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Postulated Model of Uranium Occurrence in the Central Mining Area, Marysvale District, West-Central Utah

By

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POSTULATED MODEL OF URANIUM OCCURRENCE IN THE CENTRAL MINING AREA, MARYSVALE DISTRICT, WEST-CENTRAL UTAH

By

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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 all presently 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 located 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 uranium mining area (fig. 1) is located 5.6 kilometers north-northeast of Marysvale, in a series of low hills called the Antelope Range.

Various aspects of the geology of the Marysvale area have been studied intermittently since the 1880's, as the different 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 the Antelope Range 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 Parker (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 uranium mining area is part of a regional investigation by the U.S. Geological Survey aimed at assessing the mineral resource potential of the Richfield $1^{o}x2^{o}$ quadrangle. It is a cooperative project that interacts with other projects in the U.S. Geological Survey branches of Uranium and Thorium Resources, Isotope Geology, Environmental Geology, Geophysics, Western Mineral Resources, and Exploration Research. Aspects of the work have been used to contribute to the NURE program of the Department of Energy.

GEOLOGIC SETTING

The Marysvale volcanic field is located 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 35-22 m.y. old intermediate-composition lava flows, volcanic breccias, volcaniclastic deposits, and ash-flow tuffs that have been called Bullion Canyon Volcanics (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. These rocks 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, centers around the Mount Belknap caldera. This major caldera formed 19 m.y. ago in response to eruption of the Joe Lott Tuff, and is described in Cunningham and Steven (1977, 1978).

The eastern source area, in the Antelope Range 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 intrusion of local stocks and plugs and extrusion of a series of porphyritic lava domes and flows (Tmi on fig. 1) 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 fig. 1) 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 uranium 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 fig. 1) 1.5 kilometers southwest of the central uranium 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 fig. 1). 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. An aphanitic white rhyolite dike (Tmd) just north of the central uranium 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 (fig. 2). 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 uranium district cut the 23 m.y. old central intrusive, 20 m.y. old fine-grained granite, and 19 m.y. old Red Hills Tuff. 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 this 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 URANIUM 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 primary uranium minerals in the veins are sooty pitchblende, coffinite, and umohoite, a uranium-molybdenum hydrate, 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. Kerr and others (1957) reported on the wall rock alteration associated with mineralization. Ore has been mined to depths of about 600 feet and drilling indicates that at 1,500 feet ore is still present (Callaghan, 1973), but 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 1,500 by 4,000 feet across (fig. 1). This oval is at the center of a somewhat larger highly faulted area that includes Basin-Range faults with the regional north-northwest trend, as well as more local faults of east-northeast trend. The faults are especially abundant within the central mining area and appear to mark local distention superimposed on regional late Cenozoic E-W Basin-Range extension. The central mining area is also within the eastern source area of the Mount Belknap

Volcanics which Cunningham and Steven (1977) have interpreted as being underlain by multiple shallow cupolas above a 21-18 m.y. old silicic magma chamber (fig. 2). Mineralization appears to have been related to late stages of the Mount Belknap period of igneous activity, and quite possibly to a shallow intrusive that underlies the highly faulted area and was responsible for at least some of the fracturing.

THE PORPHYRY ENVIRONMENT

The coincidence of uranium and molybdenum-bearing veins with a local area of distention within an area of concurrently active intrusion and extrusion suggests that the central mining area is localized above a shallow intrusion with which the mineralization was genetically related. 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 of the 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 figure 2, 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, it can be virtually eliminated at other places, and seems not to be a required process. 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, which would have inhibited the formation of sulfuric acid and thus reduced wall-rock alteration. This circumstance 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 "porphyry-type" ore environment worldwide 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.

Whereas most copper-gold and copper-molybdenum-gold porphyry-type deposits are almost exclusively metal sulfide systems, 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 great Climax and Henderson molybdenum mines in Colorado are known to occur in oxide minerals. In view of the generally low content of sulfur in the hydrothermal system in the central mining area (see later sections), 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 can be interpreted either to reflect horizontal distention or doming, but in the absence of good structural marker horizons it is not possible to assert which is the more likely. Horizontal distention would suggest a deeper top to the intrusion, and doming a shallower top.

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, pitchblende, coffinite, quartz, pyrite, and umohoite (a rare uranium-molybdenum hydrate (Brophy and Kerr, 1953)) were deposited during the ore-forming stage of mineralization. Whereas pyrite is widely present, it generally comprises only a very small part of the mineralized rock. We interpret this to indicate a relatively low content of sulfur in the hydrothermal solution. This interpretation is supported by the occurrence of molybdenum as a hydrate 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 fO_2 was low. The common presence of fluorite in the veins suggests that a uranium-fluorine complex was probably the transporting agent. As Langmuir (1978) has shown that uranous fluoride complexes are important in reducing environments below pH 4 at 25°C, the pH of the system probably was low. Romberger (personal commun., 1978) has computed the stability field of UF_2 at 200°C and finds that this complex is stable at approximately log fO_2 -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 pitchblende/coffinite was deposited from dilute solutions at approximately 150°C. Evidence for boiling has not been observed yet, 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 uranium 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 a 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^- was deposited as fluorite and the U^{+4} was precipitated 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. Common hematite elsewhere in the district is a product of oxidation associated with the 23 m.y. old alunitic mineralization, not the uranium mineralization.

CONCLUSIONS

The concepts and mapping presented here can best be tested by deep drilling in the central uranium area. Inasmuch as the deposits at Marysvale seem typical of those associated with rhyolite igneous centers, an excellent opportunity seems to exist for obtaining answers to many questions relating to resources in this and similar types of deposits worldwide. Specifically, deep testing would: (1) improve knowledge of known uranium reserves in the central uranium area; (2) examine the extent and form of the uranium deposits as they continue at depth; (3) test the potential for porphyry-type ore deposits beneath epigenetic uranium-bearing veins associated with rhyolite igneous centers; and (4) obtain suitable samples for quantitative geochemical and geophysical measurements to develop predictive techniques that can be applied in assessing uranium reserves in other areas.

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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

QTb 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. It 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. They contain 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 containing 30 percent phenocrysts of the following: quartz (3 percent), anorthoclase (24 percent), plagioclase (2 percent), and biotite (1 percent). K-Ar age is 19.0 ± 1.2 m.y. (Steven and others, 1977)

Tmr Red Hills Tuff Member--Crystal-poor welded alkali rhyolite welded ash-flow tuff containing 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. The granite 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. They contain 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)

BULLION CANYON VOLCANICS (MIOCENE AND OLIGOCENE)

To Osiris Tuff--Densely welded rhyodacite ash-flow tuff containing approximately 20 percent phenocrysts of plagioclase, sanidine, pyroxene, biotite, and quartz in a devitrified or glassy matrix

Ta Aplite--Dikes of fine-grained aplite consisting of crystals of quartz, orthoclase, plagioclase, and biotite

Tqm Quartz monzonite--Strongly porphyritic to equigranular, fine- to medium-grained quartz monzonite containing 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

Tbm Mount Dutton lava flows--Dark lava flows and volcanic breccias. Typically basaltic andesite to dacite in composition with prominent phenocrysts of plagioclase, pyroxene, and amphibole

Heterogeneous lava flows and volcanic breccias--Range from thick porphyritic rhyodacite and quartz latite flows containing phenocrysts of plagioclase, biotite, and clinopyroxene, to fine-grained dark lava flows and breccias of intermediate composition, with small phenocrysts of plagioclase and clinopyroxene

SEDIMENTARY ROCKS

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

CONTACT

FAULT--Dotted where covered

QUARTZ VEIN

STRIKE AND DIP OF COMPACTION FOLIATION OR LAVA FLOWS

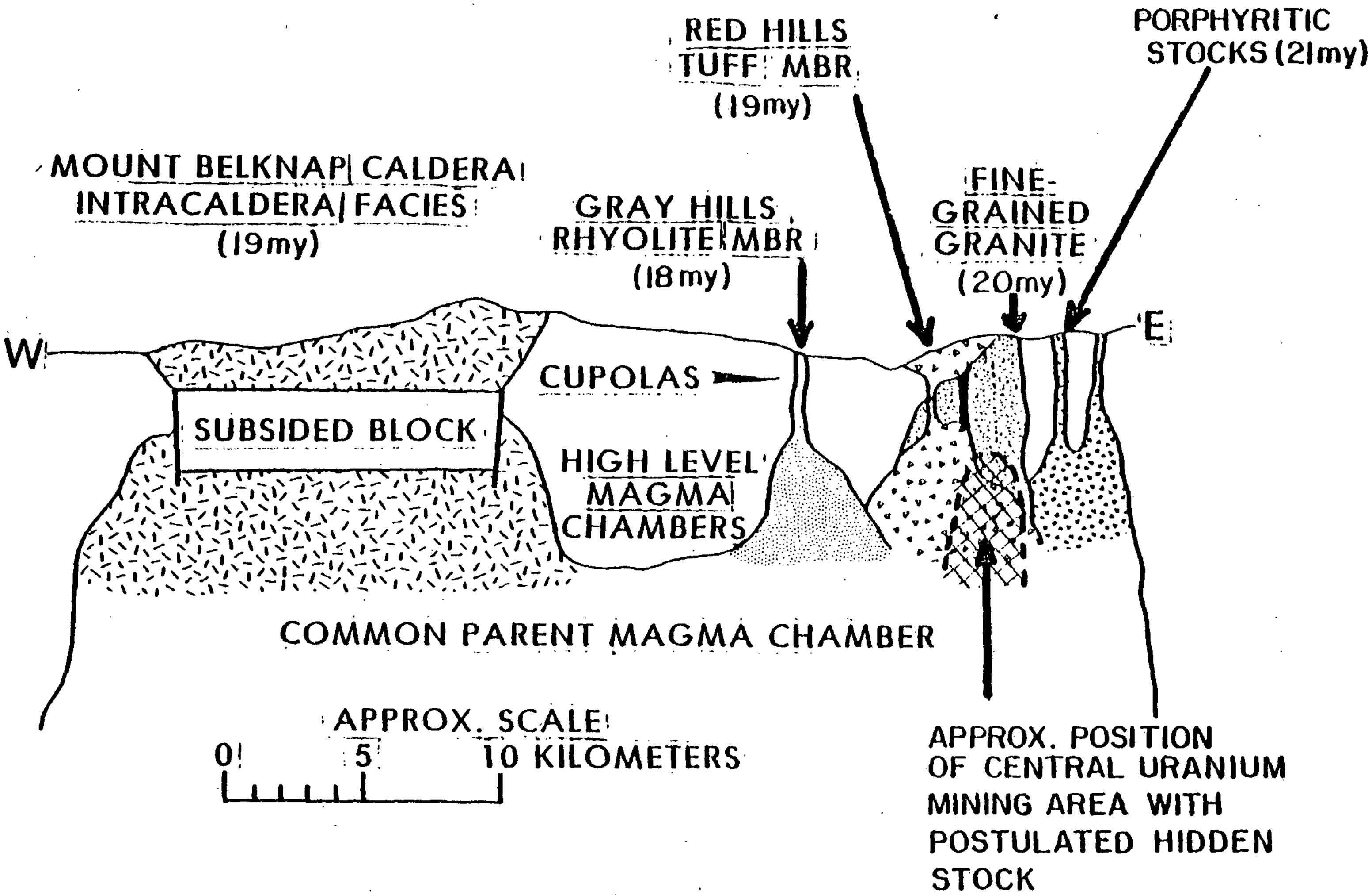

FIGURE 2.--Diagrammatic sketch showing postulated relations in the roots of source areas for the Mount Belknap Volcanics