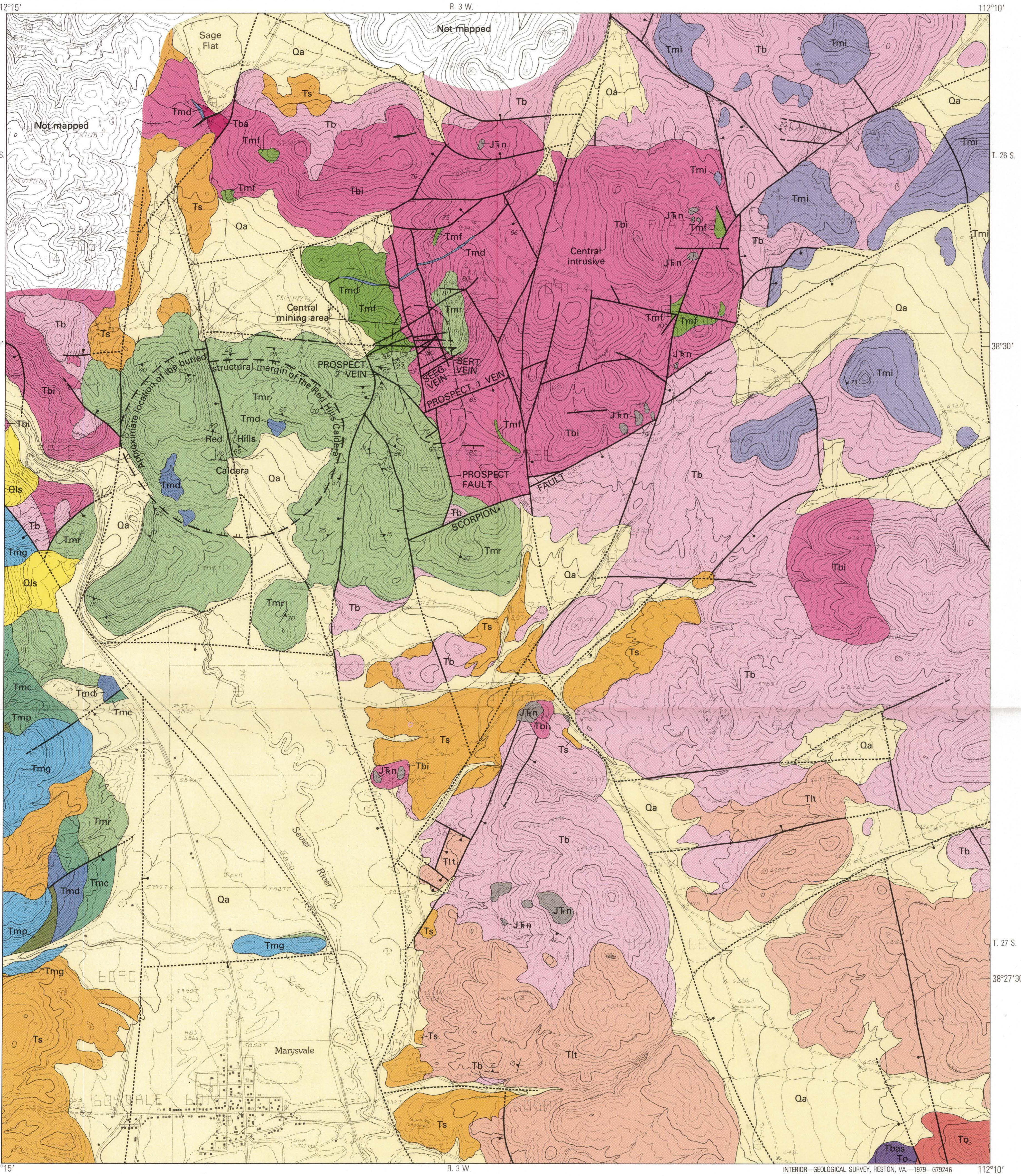


Base from U.S. Geological Survey Marysvale NW and Monroe SW, 1977

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

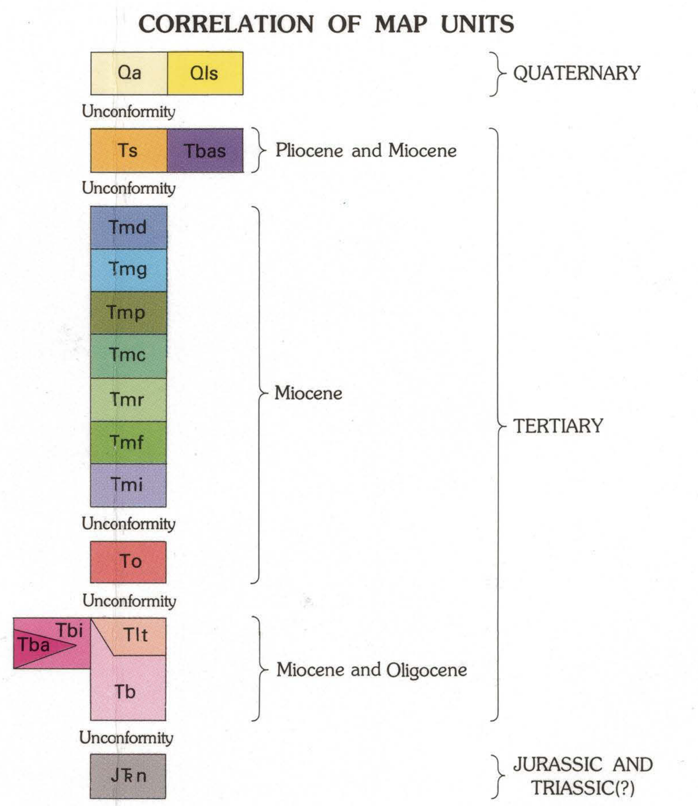
QUADRANGLE LOCATION

Geology mapped in 1978

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA.—1979—G79246

Geologic Map of the Central Mining Area, Marysvale, Utah

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qa ALLUVIAL DEPOSITS (QUATERNARY)

Qls LANDSLIDE DEBRIS (QUATERNARY)—Locally contains significant quantities of glacial drift, rock glaciers, talus, and other deposits

Tbas VESICULAR BASALT FLOWS (PLIOCENE AND MIOCENE)—Commonly contain altered olivine phenocrysts

Ts SEVIER RIVER FORMATION, (LOWER PLIOCENE AND MIOCENE)—Partly consolidated fanglomerate, conglomerate, sand, and silt

MOUNT BELKNAP VOLCANICS (MIOCENE)

Tmd Dikes and small stocks—Several small glassy to aphanitic rhyolitic dikes and stocks. Most, if not all, are younger than Red Hills Tuff Member

Tmg Gray Hills Rhyolite Member—Light-gray, spherulitically devitrified rhyolite. Contains sparse sanidine phenocrysts and is characterized by contorted flow layering

Tmp Porphyritic lava flows—A few pyroxene latite flows located west of the Sevier River. Contains phenocrysts of andesine, diopsidic augite, and oxidized hornblende in a felted groundmass of microlites and hematite

Tmc Crystal-rich member—Welded alkali rhyolite ash-flow tuff. Contains 30 percent phenocrysts of the following: quartz (3 percent), anorthoclase (24 percent), plagioclase (2 percent), and biotite (1 percent). K-Ar age is 18.5±1.2 m.y. (Steven and others, 1977)

Tmr Red Hills Tuff Member—Crystal-poor welded alkali rhyolite ash-flow tuff. Contains about 7.5 percent phenocrysts of anorthoclase, quartz, plagioclase, and minor biotite

Tmf Fine-grained granite—A small stock and related dikes that form a host for the uranium-bearing veins. Contains crystals of quartz, orthoclase, plagioclase, and minor biotite in a groundmass characterized by graphic intergrowths. K-Ar age is 20 m.y. (Steven and others, 1977)

Tmi Several small porphyritic rhyolitic stocks and lava domes near the east side of the mapped area. Contains sanidine, plagioclase, biotite, hornblende, quartz, and minor apatite, sphene, and magnetite in a devitrified or glassy matrix. K-Ar age is 21 m.y. (Steven and others, 1977)

To OSIRIS TUFF (MIOCENE)—Densely welded rhyodacite ash-flow tuff. Contains approximately 20 percent phenocrysts of plagioclase, sanidine, pyroxene, biotite, and quartz in a devitrified or glassy matrix

Tlt VOLCANIC ROCKS OF LITTLE TABLE (MIOCENE)—Dark - gray to dark - brown, intermediate composition lava flows, flow breccia, and volcanic mudflow breccia (vent facies). Largely pyroxene andesite containing sparse phenocrysts of andesine and angite

BULLION CANYON VOLCANICS (MIOCENE AND OLIGOCENE)

Tba Aplite (Miocene)—Fine-grained aplite forming small plugs and dikes. Contains crystals of quartz, orthoclase, plagioclase, and biotite

Tbi Intermediate-composition intrusive rock (Miocene)—Strongly porphyritic to equigranular, fine- to medium-grained quartz monzonite, monzonite, and granodiorite. Commonly contains approximately equal proportions of plagioclase and orthoclase, as much as 20 percent quartz, plus augite, hornblende, and biotite. Minor accessory minerals are apatite, zircon, and Fe-Ti oxides

Tb Heterogeneous lava flows and volcanic breccias (Miocene and Oligocene)—Porphyritic rhyodacite and quartz latite. Contains phenocrysts of plagioclase, biotite, and clinopyroxene. In part consists of fine-grained dark lava flows and breccias of intermediate composition, with small phenocrysts of plagioclase and clinopyroxene

JTRn NAVAJO SANDSTONE (JURASSIC AND TRIASSIC?)—Fine-grained, well sorted, crossbedded sandstone. Present as xenoliths, mostly in the quartz monzonite

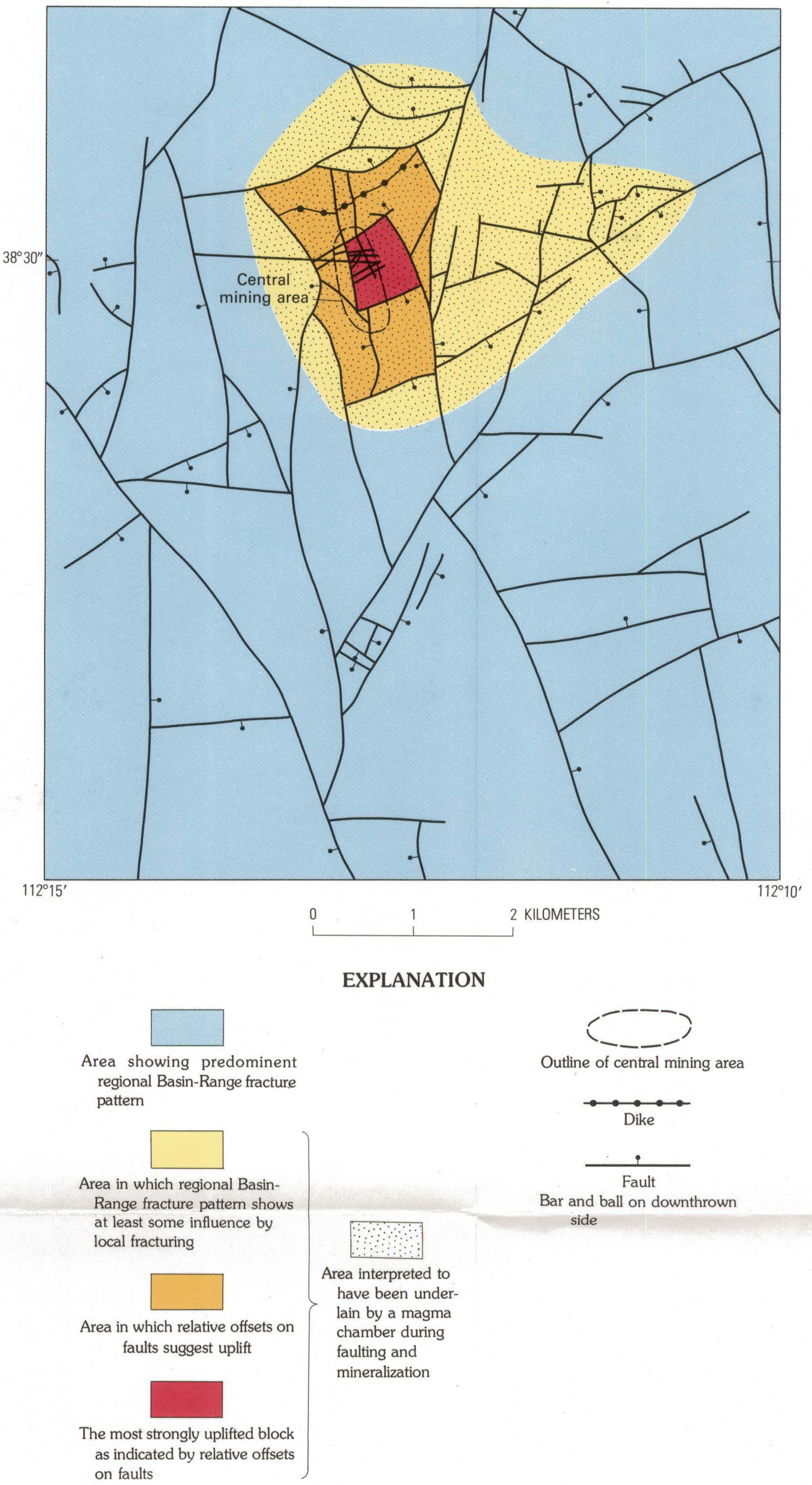
CONTACT

78 FAULT—Showing dip; dotted where concealed. Bar-and-ball on down thrown side

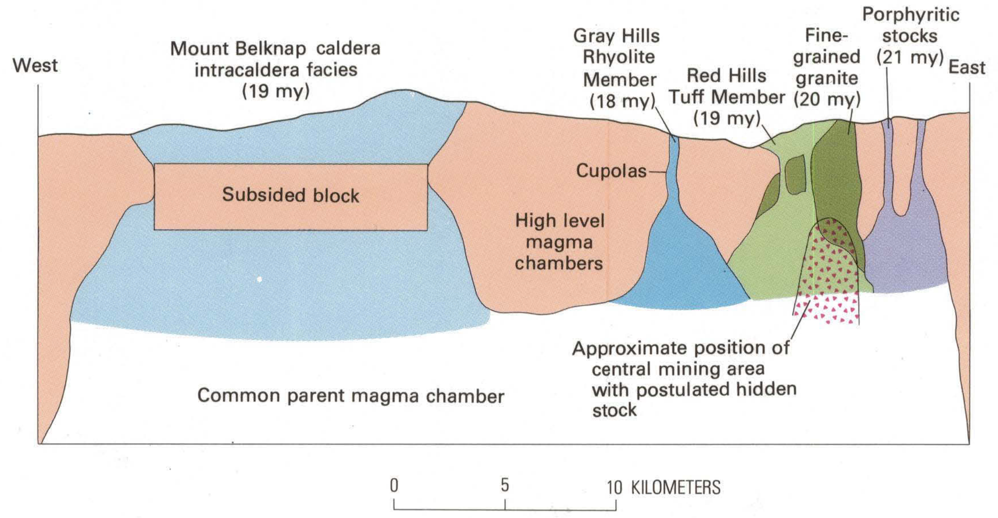
QUARTZ VEIN

APPROXIMATE LOCATION OF BURIED TOPOGRAPHIC WALL OF RED HILLS CALDERA

15 STRIKE & DIP OF COMPACTION FOLIATION OR LAVA FLOWS



Tectonic map in the vicinity of the central mining area, Marysvale district, Utah



Diagrammatic sketch showing postulated relations in the roots of source areas for the Mount Belknap Volcanics

URANIUM IN THE CENTRAL MINING AREA, MARYSVALE DISTRICT, WEST-CENTRAL UTAH

By
Charles G. Cunningham and Thomas A. Steven

1979

INTRODUCTION

Uranium in the central mining area of Marysvale, Utah occurs in hydrothermal veins cutting granitic and volcanic rocks in the eastern source area of the Mount Belknap Volcanics. A preliminary model for the origin of the veins envisages deposition in near-surface fractures above an unexposed pluton that may host a porphyry-type ore deposit. This model is based on the work in progress by the U.S. Geological Survey, and embodies currently available data from field mapping, literature study, fluid-inclusion studies, and diverse geochemical and isotopic studies. Recent advances in uranium geochemistry have been particularly helpful. The work is not yet complete so this model should be considered as a progress report suggesting possible targets for exploration and testing; such testing would in turn lead to refinements in the model and to a clearer understanding of vein-type uranium deposits in general.

Location and previous work

Marysvale, Utah is in the Sevier River Valley 260 kilometers south of Salt Lake City, Utah, within the Marysvale volcanic field. The valley is bordered on the west by the Tushar Mountains and on the east by the Sevier Plateau. The central mining area (geologic map) is located 5.6 kilometers north-northeast of Marysvale, in a series of low hills.

Various aspects of the geology of the Marysvale area have been studied intermittently since the 1880's, as deposits of gold, silver, base metals, alunite, and uranium were discovered successively. Callaghan (1939) published the first comprehensive description of the igneous rocks. The discovery of uranium in 1949 led to a period of intense study of the area by Paul Kerr and his students P. M. Bethke, G. P. Brophy, H. M. Dahl, J. Green, L. E. Woolard, and N. W. Molloy, of Columbia University, under the auspices of the U.S. Atomic Energy Commission. Many preliminary reports on these investigations were prepared, and were summarized by Kerr and others (1957), and Kerr (1968). Other pertinent publications are by Gruner and others (1951), Gilbert (1957), Myerson (1958), and Callaghan (1939). Willard and Callaghan (1962) published a geologic map of the 15′ Marysvale quadrangle, and Callaghan and Parker (1961) published a similar map of the contiguous Monroe quadrangle to the north.

Current studies

The authors began a comprehensive study of the geology and mineral deposits of the Marysvale area in 1975. Significant revisions have been made in the stratigraphy, structure, and petrologic evolution of the volcanic field, and preliminary results have been published by Steven (1978), Steven and others (1977, 1978a,b,c,d), Cunningham and Steven (1977, 1978), and Cunningham and others (1978a,b).

The study of the central mining area is part of a regional investigation by the U.S. Geological Survey aimed at assessing the mineral-resource potential of the Richfield 1°×2° quadrangle. Aspects of the work have been used to contribute to the National Uranium Resource Evaluation program of the U.S. Department of Energy. Underground data and mine maps of the central mining area were supplied by Energy Fuels Corporation, and many aspects of the geology were discussed with their geologist, James Rasmussen.

GEOLOGIC SETTING

The Marysvale volcanic field is in the High Plateaus subprovince that forms the transition between the Colorado Plateaus and the Basin and Range provinces. The volcanic rocks lie unconformably on Mesozoic and lower Cenozoic sedimentary rocks. Most volcanic rocks in the Marysvale pile consist of 35?-21 m.y. old intermediate-composition lava flows, volcanic breccias, volcaniclastic deposits, and ash-flow tuffs that have been called Bullion Canyon Volcanics (Callaghan, 1939; Steven and others, 1977). These rocks accumulated around many scattered and in part clustered stratovolcanoes, and near-source lava flows and volcanic breccias commonly pass laterally into coalescing volcaniclastic aprons. The Bullion Canyon Volcanics were intruded 23 m.y. ago by quartz monzonite stocks which set in motion hydrothermal cells that produced local alunitic alteration of the host rocks. One of these stocks, called the "central intrusive" by Kerr and others (1957), forms a host for some of the uranium deposits.

The volcanic activity and rock compositions changed abruptly about 21 m.y. ago, and silicic alkali rhyolite lava domes, lava flows, and ash-flow tuffs of the Mount Belknap Volcanics were erupted from two source areas. The western source area, in the central Tushar Mountains just west of the map area, centers around the Mount Belknap caldera. This major caldera formed 19 m.y. ago in response to eruption of the Joe Lott Tuff Member of the Mount Belknap Volcanics, and is described in Cunningham and Steven (1977, 1978).

The eastern source area, northeast of Marysvale, contains the most significant uranium deposits yet found in the Marysvale volcanic field. Volcanic activity began about 21 m.y. ago (Steven and others, 1977) with the intrusion of local stocks and plugs and the extrusion of a series of porphyritic lava domes and flows (Tmi on geologic map) 8 kilometers northeast of Marysvale. Igneous activity then progressed toward the southwest, and with time, changed systematically in location, bulk composition, and phenocryst and volatile content. A fine-grained granite (Tmf in geologic map) was intruded 20 m.y. ago (Steven and others 1977) into the 23 m.y.-old central intrusive. This granite underlies much of the central mining area and is a major host for the uranium veins. By 19 m.y. ago, the volatile-rich magma erupted as alkali-rhyolite ash flows (Tmr in geologic map) 1.5 kilometers southwest of the central mining area, and the Red Hills caldera subsided in response. Activity continued to shift southwestward, and at 18 m.y. ago volatile-rich alkali-rhyolite lava was extruded as viscous volcanic domes (Tmg in geologic map). Small glassy to felsitic rhyolite plugs and dikes (Tmd) cut these rocks. Some of these plugs are localized around the ring fracture of the Red Hills caldera and probably formed soon after eruption of the Red Hills Tuff Member (Tmr). An aphanitic white rhyolite dike (Tmd) just north of the central mining area has not been dated, but cuts the 20 m.y. old fine-grained granite (Tmf). Other rhyolite plugs west of the Sevier River have been dated at 16 m.y. and are probably glassy apophyses reflecting continued magmatic activity in the eastern source area.

The systematic progression of igneous activity in the eastern source area of the Mount Belknap Volcanics has been interpreted by Cunningham and Steven (1977) as reflecting the successive emplacement of shallow cupolas above a larger high level magma chamber (diagrammatic sketch) The systematic changes may reflect source cupolas tapping progressively shallower levels of a compositionally zoned chamber and (or) cupolas developing successively above the top of an actively differentiating chamber.

The uranium-bearing veins of the central mining area cut the 23 m.y. old central intrusive, the 20 m.y. old fine-grained granite, and the 19 m.y. old Red Hills Tuff Member. Radiometric ages determined on vein pitchblende are discordant owing to mineralogic complexity, and only indicate that mineralization took place sometime between 18 and 10 m.y. ago (Steven and others, 1978a). The older part of this span seems the more geologically reasonable time for mineralization, and we interpret that the mineralization probably was related to an unexposed intrusive formed during terminal stages of Mount Belknap volcanism in the eastern source area, 18 to 16 m.y. ago. On the other hand, the mineralization might have been younger and related to a buried system similar to the one that formed the ore deposits in the 14 m.y. old Deer Trail Mountain-Alunite Ridge mining area 16 kilometers to the southwest (Cunningham and others, 1978b).

CENTRAL MINING AREA

Most of the known production of uranium from the Marysvale volcanic field has been from an oval area known as the central mining area, located 5.6 km north-northeast of Marysvale. The uranium was discovered here in 1949, and most of the production has been from about 9 mines; the Prospector, Freedom No. 1 and No. 2, Bullion Monarch, Farmer John, Cloys, Potts, Wilhelm, and Sunnyside (Callaghan, 1973). The principal ore minerals in the veins are uraninite, coffinite (K. Ludwig, oral commun., 1978), jordisite, and umohoite, a hydrous uranium molybdate (Brophy and Kerr, 1953), which occur in a matrix of dark fluorite, quartz, and minor pyrite. Near the surface, in the zone of oxidation, secondary uranium and molybdenum minerals are common. Ore has been mined to depths of about 185 meters and drilling indicates that ore is still present at 460 meters (Callaghan, 1973), although there are subtle changes in mineralogy with depth. One million pounds of U_3O_8 have been produced from the area since 1950 (Carmony, 1977).

The central mining area, that includes all the main uranium-producing mine workings of the Marysvale district, is an oval area about 500 by 1,300 m (geologic map). This oval is at the center of a somewhat larger highly faulted area cut by Basin-Range faults that trend north-northwest and north-northeast, as well as by more local faults that trend east-northeast (tectonic map). The local faults are especially abundant within the central mining area. We interpret the fracture pattern to reflect local distention imposed by an underlying magma chamber on regional late Cenozoic E-W Basin-Range extension. The pluton that congealed in this chamber would have been the youngest intrusion in the eastern source area of the Mount Belknap Volcanics where Cunningham and Steven (1977) have already interpreted numerous shallow cupolas above a 21-16 m.y. old silicic magma chamber (diagrammatic sketch). As mineralization appears to have been related to late stages of the Mount Belknap period of igneous activity, the young, shallow intrusive postulated beneath the highly faulted area probably was responsible for the mineralizing system.

THE PORPHYRY ENVIRONMENT

The coincidence in time and space of uranium and molybdenum mineralization with a local area of distention and igneous intrusion and extrusion, strongly suggests a genetic relationship. Uranium is the only metal that has been recovered from the ore to date, but molybdenum is commonly associated and appears to be most abundant in the lower mine levels where it exceeds one percent of some veins. Any model of the uranium deposits in the central mining area must consider not only the downward extension of the vein system, but the porphyry-type ore environment at the top of the postulated underlying stock.

The geologic environment of the central mining area illustrated on the diagrammatic sketch, with multiple shallow intrusions and with hydrothermal activity associated with certain of the plutons, is typical of that demonstrated for many porphyry-type ore deposits over the world. Whereas volcanic eruptions from mineralized centers can be demonstrated at places, the process was not operative at other places, therefore does not seem to be required for mineralization. Thus the absence of volcanic activity concurrent with mineralization at the central mining area is not considered to be an adverse factor. The lack of extensively altered wall rocks adjacent to the uranium-bearing veins also is not considered especially adverse. As detailed in the following sections, the hydrothermal solutions responsible for depositing the uranium seem to have had a relatively low sulfur content and to have been in a reduced state. This would have inhibited the formation of sulfuric acid and thus lessened wall-rock alteration. The degree of wall-rock alteration would have been a condition of the shallow vein environment and should have had little influence on the processes taking place deeper, near the top of the postulated intrusion.

The worldwide porphyry-type ore environment has demonstrated a wide spectrum of variants, with a strong lithologic control on the composition of the ores. Mafic intermediate intrusions along continental margins and in island arcs, commonly have copper-gold associated in the porphyry-type ores; silicic intermediate intrusions along continental margins and within continents, more commonly contain copper-molybdenum-gold; and highly silicic intrusions within the continents, contain molybdenum with byproduct tungsten, tin, uranium, beryllium, and other lithophile metals. The Marysvale district clearly belongs to the latter category. Inasmuch as uranium with byproduct molybdenum occurs within the roots of the vein system, molybdenum with byproduct uranium probably can be anticipated in any porphyry-type ore that may exist at depth beneath the district.

Most copper-gold and copper-molybdenum-gold porphyry-type deposits are almost exclusively metal sulfide systems, but Sillitoe and others (1975) have demonstrated that some of the tin-bearing porphyries in Bolivia contain a mixture of oxide and sulfide ore minerals. The byproduct tin, tungsten, and uranium at the Climax and Henderson molybdenum mines in Colorado are known to occur in oxide minerals (Desborough and others, 1978). In view of the generally low content of sulfur in the hydrothermal system in the central mining area (see section on geochemistry), we anticipate a mixed oxide-sulfide porphyry deposit at depth with significant uranium values.

The depth to the top of the postulated intrusive underlying the central mining area cannot be interpreted at present. It conceivably could be within a kilometer of the surface, or much deeper. The fracturing seen at the surface (tectonic map) can be interpreted to reflect local uplift, but in the absence of good structural marker horizons it is not possible to determine the magnitude or dimensions of this uplift. The greater the uplift, and the steeper the structural gradients at its margins, the shallower the top of the intrusion should be.

GEOCHEMISTRY

Most uranium-bearing veins in the central mining area are along brecciated structures in granitoid intrusives. The uranium minerals were deposited in association with dark-purple fluorite in open spaces between broken fragments of wall rock. In addition to the fluorite, uraninite, coffinite, quartz, pyrite, jordisite, and umohoite were deposited during the ore-forming stages of mineralization. Although pyrite is widely present, it generally comprises only a very small part of the mineralized rock. We interpret the relatively low percentage of pyrite to indicate a relatively low content of sulfur in the hydrothermal solution. This interpretation is supported by the localized occurrence of molybdenum as jordisite and the molybdate, umohoite, rather than in the much more common sulfide molybdenite.

The mineralogical associations in the ore place geochemical constraints on the environment of ore deposition. The lack of sulfate minerals and the sparse but ubiquitous presence of pyrite within the ore-forming assemblage suggests that H_2S was the dominant sulfur species and that the oxygen fugacity was low. The common association of quartz with the ore and the presence of the uranium silicate coffinite, indicates that the hydrothermal system was often saturated with silica. The ubiquitous presence of fluorite in the veins suggests that a uranium-fluorine complex was probably the transporting agent. The hydrothermal solutions that transported the uranium also dissolved apatite in the host rock, suggesting that the fluids had a low pH. Langmuir (1978) has shown that in reducing environments at 25°C, below pH 4, uranous fluoride complexes are important species. Romberger (oral commun., 1978) has computed the stability field of UF_2 at 200°C and finds that this complex is stable at approximately log oxygen fugacity −38 to −45 and pH in the vicinity of 2 to 4.

Preliminary fluid-inclusion studies on fluorite cogenetic with uranium minerals indicates that the uraninite and coffinite were deposited from dilute solutions at approximately 150°C. Evidence for boiling has not been observed, but may be found as more samples become available. Carbon dioxide has not been found in the fluid inclusions studied to date.

The preliminary results of our data suggest that the uranium mineralization in the Marysvale central mining area was deposited from a dilute, reduced, fluorine-rich hydrothermal fluid at approximately 150°C. The uranium was probably complexed as UF_2 and (or) a similar species. Sulfur was probably present as dissolved H_2S and Ca was probably an ubiquitous component. As the acidic fluids rose along the vein structures, they cooled, entered lower pressure regimes, and interacted with the wall rocks. As the pH rose, the uranous fluoride complexes became unstable. The F^- thus freed, combined with Ca and was deposited as fluorite, and the U^+ was precipatated as uraninite and (or) coffinite. Boiling and CO_2 effervescence could have helped raise the pH (Cunningham, 1978), but evidence for this effect has not yet been found.

It is doubtful that the reduction reaction (U^{+6} to U^{+4}) proposed by Rich and others (1977) was effective at Marysvale, as the iron-bearing minerals in the wall rocks do not show significant oxidation by the hydrothermal fluids. Hematite, common elsewhere in the district, is generally a product of oxidation associated with the 23 m.y. old alunitic mineralization, not the uranium mineralization.

REFERENCES

Brophy, G. P., and Kerr, P. F., 1953, Hydrous uranium molybdate in Marysvale ore: Annual Report from June 30, 1952 to April 1,1953, U.S. Atomic Energy Commission Report, RME-3046, p.45-51.

Callaghan, Eugene, 1939, Volcanic sequence in the Marysvale region in southwest-central Utah: Transactions of the American Geophysical Union, v.20, pt.3, p. 438-452.

______ 1973, Mineral resource potential of Piute County, Utah and adjoining area: Utah Geological and Mineralogical Survey Bulletin 102,135 p.

Callaghan, Eugene, and Parker, R.L., 1961, Geology of the Monroe Quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-155. scale 1:24,000.

Carmony, J. R., 1977, Stratigraphy and geochemistry of the Mount Belknap Series, Tushar Mountains, Utah: The Pennsylvania State University, M.S. Thesis, 153 p.

Cunningham, C.G., 1978, Pressure gradients and boiling as mechanisms for localizing ore in porphyry systems: U.S. Geological Survey Journal of Research, v.6, no. 6, p. 745-759.

Cunningham, C. G., and Steven, T. A., 1977, Mount Belknap and Red Hills calderas and associated rocks, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Open-File Report 77-568, 40p.

______ 1978, Geologic map of the Delano Peak NW quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-967, scale 1:24,000.

Cunningham, C. G., Steven, T. A., and Carmony, J. R., 1978a, Evolution of the Mount Belknap and Red Hills calderas, west-central Utah: Geological Society of America Abstracts with Programs, v. 10, no. 5, p. 214.

Cunningham, C. G., Steven, T. A., and Naeser, C. W., 1978b, Preliminary structural and mineralogical analysis of the Deer Trail Mountain-Alunite Ridge mining area, Utah: U.S. Geological Survey Open-File Report 78-314.

Desborough, G. A., Mihalik, Peter, Kamilli, Robert, Gunow, Alexander, and Taylor, R. B., 1978, Accessory minerals in the plutonic igneous host of molybdenum ore, Henderson mine, Colorado: 8th regional conference for the study of minerals in polished section on the micro-scale, Centenary of the Sociéte Francaise de Mineralogie et Cristallographie, May 1978, Paris, Programme and abstracts.

Gilbert, R. E., 1957, Notes on the relationship of uranium mineralization and rhyolite in the Marysvale area, Utah, rev. ed.: U.S. Atomic Energy Commission Report RME-2030, 31 p.

Gruner, J. W., Fetzer, W. G., and Rapaport, Irving, 1951, The uranium deposits near Marysvale, Piute County, Utah: Economic Geology, v. 46, no. 3, p. 243-251.

Kerr, P. F., 1968, The Marysvale, Utah, uranium deposits, *in* Ridge, J. D., ed., Ore deposits of the United States, 1933-1967: Graton-Sales volume, v. 2, p. 1020-1042.

Kerr, P.F., Brophy, G. P., Dahl, H.M., Green, Jack, and Woolard L. E., 1952, A geologic guide to the Marysvale area, U.S. Atomic Energy Commission Report RMO-924, 57 p.

______ 1957, Marysvale, Utah, uranium area: Geological Society of America Special Paper 64, 212 p.

Langmuir, Donald, 1978, Uranium solution-mineral equilibria at low temperatures with applications to sedimentary ore deposits: Geochimica et Cosmochimica Acta, v. 42, no. 6B, p. 547-570.

Myerson, B. L., 1958, Diamond drilling report, Marysvale area, Piute County, Utah, 1953-1954: U.S. Atomic Energy Commission Report RME- 2065, 33 p.

Rich, R. A., Holland, H. D., and Petersen, Ulrich, 1977, Hydrothermal uranium deposits: New York, Elsevier-North Holland, 264 p.

Sillitoe, R. H., Halls, C., and Grant, J. N., 1975, Porphyry tin deposits in Bolivia: Economic Geology, v. 70, no. 5, p. 913-927.

Steven, T. A., 1978, Geologic map of the Sevier SW quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-962, scale 1:24,000.

Steven, T. A., Cunningham, C. G., Naeser, C. W., and Mehnert, H. H., 1977, Revised stratigraphy and radiometric ages of volcanic rocks and mineral deposits in the Marysvale area, west-central Utah: U.S. Geological Survey Open-File Report 77-569, 45 p.

Steven, T. A., Cunningham, C. G., Naeser, C. W., Mehnert, H. H., and Ludwig, K. K., 1978a, Multiple ages of mineralization in the Marysvale area, west-central Utah: International Association on the Genesis of Ore Deposits, Symposium 1978, Programs and Abstracts, p. 185.

Steven, T. A., Cunningham, C. G., and Rowley, P. D., 1978b, Geology and mineralization in the Marysvale mining area, west-central Utah, *in* Guidebook to mineral deposits of southwestern Utah: Utah Geological Association Publication 7, p. 67-70.

Steven, T. A., Rowley, P. D., and Cunningham, C. G., 1978c, Geology of the Marysvale volcanic field, west-central Utah: Brigham Young University Geology Studies, v. 25, no. 1, p. 67-70.

Steven, T. A., Rowley, P. D., Hintze, L. F., Best, M. G., Nelson, M. G., and Cunningham, C. G., 1978d, Preliminary geologic map of the Richfield 1°×2° quadrangle, Utah: U.S. Geological Survey Open-File Report 78-602, scale 1:250,000.

Willard, M. E., and Callaghan, Eugene, 1962, Geology of the Marysvale quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-154, scale 1:62,500.

Willard, M. E., and Proctor, P. D., 1946, White Horse alunite deposit, Marysvale, Utah: Economic Geology, v. 41, no. 6, p. 619-643.

For sale by Branch of Distribution, U.S. Geological Survey
Box 25286, Federal Center, Denver, CO 80225