also point toward a local primary source of mineralizing solutions and heat. Emplacement of a local intrusion, with attendant hydrothermal activity, in the area west of the Mystery-Sniffer mine about 16 m.y. ago seems a distinct possibility.

SUMMARY

The geologic history of the western Tushar Mountains, supported by numerous isotopic ages, indicates that hydrothermal activity took place during the following events: (1) in association with emplacement of monzonitic stocks related to the Bullion Canyon Volcanics 24-23 m.y. ago, (2) during the Mount Belknap caldera cycle about 19 m.y. ago, (3) possibly in association with emplacement of a younger Mount Belknap pluton about 16 m.y. ago, and (4) locally along the fault marking the western margin of the Tushar Mountains

9-8 m.y. ago. Some of the resulting mineralized areas are distinct and easily recognizable, but others are partly to completely superimposed, and the effects of the different episodes are difficult to separate. The products of the different periods of mineralization must be identified as precisely as possible, inasmuch as potential exploration targets and the mineral resources sought will vary considerably from one period of mineralization to another and from one depth environment to another.

The known gold-bearing quartz-pyrite veins associated with the Bullion Canyon period of igneous activity are small and appear to be low in grade. Propylitically altered rocks of this association are known in the vicinity of the Indian Creek Stock and in the Cork Ridge area (fig. 2), and some of the many areas of altered rocks between these two areas may have formed at about the same time. No zoning pattern was discerned within the altered areas known to be associated with the Bullion Canyon period of igneous activity that would indicate the presence of more favorable environments for mineral concentrations at depth.

Small concentrations of secondary uranium minerals have been noted in more permeable parts of the Mount Belknap caldera fill, and anomalous uranium not accompanied by other lithophile elements has been noted in Bullion Canyon rocks adjacent to the caldera. These concentrations are believed to have formed by redeposition of uranium mobilized by devitrification and hydrothermal alteration of the silicic fill in the Mount Belknap caldera. Known deposits are small, but large quantities of mobilized uranium appear to have been available and more significant deposits may occur where reducing chemical conditions coincided with permeable solution channelways.

Epizonal plutons emplaced during the Mount Belknap Volcanics period of igneous activity are known to occur in the caldera fill along the southern ring fracture zone of the caldera, and are postulated on indirect evidence to exist in the belt of Bullion Canyon Volcanics between the caldera and Beaver Valley. These plutons in part were emplaced during the caldera cycle about 19 m.y. ago, and in part about 16 m.y. ago. Anomalous concentrations of lithophile elements, believed related to these known or postulated plutons, have been outlined both in and adjacent to the caldera. The metals with the best potential for economic mineral concentrations associated with such plutons seem to be molybdenum in the porphyry environment near the top of the plutons and uranium in overlying veins. Several areas with significant anomalous concentrations of lithophile elements have been outlined and all these deserve careful study to see if exploration targets can be outlined.

Hydrothermal activity related to the late Miocene igneous activity responsible for erupting the 9-m.y.-old rhyolite of Gillies Hill was restricted to the basin-range fault zone marking the western margin of the Tushar Mountains. The Sheep Rock alunite deposit, Sheep Rock gold mine, and possibly the Sunday gold mine seem to have formed as parts of a single zoned hydrothermal system characterized by sulfur of a magmatic isotopic composition. Another alunite deposit near the mouth of Indian Creek may mark the core of another hydrothermal system. The zoned Sheep Rock system with its probable magmatic core deserves special consideration as it potentially could have significant economic mineral deposits at depth.

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(For figure 2)

DESCRIPTION OF MAP UNITS

Qa ALLUVIAL DEPOSITS (QUATERNARY)--Silt, sand, and gravel in alluvial fans, alluvial slope wash, and stream alluvium

Ql LANDSLIDE DEBRIS (QUATERNARY)--Poorly sorted rock debris that moved downslope by gravity

Qt TRAVERTINE (QUATERNARY)--Calcareous spring deposits

QTa OLDER ALLUVIUM (PLEISTOCENE TO MIOCENE?)--Poorly to moderately consolidated, fluviatile and lacustrine conglomerate, sandstone, and siltstone containing local interlayered airfall tuff beds. Includes fanglomerate and pediment gravel. Probably equivalent in part to Sevier River Formation

Trg RHYOLITE OF GILLIES HILL (MIOCENE)--Light-gray to white, flow-layered rhyolite lava flows and volcanic domes containing phenocrysts of sanidine and partly resorbed quartz in a vuggy, devitrified groundmass

MOUNT BELKNAP VOLCANICS (MIOCENE)

Intrusive rocks

Tmd Dikes and small stocks--Several small, glassy to aphanitic, rhyolitic dikes, stocks, and lava flows

Tmic Intracaldera intrusive rocks--Several small porphyritic quartz latitic to rhyolitic stocks within the Mount Belknap caldera. Contain sparse phenocrysts of quartz, plagioclase, and sanidine in a finely granular mosaic of alkali feldspar and quartz

Intracaldera facies volcanic rocks (Mount Belknap caldera)

Tmb Mount Baldy Rhyolite Member--Light-gray, crystal-poor, rhyolite lava flows and dikes consisting largely of a fine, granular mosaic of quartz and alkali feldspar, and minor plagioclase, biotite, and hematite. Contorted flow layers are common. Mostly intracaldera facies, but locally extends out across the margin of the Mount Belknap caldera

Tmv Volcaniclastic rocks--Dominantly light-gray to white volcanic mudflow breccia derived from nearby lava flows of the Mount Baldy Rhyolite Member (Tmb). Some landslide debris and fluviatile sandstone and conglomerate are included in the unit

Tmm Middle tuff member--Partially welded, crystal-poor, light-gray or tan, alkali rhyolite ash-flow tuff containing 1-2 percent phenocrysts of quartz, sodic plagioclase, sanidine, and traces of biotite

Tmbl Blue Lake Rhyolite Member--Crystal-poor, rhyolite lava flows lithologically similar to those in the Mount Baldy Rhyolite Member (Tmb). Contorted flow layers are characteristic

BULLION CANYON VOLCANICS (MIOCENE AND OLIGOCENE)

Tbi Intermediate-composition intrusive rock (Miocene)--Dark to light-gray and brown, porphyritic to equigranular, medium-grained monzonite. Contains approximately equal proportions of plagioclase and orthoclase, 0-20 percent quartz, and subordinate augite, hornblende, and biotite. Accessory minerals are apatite, zircon, and Fe-Ti oxides

Tb Heterogeneous lava flows and volcanic breccia--Porphyritic andesite, rhyodacite, and quartz latite. Contains phenocrysts of plagioclase, biotite, and clinopyroxene. In part consists of fine-grained dark lava flows and breccia of intermediate composition, containing small phenocrysts of plagioclase and clinopyroxene

JTRn NAVAJO SANDSTONE (JURASSIC AND TRIASSIC?)--Fine-grained, buff, well-sorted, crossbedded sandstone. Occurs locally as large blocks in stocks and lava flows

CONTACT

FAULT--Dotted where concealed; bar and ball on downthrown side

STRIKE AND DIP

TOPOGRAPHIC WALL OF MOUNT BELKNAP CALDERA--Solid where it follows a contact; broken where concealed

AREAS AFFECTED BY ARGILLIC OR ADVANCED ARGILLIC ALTERATION